8. GROUNDWATER

This chapter summarises the findings of the supplementary groundwater assessment undertaken to address updates to the project description made since the Surat Gas Project Environmental Impact Statement (EIS) (Coffey Environments, 2012b) was finalised. The supplementary groundwater assessment also considers new information available since preparation of the EIS.

The Supplementary Groundwater Assessment, prepared by Coffey Environments (Australia) Pty Ltd (Coffey), is included in Appendix 4. The study supplements the Groundwater Impact Assessment presented in Appendix G of the EIS, the main findings of which are summarised in Chapter 14 of the EIS.

The revised project description is provided in Chapter 3, Project Description, however aspects relevant to groundwater are also discussed in this chapter. In addition to the study findings, a list of key issues raised in submissions is presented, with responses to all issues provided in Part B, Chapter 19, Submission Responses. An updated list of commitments is also provided in Attachment 4, Commitments Update.

Groundwater also has recognised linkages with other environmental aspects of importance to the Surat Gas Project, notably potential impacts on surface water which are presented in Chapter 9, Surface Water and on groundwater-dependent ecosystems which are presented in Chapter 11, Terrestrial Ecology and Attachment 1, Matters of National Environmental Significance. Arrow's Coal Seam Gas Water and Salt Management Strategy is also presented in Attachment 5.

8.1 Studies and Assessments Completed for the EIS

This section provides an overview of the groundwater assessment completed for the Surat Gas Project EIS and the main conclusions from that assessment.

The groundwater impact assessment comprised a desktop study of geological and hydrogeological information. Information was sourced from relevant publications, government databases, published literature and reports of similar projects in the Surat Basin to gain an understanding of the existing environment. The assessment also included the development of a numerical groundwater model (termed the Arrow EIS groundwater model) to predict the groundwater drawdown response in particular aquifer units as a result of coal seam gas extraction. The Arrow EIS groundwater model was prepared by Schlumberger Water Services (Australia) Pty Ltd (Schlumberger, 2011) and peer reviewed by NTEC Environmental Technology (now CDM Smith Australia Pty Ltd (CDM Smith)). The Arrow EIS groundwater model report was presented as Appendix B of the Groundwater Impact Assessment report, which was presented as Appendix G of the EIS.

The study area defined for the groundwater impact assessment included the project development area and a representative section of the broader Surat and Clarence-Moreton Basins. The boundaries of the study area were used to define the extent of the numerical model which were limited by key geological changes or structures. The study area was also of sufficient size to extend beyond the likely extent of groundwater drawdown impacts.

Based on the geological and hydrogeological characteristics of the study area, the existing groundwater environment was divided into four groundwater systems. The systems were defined primarily on their depth and relationship to the Walloon Coal Measures, which is the target formation for coal seam gas extraction in the Surat Basin. The intrinsic characteristics of each groundwater system were assessed to define the sensitivity of each system to change resulting from coal seam gas extraction, as summarised below:

- **Shallow groundwater system**: This groundwater system contains unconfined (water table aquifers) and is dominated by the Condamine Alluvium within the project development area. Aquifers that make up this groundwater system have undergone modification due to historical over-allocation. This system was determined to have a moderate sensitivity based primarily on groundwater quality (ability to support a variety of uses including domestic supplies), connectivity with surface water features in some areas, its recharge mechanisms and resilience to change, and support of ecological communities.
- **Intermediate groundwater system**: Formations that make up this groundwater system include the Mooga, Gubberamunda and Springbok Sandstones. This groundwater system was assigned an overall moderate sensitivity ranking primarily based on water quality characteristics that support a range of uses, the inclusion of these aquifers in the Great Artesian Basin and their moderate recharge rates following disturbance.
- **Coal seam gas groundwater system**: This groundwater system represents the Walloon Coal Measures, the primary target for coal seam gas production. Groundwater quality associated with this system is generally poor in comparison with the other systems, and does not support ecological communities. The coal seam gas groundwater system was assigned a low sensitivity ranking.
- **Deep groundwater system**: Formations that make up this groundwater system include the Hutton and Precipice Sandstones. These aquifers are characterised with good water quality and the ability to support ecological communities through known discharge springs associated with discharge areas of the Great Artesian Basin (to the southwest of the project development area). These aquifers are less dynamic than shallower groundwater systems due to their depth and slower recharge rates. The deep groundwater system was assigned a high sensitivity ranking.

The Arrow EIS groundwater model was constructed using MODFLOW-2000 software (USGS, 2000). The model predicted the groundwater drawdown response in aquifers as a result of coal seam gas extraction under three scenarios:

- Scenario 1 included extraction in accordance with Arrow's forecast coal seam gas water extraction for the Surat Gas Project (in isolation from other industrial developments).
- Scenario 2 included extraction from Arrow's Surat Gas Project in conjunction with extraction by the other coal seam gas projects for which the proponent had taken their final investment decision (FID) (i.e., the Queensland Curtis Liquefied Natural Gas (QCLNG) project and the Gladstone LNG (GLNG) project.
- Scenario 3 included extraction from all four primary coal seam gas projects in the Surat Basin, regardless of FID status, and therefore included the Surat Gas Project (Arrow), QCLNG, GLNG and the Australia Pacific LNG (APLNG) projects. Scenario 3 represented the cumulative impact assessment.

The groundwater impact assessment considered the results of scenario 1 and scenario 3, as scenario 2 was considered to be less likely to occur. The results of scenario 3 were presented in Chapter 28 of the EIS, Cumulative Impacts.

The assessment identified that likely key impacts as a result of the project would be related to reduced groundwater supply (including aquifer depressurisation) and altered groundwater quality. These impacts were recognised as subsequently impacting on third-party groundwater users and groundwater-dependent ecosystems. The mechanisms or activities through which these impacts could occur, included both subsurface activities such as drilling and coal seam gas extraction and surface based activities such as fuel, chemical and produced coal seam gas water storage. The impacts of depressurisation of aquifers through the removal of gas and water were classified as either direct impacts on the Walloon Coal Measures, or indirect impacts on aquifers above and below the Walloon Coal Measures.

The assessment demonstrated that the implementation of the proposed mitigation measures for each of the identified impacts reduced the overall significance of residual impacts. The significance of residual impacts on each groundwater system reported in the EIS were as follows:

- Low to moderate for the shallow groundwater system.
- Low to moderate for the intermediate groundwater system.
- Very low to low for the coal seam gas groundwater system.
- Low to moderate for the deep groundwater system.

Arrow committed to implement a number of avoidance, mitigation and management measures to reduce impacts on groundwater values in the project development area. These commitments were developed on the basis of professional advice provided by Coffey. The commitments presented in the EIS are listed in Table 8.1.

Table 8.1 Groundwater EIS commitments

No.	Commitment
C019	Inspect and observe site locations for the presence of contamination prior to commencement of intrusive activities.
C035	Apply appropriate international, Australian and industry standards and codes of practice for the handling of hazardous materials (such as chemicals, fuels and lubricants).
C036	Develop and implement emergency response and spill response procedures to minimise any impacts that could occur as a result of releases of hazardous materials or any loss of containment of storage equipment.
C038	Carry out corrective actions immediately upon the identification of any contamination of soil or groundwater that has occurred as a result of project activities.
C048	Apply appropriate international, Australian and industry standards and codes of practice for the design and installation of infrastructure associated with the storage of hazardous materials (such as chemicals, fuels and lubricants).
C049	Avoid development on contaminated land through the completion of appropriate register searches and desktop investigations (i.e., avoid land or the contaminated portion of a parcel of land that is listed on the Contaminated Land Register or the Environmental Management Register, where practicable).
C050	Conduct physical investigations on selected parcels of land to influence facility siting decisions on a localised scale (i.e., target the portion of land that is not contaminated by understanding the extent of contamination).
C064	Avoid disturbance of contaminated soil and groundwater when it is identified or observed during intrusive works.
C065	Manage contaminated soil or groundwater that cannot be avoided through physical investigation; manage quantification of the type, severity and extent of contamination; and remediate or manage in accordance with the Queensland Government’s Draft Guidelines for the Assessment and Management of Contaminated Land (DE, 1998).

Table 8.1 Groundwater EIS commitments (cont'd)

No.	Commitment
C069	Incorporate into an emergency response plan or water management plan procedures for the controlled discharge of coal seam gas water under emergency conditions. Procedures will include water balance modelling, weather monitoring and forecasting, stream flow data, notification and reporting.
C073	Excavate any saline material during rehabilitation of coal seam water dams or brine dams and select an appropriate option for management for the material (e.g., treat for reuse, or dispose of in a registered landfill).
C074	Implement a decommissioning and rehabilitation plan in accordance with the dam design plan.
C079	Arrow will enforce a no hydraulic fracturing (fraccing) policy in the project development area.
C102	Store onsite materials in suitable containment systems constructed to industry standards and Australian standards (AS 1940-2004, The Storage and Handling of Flammable and Combustible Liquids (Standards Australia, 2004a), and AS 3780, The Storage and Handling of Corrosive Substances (Standards Australia, 2008b) at a minimum). Maintain quality control and quality assurance procedures to monitor volumes and quantities. Bund aboveground storage areas to contain spills.
C120	Prepare a baseline assessment plan to establish benchmark data in registered third-party bores (where possible) prior to the commencement of Arrow extraction activities in accordance with the Water Act, including the preparation and implementation of a groundwater monitoring and investigation strategy.
C124	Consider local biological, groundwater and surface water conditions when identifying sites for coal seam gas water dams and brine dams.
C125	Consider local groundwater conditions when identifying sites for the installation of buried infrastructure (e.g., gathering lines).
C126	Avoid unnecessary impervious surface coverings and minimise land footprint and vegetation clearing when designing facilities.
C127	Undertake bore assessments of third-party bores (where possible) in accordance with the Water Act, including: • Having the Queensland Water Commission for the Surat Cumulative Management Area identify bores requiring assessment. • Developing make-good agreements that include the outcome of bore assessments and implementation of make-good measures in the event that impaired capacity occurs.
C128	Continue an investigative program that will help quantify the connectivity between the Condamine Alluvium and the Walloon Coal Measures. The program will involve: • Monitoring the effects of groundwater extraction in the Walloon Coal Measures on the Condamine Alluvium to estimate horizontal and vertical hydraulic conductivity between the alluvium and the Walloon Coal Measures. • An investigative drilling program that will provide greater definition of the interface between the two units and will evaluate the geological and hydrogeological properties of the material at the interface of the units. • Groundwater chemistry studies to characterise mixing and migration between the units. • Groundwater modelling, utilising the connectivity data obtained through investigative components of the program, to understand important processes in the system and predict potential impacts.
C129	Continue a program of aquifer testing in dedicated groundwater monitoring bores to increase the predictability of aquifer properties and groundwater movement.
C130	Collect relevant geological and hydrogeological data from existing and future production wells, monitoring bores and registered third-party bores (where possible) together with information collated collaboratively with other proponents and regulatory authorities.

Table 8.1 Groundwater EIS commitments (cont'd)

No.	Commitment
C131	Update and calibrate the geological model and the numerical groundwater model with relevant data on an ongoing basis, including: • Aquifer thicknesses and interfaces between formations. • Aquifer properties, e.g., porosity, permeability. • The location of sensitive areas, e.g., groundwater discharge springs. • Observed responses in monitoring bores that reflect aquifer behaviour during coal seam gas extraction.
C132	Utilise the updated geological and numerical groundwater models to: • Make ongoing predictions regarding changes to groundwater levels and groundwater quality as the project develops. • Improve confidence in the understanding of the sensitivity and resilience of the aquifers within the identified groundwater systems.
C133	Perform groundwater modelling simulations to predict impacts on groundwater resources in overlying and underlying aquifers. This information will subsequently be used to evaluate the suitability of these resources for use in make-good measures.
C134	Verify the preferred water management strategy by modelling the effectiveness of substitution and injection (where conducted) in offsetting depressurisation impacts in aquifers.
C135	Consider injection of coal seam gas water or brine of a suitable quality (if proven technically feasible) into shallow or deep aquifers to offset depressurisation impacts in aquifers.
C136	Address the potential for surface deformation through participation by Arrow in a collaborative study with other proponents using historical and baseline data from the Advanced Land Observation Satellite covering a timelapse period from January 2007 until January 2011. This will allow a detailed analysis of the region and will enable the analysis of the evolution of measured surface deformation in space and time. The assessment will correlate and calibrate data deliverables (calibrated global map and vector files for measurement points) from the Advanced Land Observation Satellite to show the mean deformation rate, identify areas of large-scale deformation and compare patterns with other information (e.g., geology, basin structure, extraction wells and injection data).
C137	Construct all coal seam gas production infrastructure in accordance with the standards described in the P&G Act and regulations to that act.
C138	Construct all monitoring bores in accordance with the minimum construction requirements for water bores in Australia (LWBC & NMBSC, 2003) and the minimum standards for the construction and reconditioning of water bores that intersect the sediments of artesian basins in Queensland (DERM, 2004).
C139	Select drilling fluids to minimise potential groundwater impacts. Do not use oil-based drilling fluids.
C140	Ensure well drilling is monitored by a suitably qualified geologist to ensure aquifers are accurately identified for correct well construction.
C141	Develop the construction, design and monitoring requirements for new dams (either raw water, treated water or brine dams) and determine the hazard category of the dam in accordance with the requirements of the most recent version of Manual for Assessing Hazard Categories and Hydraulic Performance of Dams (DERM, 2011e). Construct the dams under the supervision of a suitably qualified and experienced person, in accordance with the relevant DERM schedule of conditions relating to dam design, construction, inspection and mandatory reporting requirements.
C142	Manage potential impacts to identified spring complexes by: • Supporting the identification of specific aquifers that serve as a groundwater source for discharge springs. • Assessing springs that are predicted to be subject to unacceptable impacts through the source aquifer. • Developing monitoring and mitigation strategies to avoid or minimise unacceptable impacts.
C143	Implement a well integrity management system during commissioning and operation of production wells.

Table 8.1 Groundwater EIS commitments (cont'd)

No.	Commitment
C144	Minimise impacts of groundwater depressurisation on sensitive areas (e.g., groundwater-dependent ecosystems).
C145	Develop a procedure for investigating the impaired capacity of third-party bores. The investigation will comprise (but not be limited to) the following phased investigation response: • Verify groundwater levels in the nominated bores and investigate groundwater levels and groundwater quality in compliance monitoring bores against established trigger thresholds. • Request bore information and groundwater data from affected parties. • Review and assess data. • Advise bore owners in writing of findings.
C146	If impaired capacity is confirmed (bore can no longer produce quality or quantity of groundwater for the authorised purpose, and the impact is due to coal seam gas activities), implement make-good measures in accordance with the Water Act.
C147	Include where possible, make-good measures such as substitution of groundwater allocations of equal or better quality to maintain user supply, deepening of bores, modification of pumps, or supply of groundwater from an alternative source.
C148	Connect wastewater and sewerage systems to sewers where locally present. Alternatively, install wastewater treatment or reuse systems in accordance with AS/NZS 1547:2000, On-site Domestic Wastewater Management (Standards Australia, 2000b); DERM guideline for managing sewerage infrastructure to reduce overflows and environmental impacts (DERM, 2010d); and Queensland water recycling guidelines (DERM, 2005).
C149	Store and manage all waste materials (domestic and industrial) in accordance with industry regulations and DERM conditions. Use licensed waste management contractors. Conduct audits of disposal facilities, disposal permits and onsite operations to ensure adherence to regulations.
C150	Decommission or repair all production wells and monitoring bores, either at the end of their operating life span or in the event of a failed integrity test in accordance with the minimum construction requirements for water bores in Australia (LWBC & NMBSC, 2003) and the P&G Act and regulations to that act. Should production wells be converted into monitoring bores, do so in accordance with relevant regulations.
C201	Develop and continually maintain the coal seam gas water management strategy throughout the project life to optimise the investigation and implementation of the potential coal seam gas water management options in alignment with the overall project development.
C204	Maintain water balance models for long-term planning and management of coal seam gas water. Review and update modelling in alignment with the production-forecasting schedule.
C504	Install groundwater monitoring bores near dams as a leak detection measure: • The number of monitoring bores and their location will take into account site-specific hydrogeology, preferential pathways and potential receptors of impacts. • Monitoring bores installed near dams will have groundwater levels and relevant water quality parameters monitored on a routine basis. • The number of monitoring bores and associated monitoring frequencies will be increased and further investigation will be triggered where impacts are identified.
C510	Prepare groundwater monitoring reports in accordance with the P&G Act, EP Act and Water Act.
C515	Provide chemical monitoring of contaminated soils and groundwater in relevant monitoring bores.
C521	Ensure methods used to monitor groundwater levels and quality, together with monitoring frequencies and parameters are in accordance with approved regulatory standards.
C522	Develop a structured database to host groundwater data from the project (i.e., groundwater levels and groundwater quality).

Table 8.1 Groundwater EIS commitments (cont'd)

No.	Commitment
C524	Install an appropriate regional groundwater monitoring network (that satisfies Arrow's obligations as described in the underground water impact reports) to: • Establish baseline groundwater level and groundwater quality conditions. • Assess natural variation (i.e., seasonal variations) in groundwater levels. • Monitor groundwater levels during the operations phase. • Monitor groundwater quality during the operations phase. • Establish suitable datum levels for each aquifer system. • Target sensitive areas where more frequent monitoring and investigation is required (e.g., groundwater-dependent ecosystems). • Monitor groundwater drawdown as a result of coal seam gas extraction. • Monitor impacts in accordance with the Water Act and regulations. • Provide an 'early warning system' that identifies areas potentially impacted by project activities to allow early intervention.
C525	Comply with inspection and monitoring requirements developed by the Queensland Water Commission in relation to groundwater drawdown and springs.

8.2 Study Purpose

The supplementary groundwater assessment was undertaken to address changes that have been made to the project description since the finalisation and publication of the EIS. The completion of the supplementary assessment facilitates consideration of information that has become available subsequent to the finalisation of the EIS. In addition, the supplementary assessment incorporates changes to legislation that relate to the management of groundwater resources. These aspects are discussed in the following sections.

8.2.1 Project Description Updates

Updates to the project description that are relevant to groundwater and/or have the potential to change or refine the results of the groundwater impact assessment, as presented in the EIS, include:

- Refinement of the project development area through relinquishment of land parcels, primarily in the former Goondiwindi development region (Figure 3.1, Chapter 3, Project Description).
- Refinement of Arrow's forecast coal seam gas water production profile across the project development area and over the life of the project.
- Revision of Arrow's Coal Seam Gas Water and Salt Management Strategy (Attachment 5), including refinement of the components of the strategy that have the potential to mitigate groundwater impacts.

Conceptual Development Sequence

Exploration activities that have been ongoing since finalisation of the EIS have improved the knowledge and understanding of coal seam gas reserves. This increased understanding has resulted in a number of sub-blocks within Arrow's project development area being relinquished. Relinquished sub-blocks (shown in Figure 3.1) are predominately located in the former Goondiwindi development region.

Field development planning has also progressed since the EIS was finalised. The overall project development area has been separated into 11 drainage areas (DA1, DA2 and DA4 to DA12) that correspond with the gas reserves that will be fed into the central gas processing facility (CGPF) located within each drainage area (see Chapter 3, Figure 3.1). This represents a refinement to the five development regions that were described in the EIS.

The indicative development sequence for the commissioning of production facilities (i.e., the CGPFs and field compression facilities) is presented in Chapter 3, Table 3.4, and a spatial representation of the indicative development sequence for the first 20 years of overall development is presented in Chapter 3, Figure 3.7.

As shown in Figure 3.7, the current scenario for the development sequence includes development of only eight drainage areas (DA1, DA2, DA5, DA7, DA8, DA9, DA10 and DA11), as the remaining drainage areas (DA4, DA6 and DA12) may only be developed in the event of favourable gas reservoir outcomes and future market conditions. Consequently, forecast production profiles have not been assigned to the remaining three drainage areas, and therefore do not form an input into the supplementary groundwater assessment. In the event that these drainage areas are determined to be economically viable in the future, Arrow will advise the Office of Groundwater Impact Assessment (OGIA) (formally the Queensland Water Commission (QWC)) as required by the *Water Act (2000)* (Qld) (Water Act) and as described as part of the periodic review process defined in the Underground Water Impact Report (UWIR) for the Surat Cumulative Management Area (CMA) (OGIA, 2012) (see Section 8.9, Commitments Update).

Figure 3.7 reflects the sequence in which coal seam gas and water will be extracted from within the eight drainage areas and consequently, the supplementary groundwater assessment considers the forecast production rates from each of these drainage areas in the order of anticipated development.

Coal Seam Gas Water Extraction

The EIS presented a forecast groundwater extraction volume of 694 gigalitres (GL) over a 35 year project life. The revised development case changes the coal seam gas water production profile and estimated average, peak and total volumes of water produced over the life of the project. The revised coal seam gas water production profile is shown in Chapter 3, Figure 3.6a. Based on the current development case, average coal seam gas water production is estimated at 13 gigalitres per annum (GL/a), with peak production estimated at 34 GL/a, a reduction from the average (22 GL/a) and peak (43 GL/a) production estimates reported in the EIS. The total production has decreased from 694 GL over 35 years used in groundwater modelling for the EIS, to 510 GL over 40 years. Despite production being estimated over a longer timeframe, total production has reduced due to the relinquishment of tenure and subsequent reduction in the number of wells.

It is important to note that these volumes are based on reservoir estimates. That is, the approximate volume of water extracted from wells planned to be drilled within the project development area. These volumes inform the conceptual coal seam gas water and brine management overview presented in Chapter 3, Figure 3.8.

For the purposes of numerical groundwater modelling prepared for the supplementary report to the EIS (SREIS) (discussed in Section 8.4.2), the model calculates the volume of water required to be extracted to meet certain pressure targets within the aquifers. This method generally results in higher estimated groundwater extraction volumes, which is appropriate for impact assessment purposes (i.e., impacts will not be under-represented). The estimated water extraction volume generated by the groundwater model does not change the actual water extraction forecast volumes presented above.

Coal Seam Gas Water Management

Arrow's Coal Seam Gas Water and Salt Management Strategy, has been revised and is presented as Attachment 5 of the SREIS. The water management options listed in the strategy that relate to management of groundwater impacts include offsetting the Arrow component of the modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of coal seam gas water extraction from the Walloon Coal Measures. Groundwater flux represents movement of groundwater between aquifers, as described in more detail in Section 8.4.3. Offset may be achieved by the following:

- Reducing existing extraction from the Condamine Alluvium through one or more of the following management options:
  - 'Virtual injection' (substitution of groundwater allocations from the Condamine Alluvium).
  - Purchase and retirement of groundwater allocations from the Condamine Alluvium.
- Direct injection into the Condamine Alluvium (if feasible and subject to changes to legislation to provide an indemnity framework).
- Injection of coal seam gas water of a suitable quality into target aquifers (if proven feasible) to potentially offset groundwater depressurisation impacts in those aquifers.

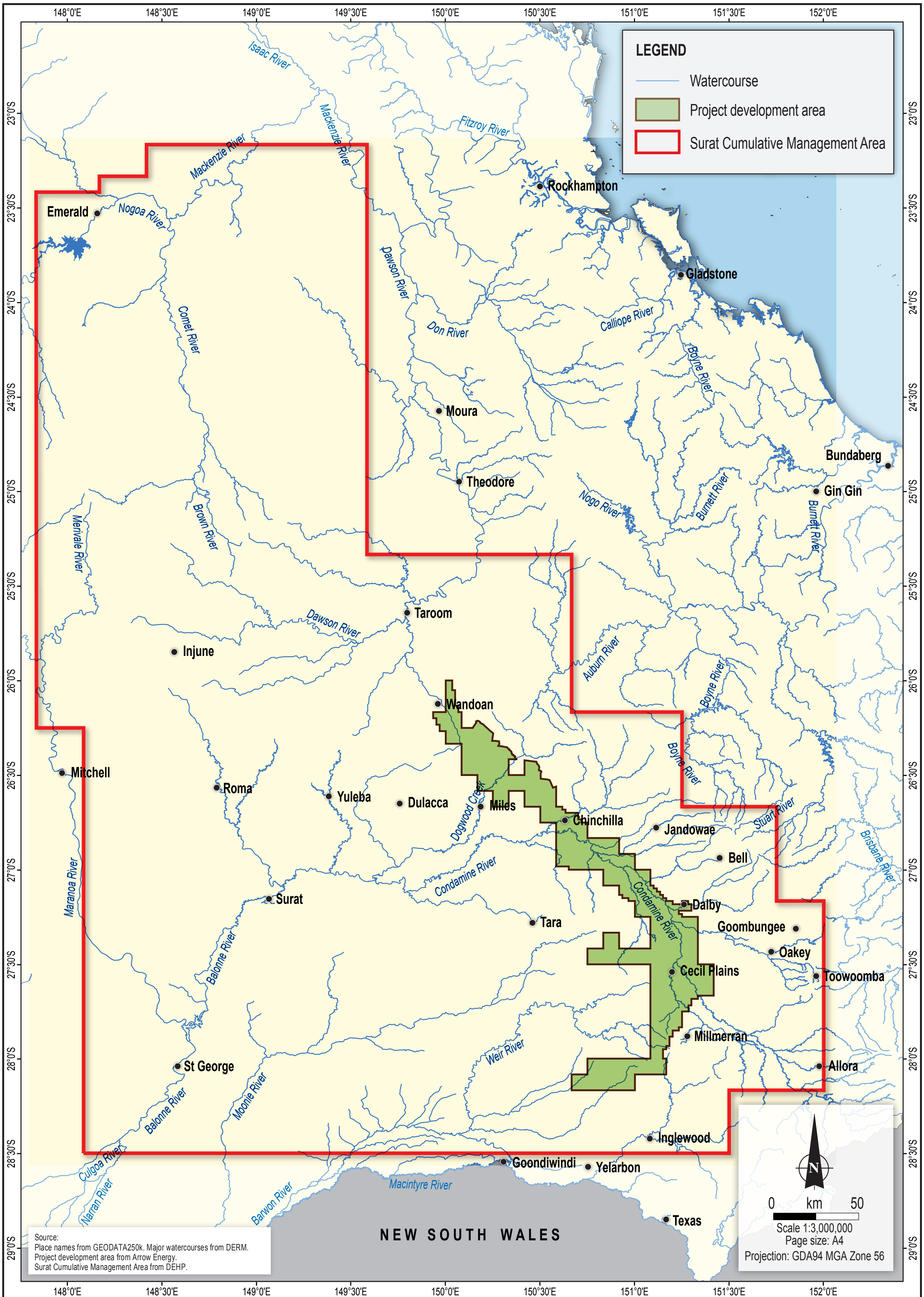
Further details on project activities are described in Chapter 3, Project Description.

8.2.2 Additional Information

As described in the EIS, the Surat Gas Project development area is located within the Surat CMA. The Surat CMA was declared by the Queensland Government in March 2011 and is shown on Figure 8.1. Under the *Water Act 2000* (Qld) (Water Act), a CMA can be declared where the impacts on water resources caused by multiple individual petroleum and gas projects may overlap.

At the time that the EIS was published, the QWC (now the OGIA) was responsible for relevant activities including the preparation of UWIRs. In 2011 a number of technical investigations and assessments were initiated to inform the Surat UWIR, including:

- Compilation of hydrogeological information in and around the Surat CMA to update the conceptualisation of the regional system.
- Development of a regional groundwater flow model to predict groundwater drawdown impacts from the petroleum and gas activities occurring, and planned to occur within the Surat CMA. This model is termed the OGIA Surat CMA groundwater model.
- Analysis of the level of uncertainty in the model predictions.
- Desktop assessments and field surveys of the relevant springs in the Surat CMA for their hydrogeological and ecological attributes.
- Development of an inventory of all existing and proposed monitoring bores and activities in the Surat CMA.



coffey environments

Date: 21.06.2013
MXD: 7040AE_12_GIS115_v1_2
File Name: 7040_12_F08.01_GIS_VS

Arrow Energy

Surat Gas Project

arrow energy go further

Location of the Surat Cumulative Management Area

Figure No: 8.1

The draft UWIR for the Surat CMA was released for public consultation on 17 May 2012, approximately two months after the EIS was placed on public exhibition. The draft UWIR was subsequently revised and submitted to the Department of Environment and Heritage Protection (EHP) on 18 July 2012. The Chief Executive of EHP approved the final UWIR for the Surat CMA, and the requirements in the endorsed report took effect from 1 December 2012.

The QWC ceased operation on 1 January 2013. The OGIA took over responsibility for the storage of data collected by responsible tenure holders, assessment of cumulative groundwater impacts and establishment of integrated water management arrangements for the Surat CMA. Updates to these requirements will be presented in future UWIRs prepared by the OGIA for the Surat CMA. The requirements set out in the UWIR are regulated by EHP to ensure that responsible tenure holders are fulfilling their legal obligations. The OGIA is an independent body within the Queensland Department of Natural Resources and Mines (DNRM).

8.2.3 Legislative Update

Changes to the legislative frameworks associated with coal seam gas developments in Queensland have occurred rapidly. In addition, aspects of the Commonwealth framework that have changed also influence groundwater management, specifically groundwater-dependent ecosystems.

Commonwealth Legislation

Changes to Commonwealth legislation related to management of groundwater and protection of groundwater values are discussed below.

Environment Protection and Biodiversity Conservation Act 1999 **(Cwlth)**

The *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act) provides for the protection of Matters of National Environmental Significance (MNES), including the community of native species dependant on natural discharge of groundwater from the Great Artesian Basin, or listed threatened species that are reliant on springs.

A bill seeking amendment to the EPBC Act is being introduced into Federal Parliament to include water resources as a MNES for coal seam gas and large coal mining developments. The proposed amendment must be debated and passed by both Houses of Parliament, and receive royal assent, before it becomes law. If passed and enacted, the amendment will require coal seam gas and large coal mining projects to assess impacts on water resources in accordance with the requirements of the EPBC Act. The Minister for Sustainability, Environment, Water, Population and Communities will decide whether to retrospectively apply the amendment to existing projects.

Water Act 2007 (Cwlth) and Basin Plan 2012

The *Basin Plan 2012* (Cwlth) (Murray-Darling Basin Plan) was prepared under the *Water Act 2007* (Cwlth) and adopted in November 2012. The plan was prepared to improve management of water, ecological health and water quality for the basin.

The Murray-Darling Basin Plan includes long-term average sustainable diversion limits for groundwater and surface water, which will restrict the amount of water that can be taken for consumption so as not to compromise key ecosystem functions, key environmental assets, the productive base of the water resource and key environmental outcomes for the water resource. The responsibility for determining the appropriate use of water resources within the Murray-Darling Basin to ensure that the sustainable diversion limits are achieved sits with the state governments. Arrow does not intend to divert surface water flow as part of the Surat Gas Project.

Groundwater extraction as part of the coal seam gas production process and the link with management of sustainable diversion limits will be managed by the Queensland DNRM through the development of water resource plans.

Queensland Regulatory Framework

Queensland legislative frameworks associated with coal seam gas developments and the management of groundwater resources have changed in response to public concern and recognition of some of the unique aspects associated with coal seam gas developments. These changes are discussed below.

Petroleum and Gas (Production and Safety) Act 2004 (Qld) (P&G Act)

Section 185 of the P&G Act, defines the underground water rights for petroleum tenures. Petroleum tenure holders may take or interfere with groundwater to the extent that it is necessary and unavoidable during the course of an activity authorised under the petroleum tenure, including coal seam gas extraction. Section 185 of the P&G Act also explains that these underground water rights are subject to the tenure holder complying with their underground water obligations, which are defined in chapter 3 of the *Water Act (2000)* (Qld) (Water Act) . The above provisions of the P&G Act were described in the EIS and have not changed, however the underground water obligations defined in the Water Act have been amended and are discussed below.

Water Act 2000 (Qld)

Chapter 3 of the Water Act provides for the management of impacts on underground water caused by the exercise of underground water rights by petroleum tenure holders. The Water Act defines several key underground water obligations that tenure holders must satisfy, specifically:

- Undertaking baseline assessments to identify the location, construction, groundwater level and groundwater quality of existing water bores within the proponent's tenure. These baseline assessments are carried out in accordance with a baseline assessment plan approved by EHP and in accordance with guidelines issued by EHP.
- The requirement to prepare UWIRs which include the following:
  - Description of the regional geology and hydrogeology, including aquifers, their groundwater quality and connections to other formations from which coal seam gas water is extracted.
  - Existing and forecast petroleum and gas production rates.
  - Prediction of groundwater drawdown as a result of the exercise of underground water rights, including identification of areas for each aquifer in the tenure where groundwater drawdown is predicted to exceed the bore trigger threshold. Bore trigger thresholds are defined in the Water Act as 2 m for an unconsolidated aquifer and 5 m for a consolidated aquifer. Predicted drawdown in each aquifer that exceeds the relevant bore trigger threshold in the next three years is defined as the Immediately Affected Area (IAA), and at any time in the future as the Long-term Affected Area (LAA) for that aquifer. Potentially affected springs are defined where drawdown is predicted to exceed the spring trigger threshold (defined in the Water Act as 0.2 m) at any time.
  - Report obligations, including description a Water Monitoring Strategy (WMS) including a program for monitoring changes in groundwater levels and groundwater quality. The WMS is designed to establish background groundwater trends (both in terms of levels and quality) in advance of the occurrence of impacts predicted as a result of coal seam gas extraction.

  - Report obligations including description of a Spring Impact Management Strategy (SIMS) including details of potentially affected springs in the tenure, assessments of the connectivity of the spring to the underlying aquifers and a prediction of risk and likely impact to the ecosystem and cultural and spiritual values of the spring. Once potential impacted springs are identified, the SIMS requires the development of a mitigation strategy or a monitoring program based on information gathered from the aforementioned studies.
  - Assignment of responsible tenure holder for report and make good obligations if the report is prepared for a CMA.
  - Program for annual review.
- Make good obligations including the requirement to:
  - Undertake a bore assessment for all bores located in an IAA to determine whether the bore has, or is likely to start having, an impaired capacity. An impaired capacity means that the bore can no longer provide a reasonable quantity or quality of groundwater because of a decline in groundwater level in response to the exercise of underground water rights by petroleum tenure holders.
  - Enter into a make good agreement with the owner of the bore which documents the outcome of the bore assessment, and defines make good measures for the bore to be undertaken by the tenure holder. Make good measures will be determined on a case by case basis, but could include ensuring the bore owner has access to a reasonable quantity and quality of water, Monitoring the bore, and/or compensating the bore owner.

Surat Cumulative Management Area Underground Water Impact Report

The finalisation of the UWIR for the Surat CMA, and its endorsement by the Chief Executive of EHP means that it has become a statutory instrument under the Water Act. Obligations for individual petroleum tenure holders for activities arising from the UWIR are now legally enforceable, and EHP is responsible for ensuring petroleum tenure holders comply with their obligations.

Given that the activities of multiple coal seam gas proponents may cause drawdown observed in third-party bores or source aquifers to groundwater dependent ecosystems, the UWIR assigns responsibility for monitoring and management strategies at those locations to one tenure holder.

The Water Act requires that the UWIR assigns responsible tenure holders to conduct certain activities within their own tenures and also within the IAAs and LAAs. The Surat CMA UWIR identifies the responsible tenure holder assigned to the following:

- **Baseline assessments**. The Water Act requires tenure holders to carry out baseline assessments of all third-party bores within priority areas of tenures where production testing or production of petroleum has occurred. In addition, the Surat CMA UWIR also identifies those bores within the LAA for each aquifer requiring a baseline assessment, i.e., those with a predicted 1 m drawdown in the next 3 years. The tenure holder responsible for conducting baseline assessments in areas outside petroleum tenures is defined under the UWIR as the holder of the petroleum tenure within the production area that is closest to the location of the required baseline assessment.
- **Water Monitoring Strategy**. The UWIR identifies the responsible tenure holder assigned to each well in the regional monitoring network and the year in which they are required to complete installation of monitoring wells and commence recording groundwater level and

quality monitoring data. Information on Arrow's water monitoring strategy is contained in Section 8.5.4.

- **Spring Impact Management Strategy**. The Surat CMA UWIR assigns a responsible tenure holder to each potentially affected spring. Arrow is not identified as a responsible tenure holder for any potentially affected springs.
- **Bore assessments and make good obligations**. Responsible tenure holders are assigned to third-party bores within the IAA defined in the Surat CMA UWIR. The responsible tenure holder must carry out bore assessments and enter into make good agreements with the owners of these bores. Arrow is the responsible tenure holder for 12 bores.
- **Periodic reporting and review**. Responsible tenure holders are required to provide the OGIA with monitoring data and updates to production plans on an annual basis. Based on this information, the OGIA Surat CMA groundwater model will be re-run. Through this process, the OGIA will make predictions about future water levels and the defined IAAs and LAAs will be progressively refined.

The UWIR will be revised and reissued by the OGIA every three years. The OGIA will maintain a database for data collected under monitoring plans carried out in accordance with monitoring programs in approved UWIRs. The database will also store baseline data collected by petroleum and gas operators as a part of their individual obligations under the Water Act.

Coal Seam Gas Water Management Policy 2012

Since the release of the EIS, the Queensland Government's policy for the management of coal seam gas water has been revised, and the revised Coal Seam Gas Water Management Policy was approved in December 2012.

This policy encourages the beneficial use of coal seam gas water in a way that protects the environment and maximises its productive use as a valuable resource. After feasible beneficial use options have been considered, treating and disposing coal seam gas water in a way that firstly avoids, and then minimises and mitigates, impacts on environmental values may be pursued. The policy provides a hierarchy of options for managing coal seam gas water and saline waste. Arrow's Coal Seam Gas Water and Salt Management Strategy (Attachment 5) is aligned with this policy document.

There are legislative links between groundwater extraction and Arrow's subsequent management of coal seam gas water at the surface, specifically:

- **Injection into an aquifer**. In the event that the target aquifer is used or potentially used as a source of supply for drinking, under the *Water Supply (Safety & Reliability) Act 2008* (Qld), the coal seam gas water is defined as 'recycled water' and requires a recycled water management scheme, including the appointment of a scheme manager. However, an application for exemption from these requirements can be made to the Office of the Water Supply Regulator in the Queensland Department of Energy and Water Supply. Extensive monitoring, analysis, modelling and risk assessment are required for exemption to be granted.
- **'Virtual injection'** (substitution of groundwater allocations from the Condamine Alluvium). Under the Water Act, this coal seam gas water management option triggers a Water Supply Licence and where not covered by environmental authority conditions, a beneficial use approval (general or specific). A water supply agreement between Arrow and the third party is also required, which includes commercial arrangements.

Code of Practice for Constructing and Abandoning Coal Seam Gas Wells in Queensland

The development of the Code of Practice for Constructing and Abandoning Coal Seam Gas Wells in Queensland (Queensland Government, 2011) was facilitated by the Department of Employment, Economic Development and Innovation (DEEDI) (note that this function now forms part of the DNRM) and aims to ensure that all coal seam gas wells are constructed and abandoned to a minimum acceptable standard to ensure:

- Protection of the environment, in particular groundwater resources.
- Management of risks to public and coal seam gas workers to a level that is as low as reasonably practicable.
- Compliance with regulatory and applicable Australian and International Standards, as well as the operator's internal requirements.
- Effective management of a coal seam gas well through all phases, including design, construction and decommissioning.
- Implementation of appropriate monitoring programs during the life of the coal seam gas well.

It is intended that this code of practice will be enforceable in Queensland by being referenced under the P&G Regulation as a safety requirement. Where any conflict arises, the P&G Act and the P&G Regulation will take precedence over the Code.

GasFields Commission

In April 2013, the Gasfields Commission Bill 2012 (Qld) was reintroduced to the Queensland Parliament, where amendments were considered, debated and passed by members of parliament. The powers of the GasFields Commission formally took effect from 1 July 2013 under the *Gasfields Commission Act 2012* (Qld) (Gasfields Commission Act).

The purpose of this Gasfields Commission Act is to establish the GasFields Commission to manage and improve the sustainable coexistence of landholders, regional communities and the onshore gas industry in Queensland. The functions of the GasFields Commission are varied, but focus on facilitation of better relationships between proponents, landholders and communities, and provision of advice and recommendations to Queensland government entities in relation to these relationships. The functions of the GasFields Commission are broad, and may include groundwater issues and associated management.

8.3 Study Method

The supplementary groundwater assessment methods closely align with those described in the EIS. The methods applied include:

- A desktop review of information made available since the preparation of the EIS including additional government and industry research and studies, and numerical groundwater modelling. Some information sources considered in the EIS were re-visited in light of the new information available.
- Review and assessment of the results of numerical groundwater modelling completed specifically for the SREIS using the current development case.

- Review of the potential impacts identified in the EIS to assess adequacy with respect to the revised project description and current development case. Additional impacts and/or impacts no longer relevant to the project are identified.
- Review and revision of the impact assessment including management and mitigation measures to capture any additional impacts or changes to the impact significance as reported in the EIS.

The study methods of the supplementary groundwater assessment are summarised below.

8.3.1 Desktop Assessment

The supplementary groundwater assessment included a desktop review of the information sources referred to in the EIS, to capture any relevant updates or amendments. Additional sources of information identified following the finalisation of the EIS were also reviewed within the context of the project development area and the broader Surat CMA.

Key Information Sources from the EIS

Selected information sources used in the desktop assessment completed for the EIS were re-visited for the SREIS. These sources provide information associated with aquifer recharge rates in the Great Artesian Basin (Kellett et al., 2003) and surface-groundwater connectivity across the Murray-Darling Basin (Parsons et al., 2008) at a regional scale. Groundwater connections between the Walloon Coal Measures and the Condamine Alluvium remain a focus of the supplementary groundwater assessment, and therefore relevant documents, including Hillier, 2010, were re-visited. The Directory of Important Wetlands in Australia (Environment Australia, 2001) and the web-based information sheet for Lake Broadwater were also accessed (SEWPaC, 2013) to obtain any updated information. Information prepared for the CSIRO Murray-Darling Basin Sustainable Yields Project was also re-visited, including the model calibration report for the upper Condamine groundwater model (Barnett & Muller, 2008).

Studies Informing the Surat CMA UWIR

Following finalisation of the EIS, several studies and investigations relating to springs were commissioned by the OGIA. The information collected, and the results of the investigations underpin the Surat CMA UWIR (OGIA, 2012).

These publications were reviewed as part of the desktop study, and include hydrogeological, botanical and ecological attributes associated with springs in the Surat CMA. These studies provide more detail on the understanding of potential source aquifers (the aquifers supplying groundwater to the spring), and focus on springs associated with species listed under the EPBC Act and the community of native species dependent on the discharge of groundwater from the Great Artesian Basin. Other springs located on a petroleum lease, or within 20 kilometres (km) of a petroleum lease within the Surat CMA that had not previously been surveyed, were also included in these investigations.

The information collected during the desktop and targeted field investigations allowed the OGIA to perform a risk assessment on the likelihood and consequence of coal seam gas activities impacting on springs identified within the Surat CMA. This process identified priority springs, i.e., those with an elevated risk of potential impact.

Details of the specific information sources used are listed below:

- Hydrogeological Attributes Associated with Springs in the Surat Cumulative Management Area (Klohn Crippen Berger (KCB), 2012a).

- Ecological and Botanical Survey of Springs in the Surat Cumulative Management Area (Fensham et al., 2012).
- Desktop Assessment of the Source Aquifer for Springs in the Surat Cumulative Management Area (KCB, 2012b).
- Assessment of the Risks and Potential Consequences to Springs in the Surat Cumulative Management Area (QWC, 2012a).

The OGIA Surat CMA groundwater model was informed by existing hydrogeological information prepared by the OGIA and represents an understanding of the groundwater systems within the Surat CMA (QWC, 2012b). This information was then used to underpin the Surat CMA UWIR (OGIA, 2012).

The Surat CMA UWIR was also informed by a number of groundwater models prepared to characterise the Condamine Alluvium and to predict groundwater drawdown in response to cumulative coal seam gas production in the Surat CMA.

A pre-existing detailed calibrated model of the Condamine Alluvium (termed the Condamine Alluvium groundwater model) was commissioned by the Department of Environment and Resource Management (DERM), in collaboration with the National Water Commission in 2011. The model was prepared as part of a four-staged project to assist resource managers with the administration of groundwater resources associated with the Condamine Alluvium. The stages of the project included:

- Central Condamine Alluvium, Stage I – Data Availability Review (KCB, 2010a).
- Central Condamine Alluvium, Stage II – Conceptual Hydrogeological Summary (KCB, 2010b).
- Central Condamine Alluvium, Stage III – Detailed Water Balance (KCB, 2011d).
- Central Condamine Alluvium, Stage IV – Numerical Modelling (KCB 2011b).

The OGIA incorporated the more detailed Condamine Alluvium groundwater model into the Surat CMA groundwater model. The Condamine Alluvium groundwater model is therefore a sub-model to the OGIA Surat CMA groundwater model.

Predictive uncertainty of the OGIA Surat CMA model was conducted by WaterMark Numerical Computing, 2012 to characterise the potential uncertainty associated with predictions made by the model.

Studies Related to Springs and Groundwater-Dependent Ecosystems

Information on springs and groundwater-dependent ecosystems primarily relate to additional studies conducted in the Surat CMA following the release of the UWIR, as well as additional resources available to identify and assess groundwater-dependent ecosystems.

Following the release of the predicted groundwater drawdown contours presented in the OGIA Surat CMA groundwater model, a joint industry investigation was conducted to locate springs within 100 km of the maximum extent of predicted groundwater drawdown in the Surat CMA (Halcrow, 2012) as a result of coal seam gas extraction. Remote sensing and mapping was used to identify these springs, and those with the potential to be impacted by coal seam gas activities were identified for the Phase 2 Assessment, which included aerial validation. The results of the aerial validation (Halcrow, 2013) were used to recommend springs for inclusion in a ground survey (Phase 3). At the time of preparing this supplementary assessment planning for the ground survey works had commenced.

Other sources of information reviewed for the desktop study and relevant to groundwater-dependent ecosystems included:

- The Australian groundwater-dependent ecosystem toolbox assessment framework (Part 1) (Richardson et al., 2011a) and assessment tools (Part 2) (Richardson et al., 2011b). These tools detail a framework for defining and identifying different types of groundwater-dependent ecosystems in a landscape, and provide tools to quantify their level of groundwater-dependence.
- Environmental Hydrology Associates (EHA) documents on the development of a methodology to confirm the source aquifer for Great Artesian Basin discharge springs and areas of groundwater baseflow to watercourses (EHA 2009a and EHA 2009b).
- The National Atlas of Groundwater Dependent Ecosystems, administered by the Bureau of Meteorology (BOM, 2013). This online mapping tool presents the current ecological and hydrogeological understanding of known and potential groundwater-dependent ecosystems across Australia. The supporting report, prepared by Sinclair Knight Merz (SKM, 2012) contains information on the methodology used to develop the atlas.

Management of Coal Seam Gas Water

The Coal Seam Gas Water Feasibility Study forms part of Queensland's Healthy HeadWaters Program. This program is a collection of projects aimed at securing a sustainable future for the Murray-Darling Basin Queensland's Healthy HeadWaters program and forms part of a national approach to the management of the Murray-Darling Basin. The Coal Seam Gas Water Feasibility Study examined the opportunities, risks and practicality of using coal seam gas water to address water sustainability and water allocation issues in the part of the Murray–Darling Basin that lies in Queensland.

Activity 1 from the feasibility study investigated the chemistry, origins and hydrogeology of coal seam gas water. Relevant aspects of this study include:

- Activity 1.1 – Conceptualisation of the Walloon Coal Measures beneath the Condamine Alluvium (KCB, 2011a), provided a description of the relationship between the Walloon Coal Measures and the Condamine Alluvium through the development of a three dimensional geological model.
- Activity 1.2 – Spatial analysis of coal seam water chemistry (WP, 2012) provided a unified database of historical groundwater quality and stratigraphic information for the Surat and Bowen Basins from existing publically available data sources.

Activity 6 is an aquifer injection feasibility study, and Activity 6.1 investigated the feasibility of injecting coal seam gas water into the Central Condamine Alluvium (KCB, 2011e) and included the generation of numerous geological cross sections through the Condamine Alluvium.

Management of coal seam gas water can assist in mitigating groundwater impacts. As such, this supplementary groundwater assessment also considered Arrow's revised Coal Seam Gas Water and Salt Management Strategy (Attachment 5).

Subsidence

The potential for coal seam gas extraction activities to cause surface subsidence was identified as a potential impact in the EIS. Since the release of the EIS, Altamira Information performed a ground motion baseline study on behalf of Arrow Energy, Origin Energy, QGC and Santos (Altamira Information, 2012a). A report specific to Arrow's tenure was also prepared by Altamira

Information (Altamira Information, 2012b). The study analysed ground motion using satellite interferometry in the Surat and Bowen basins. The study was undertaken in response to Commonwealth conditions of approval for the QCLNG, APLNG and GLNG projects that require ‘baseline and ongoing geodetic monitoring to quantify deformation at the land surface within the proponent’s tenures’. The project established a baseline of ground surface motion across the Surat Basin coal seam gas fields prior to significant expansion of coal seam gas production, although the timeframe for monitoring (2006 to 2011) does include some coal seam gas extraction activities within the Surat Basin, including Arrow’s current developments.

Other information sources relevant to the mechanisms of subsidence, include a report prepared by Geoscience Australia that summarises advice on the potential impacts of coal seam gas extraction in the Surat and Bowen basins (Geosciences Australia and Habermehl, 2010) and an analysis of coal seam gas production and natural resource management in Australia (Williams, 2012).

8.3.2 Numerical Groundwater Model

Standard industry practice is for groundwater models to undergo a process of continual review and update as new data and information becomes available.

A numerical groundwater model was prepared for the EIS (the Arrow EIS groundwater model) to predict groundwater drawdown in response to the Arrow Surat Gas Project. This model also presented cumulative drawdown predictions that included extraction associated with the QCLNG GLNG and the APLNG Projects (model scenario 3). At the time of finalisation of the EIS, the Arrow EIS groundwater model represented the most comprehensive assessment of predicted cumulative drawdown in the Surat CMA.

Since the EIS was finalised, the OGIA developed an independent numerical groundwater model (OGIA Surat CMA groundwater model) to predict the cumulative impacts of all coal seam gas developments. This model was developed independently by the OGIA. Details of the OGIA Surat CMA groundwater model are provided in following section.

The modelling work undertaken to support the UWIR for the Surat CMA involved a combination of the OGIA Surat CMA groundwater model, null space monte carlo method (a probabilistic uncertainty analysis method) (WaterMark Numerical Computing, 2012) and the Condamine Alluvium groundwater model (KCB, 2011b). Coal seam gas proponents within the Surat CMA are already regulated by the requirements in the UWIR.

Arrow has adopted the OGIA Surat CMA groundwater model for modelling groundwater drawdown impacts in the SREIS for the current development case.

The OGIA Surat CMA Groundwater Model

The OGIA Surat CMA groundwater model was initially constructed and calibrated by the OGIA and GHD in 2012. Some minor revisions, uncertainty analysis and predictive modelling were then carried out by the OGIA and WaterMark Numerical Computing (2012). All of these packages of work are summarised in the Surat CMA UWIR (OGIA, 2012). All modelling work was undertaken in accordance with the recommendations of the Murray Darling Basin Commission Groundwater Flow Modelling Guideline (Aquaterra, 2000). These guidelines are fundamentally similar to the recently published Australian Groundwater Modelling Guidelines (Barnett et al., 2012).

A detailed and calibrated model of the Condamine Alluvium aquifer was commissioned by DERM, in collaboration with the National Water Commission in 2011 (KCB, 2011b). The value of this pre-existing and more detailed Condamine Alluvium groundwater model (KCB, 2011b) was recognised by the OGIA and the relevant details were incorporated into the OGIA Surat CMA groundwater model. The extent of the Condamine Alluvium groundwater model and the OGIA regional Surat CMA groundwater model are presented in Figure 8.2.

The Arrow SREIS Groundwater Model

A revised numerical groundwater model has been prepared for the supplementary groundwater assessment (termed the Arrow SREIS groundwater model). Arrow has obtained the model files used by the OGIA to develop the OGIA Surat CMA groundwater model, and applied two key changes:

- A revised water production profile (referred to as the Arrow current development case) has been incorporated into the model.
- A different set of predictive extraction scenarios has been modelled for the purposes of determining Arrow's contribution to cumulative drawdown impacts within the Surat CMA.

The groundwater model developed for the SREIS and associated report was prepared by GHD and peer reviewed by CDM Smith.

Predictive Modelling Scenarios

The following predictive scenarios have been simulated by the Arrow SREIS groundwater model:

- **Non Coal Seam Gas Case**: Modelling only of extraction that is not associated with petroleum and gas activities from 1995 onwards.
- **Base Case**: Modelling of water extraction associated with the current and other proposed coal seam gas projects (GLNG, QCLNG and APLNG projects) and other petroleum activities from 1995 onwards. Arrow coal seam gas activities are specifically excluded from this modelling run.
- **Cumulative Case**: Modelling of water extraction associated with all current and proposed coal seam gas projects (GLNG, QCLNG, APLNG and Surat Gas Project), along with extraction that is not associated with petroleum and gas activities from 1995 onwards.
- **Arrow-only Case**: This case was not formally modelled as a separate scenario. The impacts have been calculated by determining the incremental drawdown difference between predicted groundwater levels and flows for the base case and those for the cumulative case.
- **Substitution Case**: Assessment of the flux impacts to the Condamine Alluvium with and without offsetting the Arrow component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of coal seam gas water extraction from the Walloon Coal Measures. Of the offset options described in Section 8.2.1, 'virtual injection' of treated coal seam gas water via substitution was simulated. Substitution is a process whereby Arrow will provide treated coal seam gas water in lieu of existing groundwater allocations from the Condamine Alluvium. This involved identification of landholder bores in the vicinity of maximum predicted drawdown. Extraction from these bores was reduced to simulate 'virtual injection'. The scenario assumed a supply of treated coal seam gas water for substitution over a 25 year period (from 2018 to 2043) to offset the Arrow component of modelled likely flux impacts to the Condamine Alluvium.

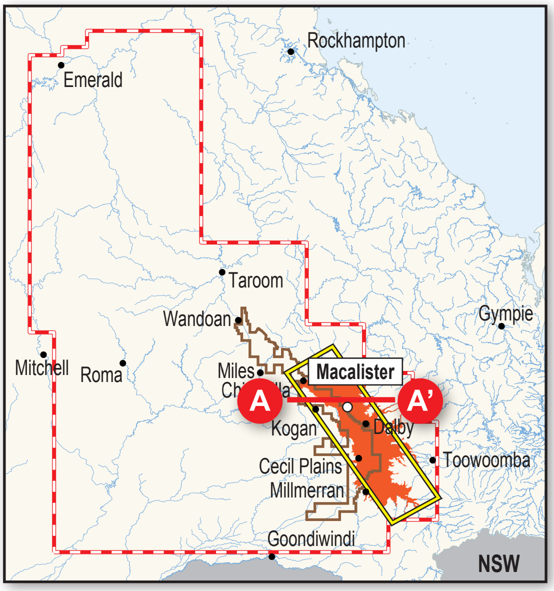
OGIA Surat CMA Groundwater Model

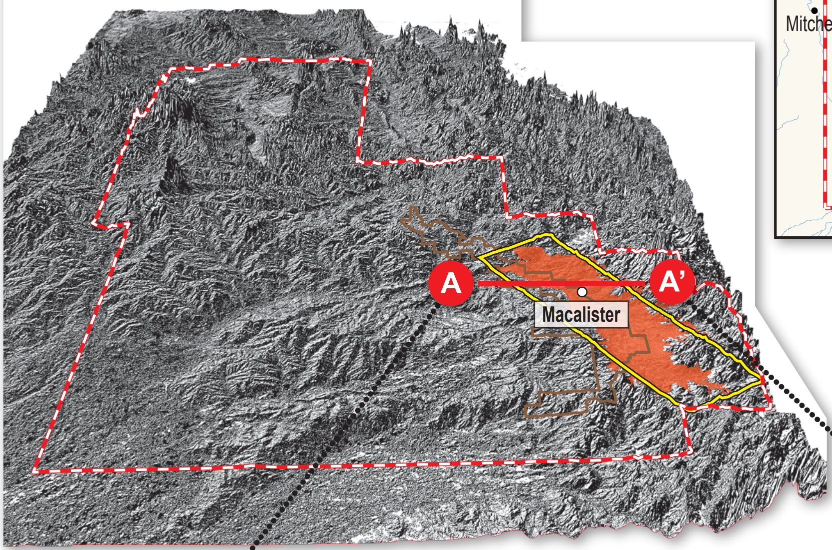
BLOCK DIAGRAM

N

0 km 100

Projection: GCS GDA 1994





LEGEND

- Major watercourse
- Condamine Alluvium model domain
- Condamine Alluvium boundary
- Surat Cumulative Management Area
- Project development area

LEGEND

- Water table
- Inferred groundwater flow direction
- Sheetwash Alluvium
- Floodplain Alluvium
- Clay Horizons
- Kumbarilla Beds
- Walloon Coal Measures

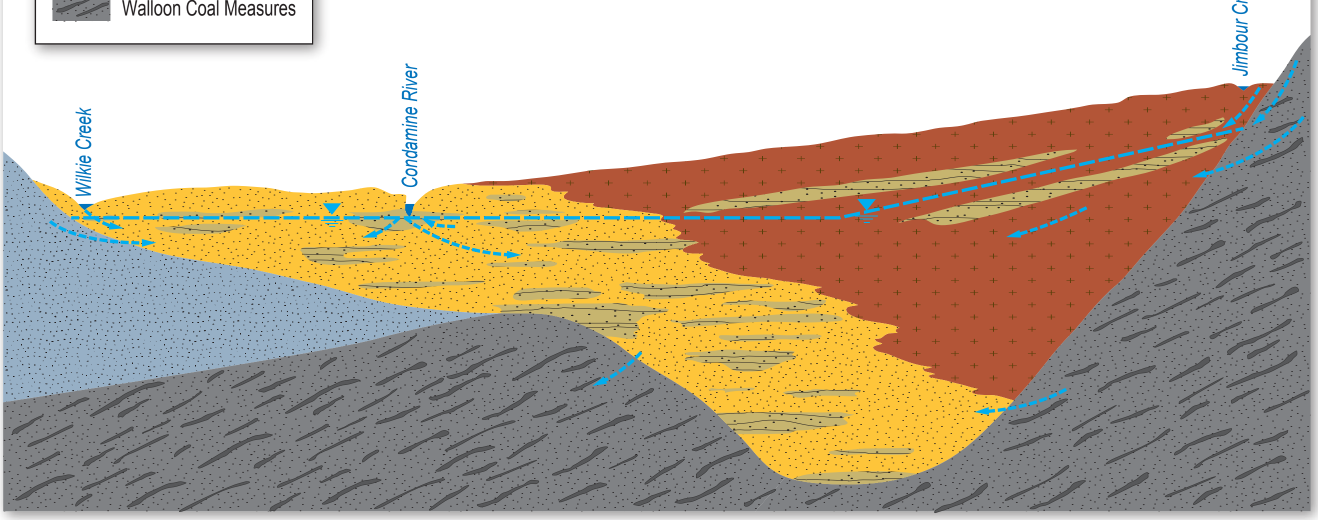
Source:
Place names and watercourses from DERM. Surat CMA from EHP.
Condamine Alluvium boundary and project development area from Arrow Energy.
Condamine Alluvium model grid derived from Klohn Crippen Berger report (indicative boundary only).
Digital elevation model from Commonwealth of Australia (Geoscience Australia) 2011.
Cross-section from Huxley (1982).

A

A'

Condamine Alluvium Groundwater Model

CROSS-SECTION A - A'
(Near Macalister)



coffey environments	Date: 27.06.2013 MXT: 7040AF_GW03_GIS011_v0_2 File Name: 7040_12_F08.02_GIS_HB	Arrow Energy Surat Gas Project	arrow energy go further	OGIA Surat CMA groundwater model components	Figure No: 8.2

A comparison of the Arrow EIS groundwater model with the OGIA Surat CMA model is provided in Section 8.4.2 as an outcome of the desktop assessment. An understanding of the key differences and similarities between these models is required when interpreting the outputs of the Arrow SREIS groundwater model. The results of the Arrow SREIS groundwater model are presented in Section 8.4.3.

8.3.3 Review and Update of the EIS Impact Assessment

The findings of the desktop study and the results of the Arrow SREIS groundwater model were used to review the groundwater impact assessment presented in the EIS. The groundwater impact assessment prepared for the EIS adopted a significance assessment approach, whereby the significance of potential impacts were determined through the definition of environmental values, their sensitivity to change, and the magnitude of potential impacts on those values (Table 8.2).

The method used to review and update the EIS impact assessment for the supplementary groundwater assessment is as follows:

- Detail any changes to the overall sensitivity rankings applied to groundwater environmental values.
- Confirm if the potential impacts identified in the EIS remain relevant. Identify any new impacts, or impacts that no longer apply to the project.
- Identify the impacts that require review. The review was conducted where changes to the project description, or the availability of new information since the EIS was finalised, results in a material change to the potential significance of the impact.
- Redefine the magnitude rankings applied prior to the implementation of mitigation measures to determine the pre-mitigation significance of impact. This step was only required for those impacts where a review of the EIS assessment was triggered.
- Review mitigation and management measures where required. Revise or omit any mitigation and management measures developed during the EIS that are no longer appropriate, or that require clarification or updates.
- Redefine magnitude rankings applied after the implementation of mitigation measures to determine the residual significance of impact. This step was only required for those impacts where are review of the EIS assessment was triggered.

Table 8.2 Groundwater significance assessment matrix

	Sensitivity of the Environmental Value				
Magnitude of Impact	**Very High**	**High**	**Moderate**	**Low**	**Very Low**
Very High	**Very High**	**Very High**	High	High	Moderate
High	**Very High**	High	High	Moderate	Low
Moderate	High	High	Moderate	Moderate	Low
Low	High	Moderate	Moderate	Low	**Very Low**
Very Low	Moderate	Low	Low	**Very Low**	**Very Low**

8.4 Study Findings

The findings of the supplementary groundwater assessment comprise three key components:

- A more detailed understanding of the existing environment in and around the project development area, collated from the information sources identified in Section 8.3.1.
- A comparison of the modelling approach and assumptions adopted in the Arrow EIS groundwater model and the OGIA Surat CMA groundwater model. The results of the Arrow SREIS groundwater model (which uses the OGIA Surat CMA groundwater model files updated with Arrow's current development case) can then be interpreted in comparison with the Arrow EIS groundwater model.
- The results of the Arrow SREIS groundwater model.

Updates to the understanding of the existing environment and the results of the SREIS model are described below.

8.4.1 Existing Environment Updates

The information sources reviewed during the desktop study largely confirm the characterisation of the existing environment presented in the EIS. Areas where additional details have become available relate primarily to the internal structure and hydrogeology of the Condamine Alluvium, and the level of connectivity between the Condamine Alluvium and the underlying Walloon Coal Measures. New information has also allowed a more detailed description of groundwater-dependent ecosystems, including springs, watercourse springs, groundwater-fed watercourses and lakes and ecosystems dependent on the subsurface presence of groundwater. The findings of these additional studies are discussed in the following sections.

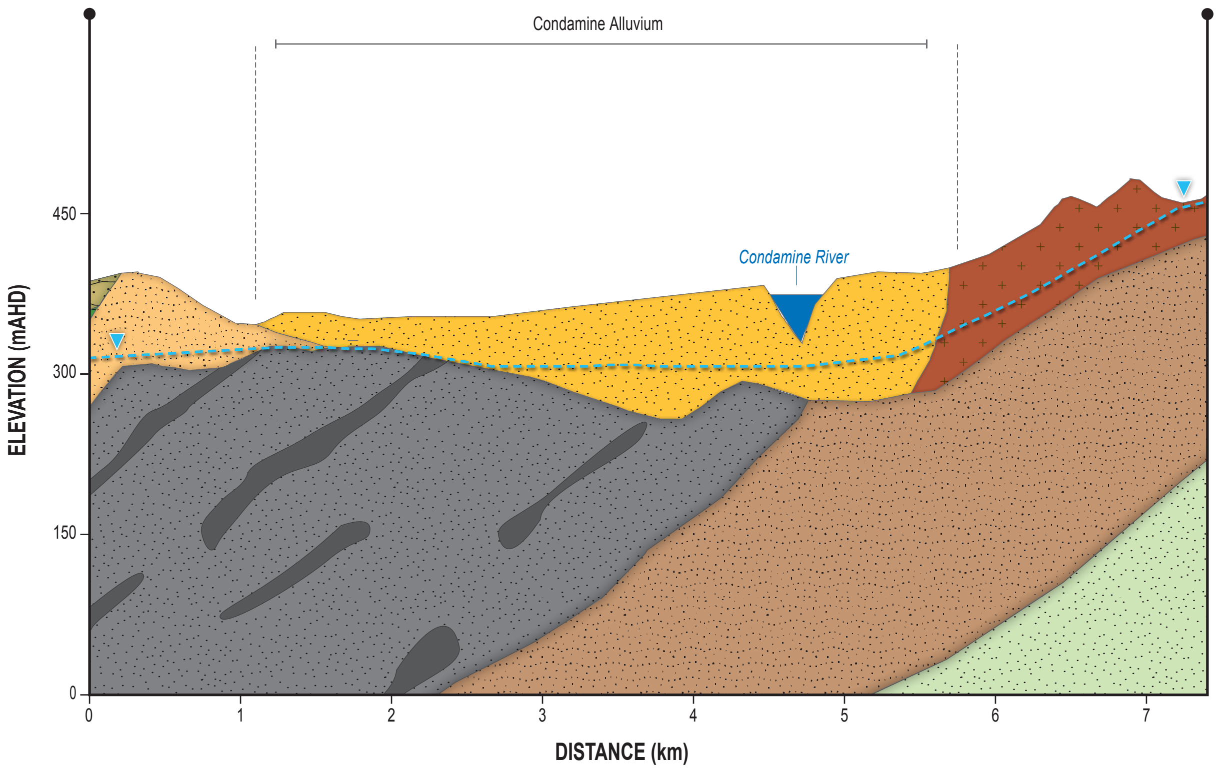
Condamine Alluvium

Studies completed as part of the Groundwater Management Modelling of the Central Condamine Alluvium (KCB, 2010a; KCB, 2010b, KCB, 2011b; KCB, 2011d) allow a more detailed understanding of the sedimentary structure of the unit and the groundwater flow processes within the Condamine Alluvium. The Condamine River and its tributaries have deposited sediments over time to form an alluvial plain that runs in a south-north direction from the headwaters east of Millmerran to near Chinchilla in the north. The distribution of the Condamine Alluvium covers the eastern portion of the project development area.

The southern extent of the Condamine Alluvium represents the headwaters of the system, and in this area the channel is relatively symmetrical and the sedimentary sequence no more than 50 m thick. As the sediments were deposited further north, the alluvial plain widened and the channel became asymmetrical. In this area, the sedimentary sequence is thicker (up to 150 m), with the deepest part of the channel located to the east, towards Dalby (Figure 8.3).

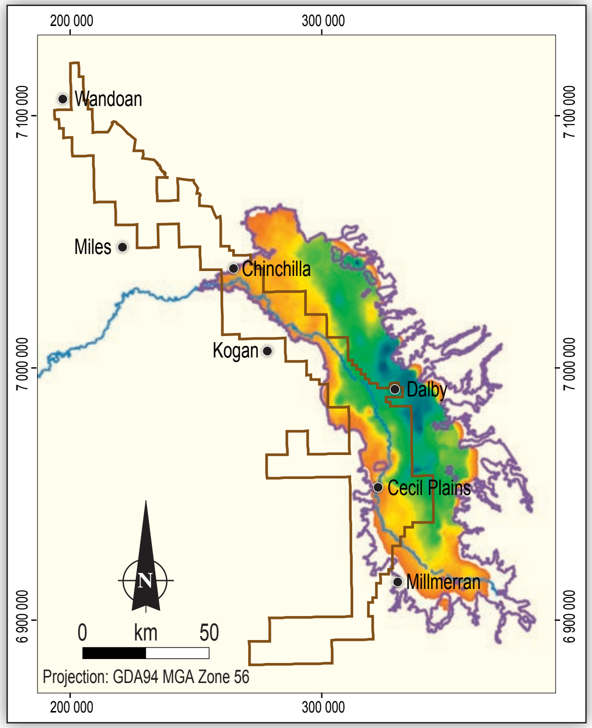
The sediments within the Condamine Alluvium are divided into a sheetwash unit and an alluvial unit. The sheetwash layer represents a wedge of generally fine grained material next to the eastern channel wall. These finer grained sheetwash deposits overlie the fluvial floodplain deposits (the alluvium unit), and are thicker to the east. Individual clay and silt horizons are found within the sheetwash unit and can be over 20 m thick. Where these horizons are laterally continuous, they can act as confining layers and influence groundwater flow within the overall Condamine Alluvium unit. As the sheetwash unit thins to the west, it overlies the alluvial layer which dominates the western extent of the Condamine Alluvium.

Indicative cross section of the Condamine Alluvium



LEGEND

- Water Table
- Condamine Alluvium
- Main Range Volcanics
- Gubberamunda Sandstone
- Springbok Sandstone
- Walloon Coal Measures
- Hutton Sandstone
- Evergreen Formation (Boxvale Sandstone)



LEGEND

- Condamine River
- Project development area
- Condamine Alluvium boundary

Inferred thickness of Condamine Alluvium (m)
High : 157
Low : 0

Source: Place names and Condamine River from DERM. Cross-section reproduced from GHD (2013) Figure 13. Project development area and Condamine Alluvium boundary and base depths from Arrow Energy.	coffey environments	Date: 27.06.2013 File Name: 7040_12_F08.03_VS	Arrow Energy / Surat Gas Project	arrow energy go further	Thickness of the Condamine Alluvium and relationship with underlying formations	Figure No: 8.3

The alluvial unit has more varied grain sizes and contains a mix of relatively thin (< 10 m) horizons of fine grained clays and silts, mixed with sandy clay, silty gravel and coarse granular sands and gravels. In general, finer sediments increase to the northern extent of the alluvium unit (Figure 8.2).

The Condamine Alluvium is primarily recharged from leakage of the Condamine River and associated tributaries (KCB, 2010b). Other minor recharge mechanisms include interaction with underlying formations (e.g. inflow from bedrock units located to the east and west), recharge by flood waters and deep drainage of water used in irrigation (KCB, 2011b).

Recharge to the Condamine Alluvium also occurs via direct rainfall infiltration. Historical studies (Lane, 1979; Huxley, 1982; SKM, 2003 and Barnett and Muller, 2008) concluded that recharge of the unit via rainfall infiltration would be limited by a soil zone at the surface with low permeability (e.g., black soils) across much of the surface of the Condamine Alluvium. More recent water balance modelling completed by KCB (KCB, 2011b) indicates rainfall recharge rates are low (0 to 25 millimetres per annum (mm/a). Nevertheless, rainfall recharge does make up a more substantial mechanism of recharge to the Condamine Alluvium than previously interpreted as it occurs over a large surface area.

Connectivity of the Condamine Alluvium with Underlying Formations

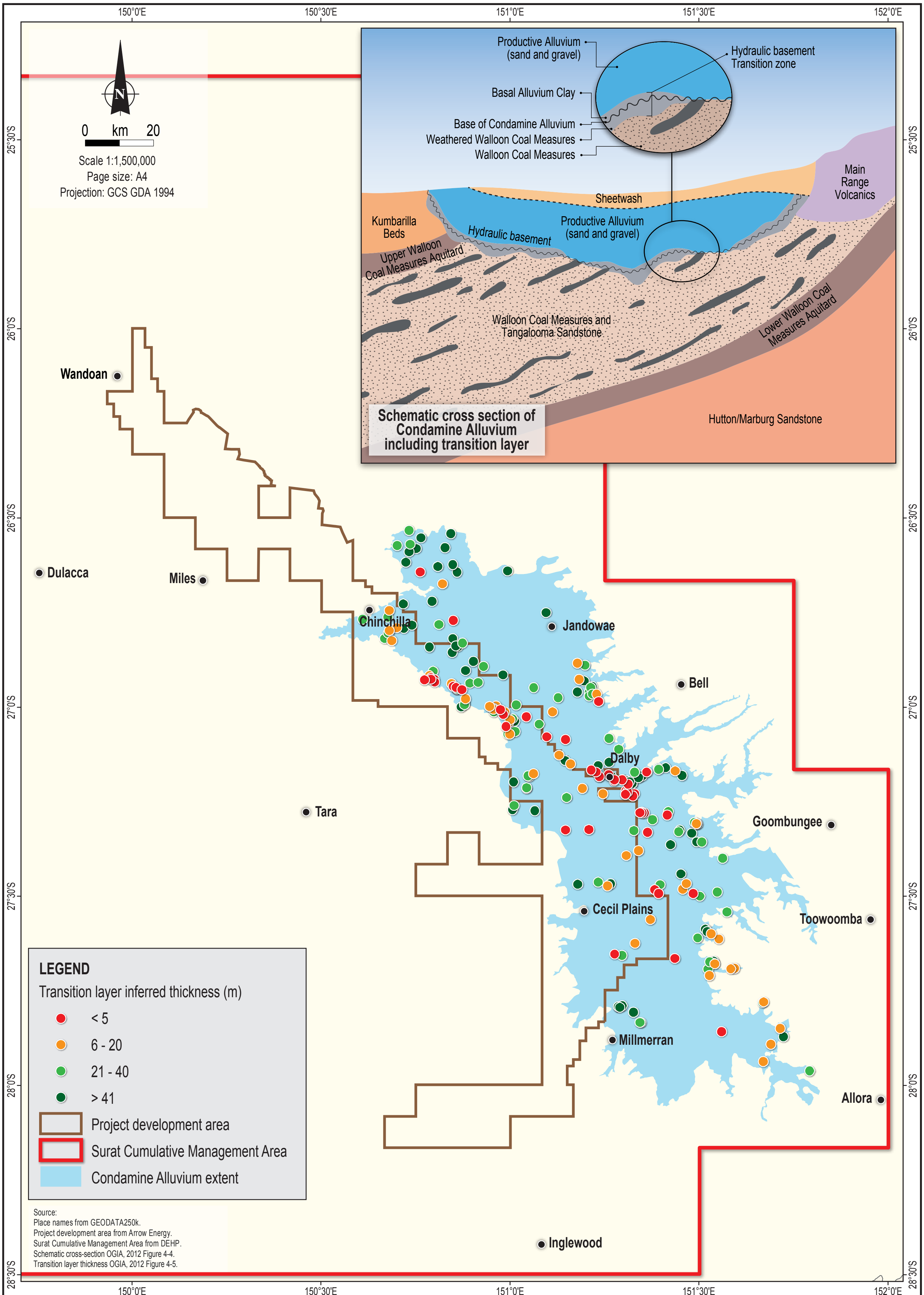
The connectivity of the Condamine Alluvium with underlying formations can be described as a function of the physical connection (the actual interface between the units) and the hydraulic characteristics of this interface and their influence on the movement of groundwater between formations.

The base of the Condamine Alluvium overlies a number of different formations. In the central portion of the Condamine Alluvium it predominately overlies the Walloon Coal Measures (OGIA, 2012). To the north and northeast, the base of the Condamine Alluvium is bounded by the Hutton Sandstone and Main Range Volcanics. In the south along the eastern margin, the Hutton Sandstone typically underlies the Condamine Alluvium. Also in the south, along the western margin, the alluvium is bounded by the Kumbarilla Beds including the Springbok and Gubberamunda Sandstones (KCB, 2010a) (Figure 8.3).

Connectivity between the Condamine Alluvium and the Walloon Coal Measures

A layer of alluvial clays and weathered material exists at the interface between the Condamine Alluvium and the Walloon Coal Measures. This layer has low permeability and is often referred to as the “hydraulic basement” of the Condamine Alluvium, or the ‘transition layer’ in the Surat CMA UWIR (OGIA, 2012). The thickness and permeability of this layer can influence the degree of connectivity between the Condamine Alluvium and the Walloon Coal Measures (Figure 8.4).

Available monitoring data on groundwater levels has been used in a number of recent studies (Hillier, 2010; KCB, 2010a; KCB, 2010b; KCB, 2011a; OGIA, 2012) to quantify the degree of hydraulic connection between the Condamine Alluvium and the Walloon Coal Measures. Prior to the widespread use of groundwater from the Condamine Alluvium, the depth to the groundwater levels in the Condamine Alluvium and the Walloon Coal Measures were likely to be similar. Over time, extraction from the Condamine Alluvium primarily for irrigation and agricultural use has lowered the groundwater level in this unit to the point where it can be up to 20 m lower than groundwater levels in the Walloon Coal Measures. This difference in groundwater level produces a pressure gradient whereby groundwater will tend to flow from the Walloon Coal Measure, to the Condamine Alluvium.



Source:
Place names from GEODATA250k.
Project development area from Arrow Energy.
Surat Cumulative Management Area from DEHP.
Schematic cross-section OGIA, 2012 Figure 4-4.
Transition layer thickness OGIA, 2012 Figure 4-5.

coffey environments	Date: 27.06.2013 MXD: 7040AF_GW03_GIS035_v1_2 File Name: 7040_12_F08.04_GIS_FT	Arrow Energy Surat Gas Project	arrow energy go further	Inferred thickness of the transition layer between the Condamine Alluvium and the Walloon Coal Measures	Figure No: 8.4

While some areas may experience a reverse pressure gradient, the data suggests a net groundwater flow from the Walloon Coal Measures to the Condamine Alluvium under current conditions.

Differences in observed groundwater quality in two adjacent formations can provide a useful indicator of the degree of connectivity between the formations (Appendix 4, Supplementary Groundwater Assessment). While the groundwater quality in the Walloon Coal Measures is variable and can support a range of uses, including domestic supplies, recorded salinity levels can reach 20,000 milligrams per litre (mg/L), with an average of approximately 4,500 mg/L (KCB, 2010b]). Average salinity levels recorded in the Condamine Alluvium are generally lower, at 1,000 mg/L (KCB, 2010b). Groundwater quality in the Condamine Alluvium shows a general deterioration (i.e., an increase in salinity readings) in the downgradient direction, towards the north and northwest extents of the Condamine Alluvium (KCB, 2010b). Historical data (from 1960-2009) collected as part of the Central Condamine Alluvium Stage II investigation (KCB, 2010b) was mapped, and indicates that the downgradient deterioration in water quality has been a feature of this system at least for the last 50 years.

The Condamine Alluvium and its tributaries have been extensively developed for irrigation, industrial, stock and domestic purposes and are characterised by the over-development and over-allocation with respect to the productive yield of the system (DNRM, 2012c). The effects of groundwater extraction are shown on Figure 8.5, which provides a comparison between the pre-development groundwater levels in 1969 and the groundwater levels in 2008. The figure shows the development of a groundwater depression located to the east of Cecil Plains where recorded drawdowns are in excess of 20 m.

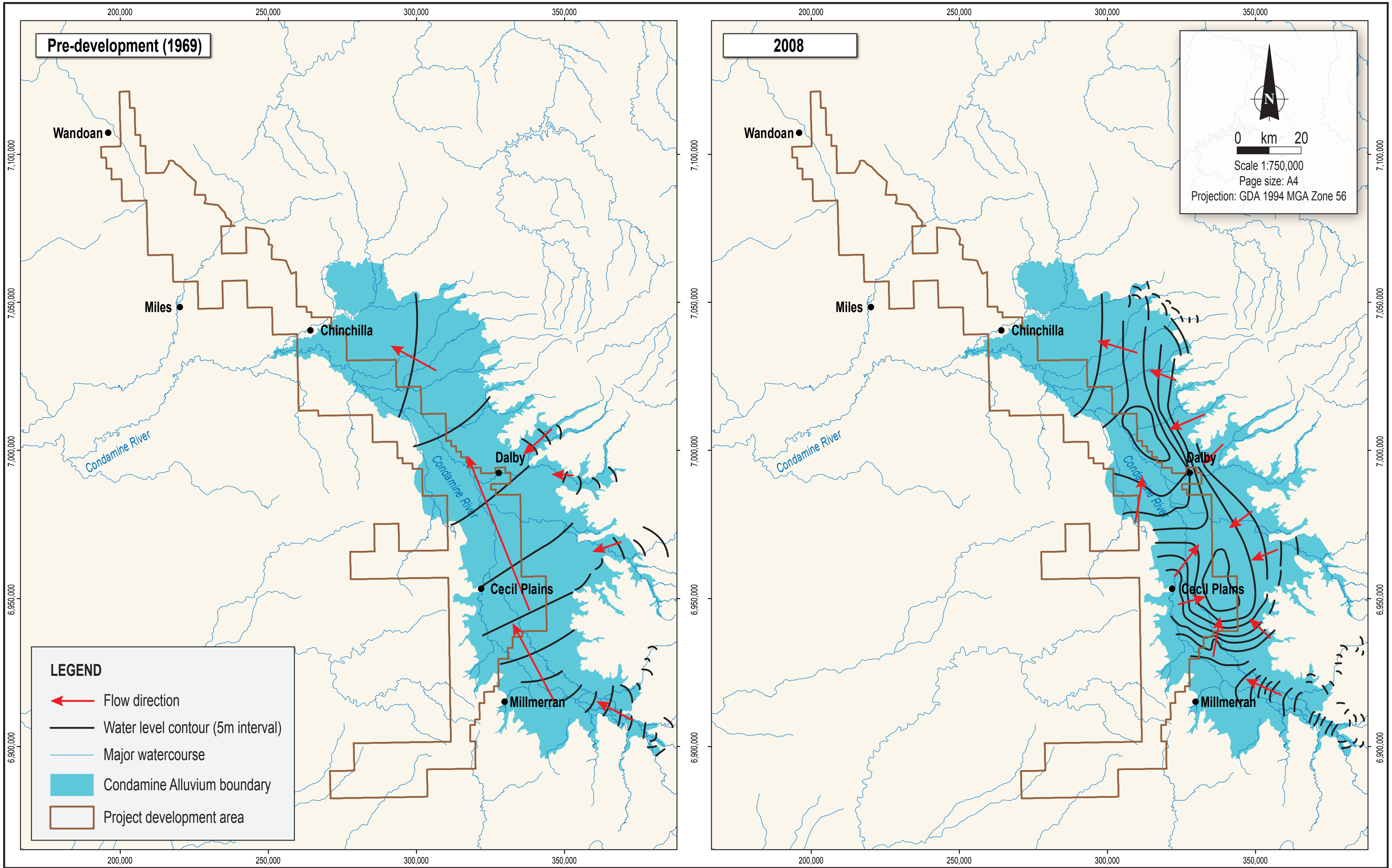
Since 1970, the impact of non-coal seam gas extraction on this resource was recognised and further access to Condamine Alluvium groundwater was limited. A moratorium to limit development of groundwater from the Condamine Alluvium and the basalts in the Upper Condamine Catchment was published in June 2008. This moratorium was recently amended to further restrict new take of groundwater in the system (DNRM, 2012c).

Groundwater movement, from the Walloon Coal Measures to the overlying Condamine Alluvium is thought to occur, yet a widespread deterioration in groundwater quality in the Condamine Alluvium has not been observed. This groundwater quality data indicates that the level of connectivity between the Walloon Coal Measures and the Condamine Alluvium is relatively minor.

Additional detail on the modelled degree of interconnectivity between these units and the predicted groundwater flux impacts to the Condamine Alluvium as a result of coal seam gas water extraction from the Walloon Coal Measures is presented in Section 8.4.3.

Connectivity between the Condamine Alluvium and other Formations

The relationship between the Condamine Alluvium and other formations was characterised in the investigation conducted by KCB, 2010b. The investigation indicates a groundwater flow direction from higher pressures in the Hutton Sandstone to lower pressures in the Condamine Alluvium. Similarly, the Main Range Volcanics show a consistently higher hydraulic head in comparison with the adjoining Condamine Alluvium. These findings indicate that the Condamine Alluvium receives groundwater from the Hutton Sandstone and the Main Range Volcanics.



Source:
Place names from GEODATA250k. Watercourses from DERM.
Project development area and Condamine Alluvium boundary from Arrow Energy.
Water level contours and flow directions digitised from DNRM report
'Upper Condamine Alluviums groundwater systems background summary" (September, 2012).

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MXD: 7040AF_GW03_GIS082_v1_3
File Name: 7040_GW03_F08.05_GIS_GL

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Groundwater level changes in the Condamine Alluvium due to non-coal seam gas activities

Figure No: 8.5

Groundwater-Dependent Ecosystems

Groundwater-dependent ecosystems were identified and discussed in the groundwater impact assessment prepared for the EIS. Additional information has allowed identification of the types of groundwater-dependent ecosystems present within the Surat CMA in a manner consistent with the classification system adopted in the Australian groundwater-dependent ecosystem toolbox assessment framework (Richardson et al., 2011a and 2011b), as follows:

- Ecosystems dependent on the surface expression of groundwater including:
  - Springs (including spring wetlands and spring fed watercourses).
  - Groundwater discharge to watercourses and wetlands.
- Ecosystems dependent on the subsurface presence of groundwater, including plant roots accessing shallow groundwater.

The National Groundwater-dependent Ecosystem Atlas (SKM, 2012) is a useful tool for identifying other areas with the potential to be groundwater-dependent, including where groundwater potentially discharges to watercourses and wetlands, or where plants may access groundwater. However, in some areas this groundwater-dependency has not been verified through field investigations.

A summary of the updated information related to groundwater-dependent ecosystems in the Surat CMA is provided in the sections below. Further details are provided in Appendix 4, Supplementary Groundwater Assessment.

Springs

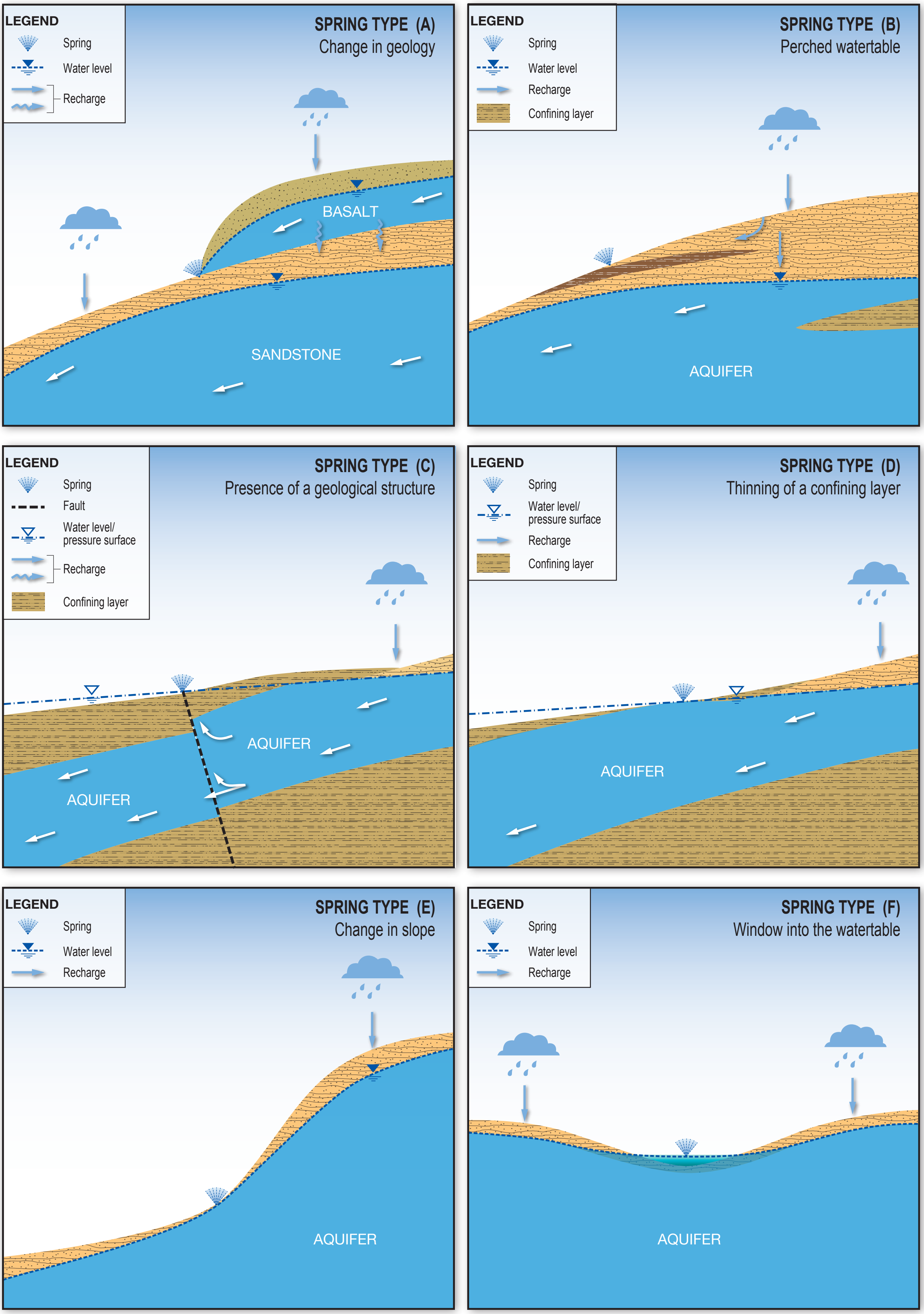
The Surat CMA UWIR presents six types of springs (type a – f) that may be found within the Surat CMA. These are shown in Figure 8.6.

Springs in the Surat CMA typically occur as a result of the presence of a geological structure (type c) that acts as a conduit for groundwater flow from deeper aquifers. These types are also known as spring vents, or discharge springs. Discharge springs may also occur where there is a thinning of a confining layer (type d).

Spring types (type a, b, and e) shown in Figure 8.6 describe the interaction of the water table or a perched (isolated) aquifer with the ground surface. These types are typically known as recharge springs as they often occur in aquifer recharge zones and in areas where the rates of recharge (from direct rainfall and surface runoff) exceeds the infiltration rate into the underlying shallow or perched groundwater system. The groundwater flow path from the source aquifer that supports a recharge spring is often shorter in comparison with discharge springs, which can be sourced from aquifers at greater depths e.g., aquifer units of the Great Artesian Basin.

Springs that represent a window into the water table (type f), occur where the water table discharges directly to a watercourse or wetland feature. These features are also referred to in the Surat CMA UWIR as watercourse springs or baseflow fed watercourses.

The locations of known springs and watercourse springs within the Surat CMA are presented in Figure 8.7. Each spring is ranked according to conservation importance, with rankings ranging from highest importance (ranking of 1) to lowest importance (ranking of 5) based on the biological importance of each spring.



Source: OGIA, 2012 Figure 8-1

coffey environments	Date: 27.06.2013	Arrow Energy	arrow energy go further	Types of springs in the Surat Cumulative Management Area	Figure No: 8.6
	File Name: 7040_12_F08.06_HB	Surat Gas Project			

To date, 71 spring complexes (comprising 330 known spring vents) have been identified in the Surat CMA. A spring complex is defined as a cluster of spring vents, in similar geology, fed by the same source aquifer and located no more than 6 km apart. There are no known spring vents within the project development area.

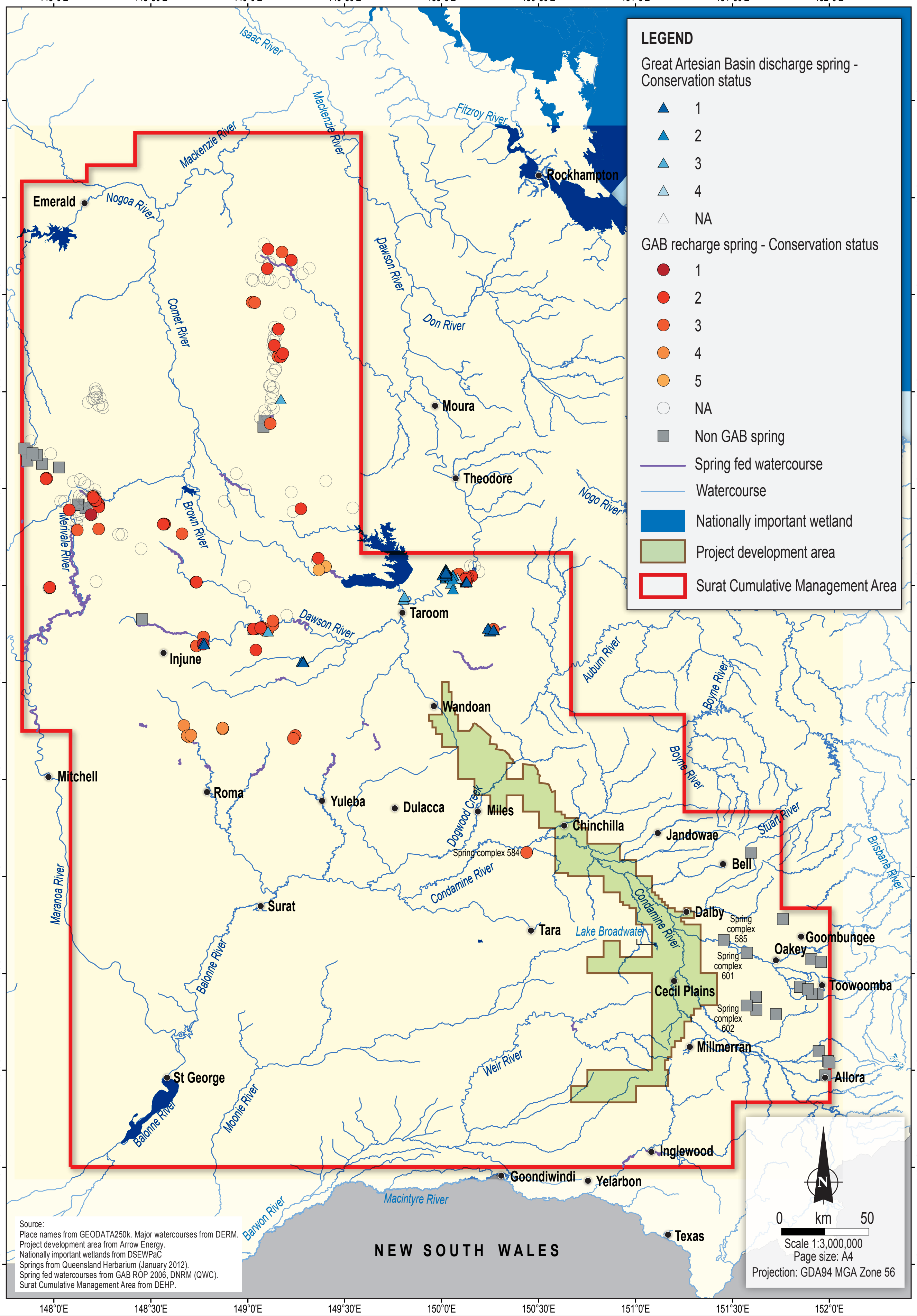
A total of 43 watercourse springs have been identified in the Surat CMA. There are no known watercourse springs within the project development area.

Results of the Halcrow investigations (Halcrow, 2012 and Halcrow, 2013) are yet to be confirmed through field surveys. As such, the location of additional springs identified through remote sensing mapping and aerial investigation are not included in Figure 8.7.

A summary of the key features of known springs and watercourse springs (based on information presented in Fensham et al., 2012, KCB, 2012a and OGIA, 2012) within the Surat CMA are summarised in Table 8.3 below. More detailed information is presented in the supplementary groundwater assessment (Appendix 4).

Table 8.3 Features of known springs and watercourse springs in the Surat CMA

Wetland	Springs	Watercourse springs
Location	There are two broad areas in the Surat CMA where springs are known to occur: • An area in the northern half of the Surat CMA, to the northwest of the project development area (Figure 8.7). • The eastern-most portion of the Surat CMA, immediately east of the project development area (Figure 8.7).	Watercourse springs are generally located in the northern portion of the Surat CMA (Figure 150), associated with the Dawson River and Merivale River (Figure 8.7).
Ecological characteristics	• EPBC Act listed communities have been identified at 92 spring vents. • EPBC Act listed species have been identified at 36 spring vents. • NC Act listed species have been identified at 43 spring vents.	A single watercourse spring has NC Act listed species. No EPBC Act listed species or communities have been identified at known watercourse springs.
Source Aquifer	Source aquifers vary and can be broadly grouped as follows: • Primary source aquifers for the springs in the northern area are considered to be the Gubberamunda Sandstone, Hutton Sandstone, Evergreen Formation (including Boxvale Sandstone member) or Precipice Sandstone. A lesser number have either the Birkhead Formation (a lateral equivalent of the Walloon Coal Measures) or Clematis Sandstone (a unit within the Bowen Basin) listed as a secondary option for the potential source aquifer. • Springs in the eastern area are generally associated with drainage from the Main Range Volcanics, and therefore do not represent springs sourced from the Great Artesian Basin.	Source aquifers have been assigned for watercourse springs listed in the UWIR as potentially affected. Source aquifers for these springs are nominated as either the Kumbarilla Beds (including Mooga and Gubberamunda Sandstones) or Hutton Sandstone, and relate directly to the outcrop geology at the watercourse spring location.
Conservation ranking	There are seven spring complexes within the Surat CMA with a category 1 ranking (highest importance).	A single watercourse spring has a category 1 ranking (highest importance).



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MXD: 7040AE_12_GIS150_v1_1

File Name: 7040_12_F08.07_GIS_HU

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Location of springs, watercourse springs and nationally important wetlands in the Surat CMA

Figure No: 8.7

Groundwater Discharge to Watercourses

An understanding of groundwater-surface water interaction can be used to determine the degree of potential groundwater-dependency in an area. Areas of connectivity occur where the depth to groundwater is shallower than the base of the surface water feature, which can include watercourses and wetlands.

A study of surface-groundwater connectivity across the Murray-Darling Basin (Parsons et al., 2008) included individual connectivity assessments for 13 watercourse catchments across the Murray-Darling Basin. The project development area intersects the Condamine-Balonne, Border Rivers and Moonie River catchments of the broader Murray-Darling Basin (Figure 8.8). All of these catchments were included in this study, although the project development area intersects such a minor section of the Moonie River catchment (less than 1%), that it is not discussed further here.

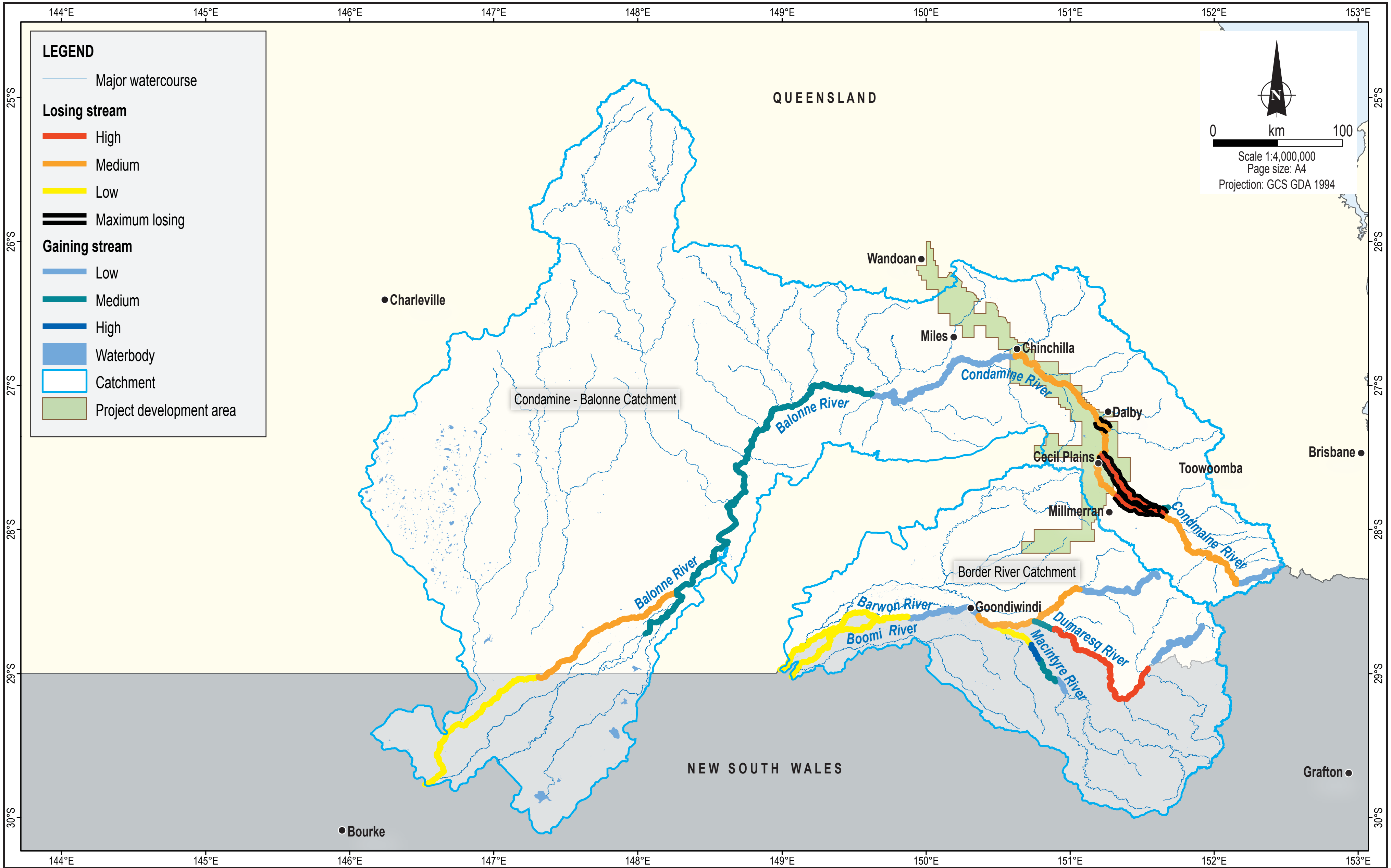
The study used watertable elevation data in reaches of each mapped watercourse and the underlying groundwater system. Mapped watercourse reaches were classified as one of the following:

- Gaining watercourse, whereby the watercourse is receiving groundwater, and therefore has the potential to support groundwater-dependent ecosystems.
- Losing watercourse, whereby surface water is lost to the underlying groundwater system or unsaturated soil, and therefore do not have the potential to support groundwater-dependent ecosystems.
- Seasonally varying, whereby the watercourse reach may fluctuate through time between gaining and losing, and therefore has the potential to support groundwater-dependent ecosystems.
- Maximum losing, to represent watercourses that are hydraulically disconnected from the underlying groundwater system. Typically this coincided with areas of high groundwater extraction, and lowered watertable.

Figure 8.8 presents the results of the study conducted in the Condamine-Balonne and Border River catchments.

The Condamine River is mapped as a losing watercourse throughout most of the Condamine Alluvium. This area has historically experienced significant development of groundwater resources, primarily for agriculture and stock and domestic purposes. As such, the watertable elevation mapping reflects a decline in groundwater levels in the Condamine Alluvium to the point where there is now disconnection between the Condamine River and the underlying groundwater system (i.e., the groundwater table in the Condamine Alluvium is below the base of the Condamine River bed).

Watertable elevation in some areas of the Condamine Alluvium is up to 20 m below the river bed as a result of groundwater extraction (Barnett & Muller, 2008). Beyond the western boundary of the project development area near Chinchilla, the Condamine River is mapped as a ‘low gaining’ reach and represents a section of the Condamine River supported by groundwater baseflow. This area may support groundwater-dependent ecosystems.



Source:
Place names, waterbodies and watercourses from GEODATA250k.
Project development area from Arrow Energy.
Catchments and connectivity classifications derived from CSIRO report Surface–groundwater connectivity assessment, CSIRO Murray-Darling Basin Sustainable Yields Project', S. Parsons, R. Evans and M. Hoban, September 2008

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Surface-groundwater connectivity for the Condamine-Balonne and Border River Catchments

Figure No: 8.8

The Border Rivers catchment assessment indicates variable groundwater and surface water interaction, typically with gaining watercourse reaches in the upper catchment south of Millmerran, and then transitioning to losing watercourse reaches downstream in areas where the narrower upland valleys give way to wider plains.

Detailed outputs from the National Atlas of Groundwater Dependent Ecosystems show that there are inconsistencies between watercourse reaches identified in the atlas as dependent on the surface expression of groundwater, and the water elevation mapping presented in Figure 8.8. The watertable elevation mapping has been interpreted as the primary tool for determining watercourse reaches within the project development area that have a potential to be supplied by groundwater. Where data from the watertable elevation mapping is unavailable (i.e., for tributaries of the Condamine River), watercourse reaches identified in the atlas with a high potential for groundwater interaction have also been considered as having a potential to be supplied by groundwater. Using this rationale, the following watercourse reaches are identified in the project development area as having the potential to be supplied by groundwater and support groundwater-dependent ecosystems:

- Reaches of Roche Creek, north-east of Wandoan that correlate with areas with a high potential for groundwater interaction mapped by the atlas.
- Reaches of Juandah Creek south of Wandoan that correlate with areas with a high potential for groundwater interaction mapped by the atlas.
- 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 that correlate with areas with a high potential for groundwater interaction mapped by the atlas.

Nationally Important Wetlands

Wetlands can also be supplied by groundwater and can therefore support groundwater-dependent ecosystems. A search of the EPBC Act ‘Protected Matters: Nationally Important Wetlands’ (SEWPaC, 2013) directory identified seven wetlands within the Surat CMA (Figure 8.7). Of these wetlands, only Lake Broadwater occurs within the project development area. The Directory of Important Wetlands in Australia (Environment Australia, 2001) and the web-based information sheet for Lake Broadwater (SEWPaC, 2013) were used to provide an interpretation on the potential for each wetland to be supported by groundwater, and therefore provide suitable conditions for groundwater-dependent ecosystems. A summary is provided in Table 8.4:

Table 8.4 Summary of Nationally Important Wetlands within the Surat CMA

Wetland	Wetland Category and Location	Potential to Support Groundwater-Dependent Ecosystems
Balonne River floodplain	Inland wetland located outside the project development area	The Balonne River floodplain is located in the southwest corner of the Surat CMA, and has the potential to be both groundwater and surface water-fed. The Balonne River flood plain may support groundwater-dependent ecosystems.
Boggomoss Springs	Inland wetland located outside the project development area	The Boggomoss Springs is a spring complex known to be dependent on groundwater from the Great Artesian Basin, and are acknowledged as forming part of a nationally important wetland landscape. The Boggomoss Springs were assessed during the 2011 spring field surveys conducted to inform the Surat CMA UWIR (KCB, 2012a and Fensham et al., 2012).

Table 8.4 Summary of Nationally Important Wetlands within the Surat CMA (cont'd)

Wetland	Wetland Category and Location	Potential to Support Groundwater-Dependent Ecosystems
Fairbairn Dam	Human-made wetland located outside the project development area	Runoff and surface water flow are identified as the principle water sources supporting Fairbairn Dam. Conditions at this wetland are unlikely to support groundwater-dependent ecosystems.
Lake Broadwater	Inland wetland located inside the project development area	Runoff, surface water flow and floodout waters from the surrounding catchment are identified as the principle water sources supporting Lake Broadwater. Conditions at this wetland are unlikely to support groundwater-dependent ecosystems. Lake Broadwater is known to fill and occasionally flood during the summer rainfall, and subsequently recede. The lake has also been known to dry out completely supporting the assessment that Lake Broadwater is not reliant on a groundwater supply.
Lake Nuga Nuga	Inland wetland located outside the project development area	Runoff and surface water flow are identified as the principle water sources supporting Lake Nuga Nuga. Conditions at this lake are unlikely to support groundwater-dependent ecosystems.
Palm Tree and Robinson Creeks	Inland wetland located outside the project development area	Runoff and surface water flow are identified as the principle water sources supporting Palm Tree and Robinson Creeks. Conditions at this location are unlikely to support groundwater-dependent ecosystems. Water depths are seasonally variable and semi-permanent which supports the assessment that Palm Tree and Robinson Creeks are not reliant on a groundwater supply.
The Gums Lagoon	Inland wetland located outside the project development area	The Gums Lagoon fills once every 7 to 10 years, and is unlikely to support groundwater-dependent ecosystems.

The National Atlas of Groundwater Dependent Ecosystems atlas identifies Lake Broadwater with a moderate potential for groundwater interaction. However, the hydraulic characteristics of Lake Broadwater and its interaction with surface water processes indicate that it is not groundwater-dependent and is unlikely to support groundwater dependent ecosystems.

Ecosystems Dependent on the Subsurface Presence of Groundwater

Ecosystems dependent on the subsurface presence of groundwater occur in areas where groundwater levels are near the surface or where the root systems of vegetation are able to access deeper groundwater systems. The National Atlas of Groundwater Dependent Ecosystems defines these systems as groundwater-dependent ecosystems that potentially rely on the subsurface presence of groundwater. The atlas presents areas classified with a low, moderate or high potential for interaction with the subsurface presence of groundwater. None of the areas identified in the atlas that are located within, or in the vicinity of the project development area have been identified as groundwater-dependent through previous field or desktop assessments.

Inconsistencies are evident between areas identified in the atlas as dependent on the subsurface presence of groundwater and the water elevation mapping presented in Figure 8.8. The watertable elevation mapping has been interpreted as the primary tool for determining regions within the project development area where groundwater levels are expected to be shallow enough to support vegetation.

Overall, and based on the water elevation mapping, the project development area is located within a losing system, whereby surface water is lost to the underlying groundwater systems. Any areas identified in the atlas with a moderate or high potential for interaction with the subsurface presence of groundwater that are located along the Condamine River or its tributaries are not considered to be located in areas where plant roots can access the underlying groundwater system.

Where data from the watertable elevation mapping is unavailable (i.e., for areas away from the Condamine River), the areas identified in the atlas with a high potential for interaction with the subsurface presence of groundwater are considered to represent areas where conditions may support ecosystems dependent on the subsurface presence of groundwater. Using this rationale, the following vegetated areas are identified in the project development area that may be dependent on the subsurface presence of groundwater:

- An area in the northern portion of the project development area, which is located in the fringe of the Barakula State Forest.
- An area to the west of Cecil Plains on the edge of the project development area, in the vicinity of the Kumbarilla and Dunmore State Forests.

The vegetation communities in these two areas are mapped as regional ecosystems 11.7.5 and 11.5.4 which have been identified in Chapter 11, Terrestrial Ecology as areas of low sensitivity not of conservation interest under the EPBC Act, *Vegetation Management Act 1999* (Qld) *and Environmental Protection Act 1994* (Qld).

Summary of Groundwater-Dependent Ecosystems

No known springs or watercourse springs identified in the Surat CMA UWIR are located within the project development area. There are no known wetlands dependent on groundwater supply, and the majority of watercourse reaches within the project development area are considered to be losing systems, and therefore not supported by groundwater.

There are limited areas identified by the National Atlas of Groundwater Dependent Ecosystems within the project development area that are mapped with a high potential for interaction with groundwater. These areas have not undergone field investigations, and the areas mapped as ecosystems dependent on the subsurface presence of groundwater do not contain vegetation communities of conservation status. Dependency of these vegetated areas on groundwater is unconfirmed and relies on the potential for groundwater drawdown to occur in areas where the source aquifer is close to the surface (outcrop areas).

Groundwater Quality

The EIS presented groundwater quality data sourced from the Queensland Government Groundwater Database (accessed in October 2009) from registered bores within the project development area. Additional data sources have since been reviewed to provide a more comprehensive summary of groundwater quality across the Surat CMA.

The database of historical groundwater and stratigraphic information for the Surat and Bowen basins (developed as part Activity 1.2 of the Coal Seam Gas Water Feasibility Study (WP, 2012)) was used to generate a representative data set of groundwater quality across the Surat CMA over a consistent time period.

Groundwater within key aquifer units has been classified by its groundwater quality composition, based on major ion composition, total dissolved solids (TDS) and pH and are summarised in Table 8.5. The geological formations presented in the table represent key formations within the project development area and form a sub-set of those formations represented in the Activity 1.2 database (WP, 2012). The dominant water quality composition categories presented in the supplementary groundwater assessment (Appendix 4) are generally consistent with those identified in the EIS and show that groundwater composition for aquifers within the Great Artesian Basin are similar.

Table 8.5 Summary of Surat Basin groundwater chemistry

Groundwater System	Formation[1]	Number of Samples	Dominant Groundwater Composition	Median TDS concentration (mg/L)	Median pH	Comments
Shallow groundwater system	Alluvium	1297	Sodium-bicarbonate with variable chloride influence	714	7.6	In addition to the dominant groundwater composition identified the supplementary report, the EIS also indicated the presence of magnesium in the water quality for the Condamine Alluvium. Values for pH are generally consistent, however additional data available indicates higher TDS concentrations. Data presented in the supplementary report is based on an increased sample size in comparison to the EIS and is therefore considered to better represent aquifer groundwater chemistry conditions.
Intermediate groundwater system	Bungil Formation, Mooga Sandstone and Orallo Formation	556	Sodium-bicarbonate to sodium-bicarbonate-chloride	1080	8.3	Water quality is generally consistent with data for the Kumbarilla beds provided in the EIS.
	Gubberamunda Sandstone	669	Sodium-bicarbonate to sodium-chloride-bicarbonate	689	8.3	
	Westbourne Formation	11	Sodium-chloride-bicarbonate	1195	8.2	
	Springbok Sandstone	79	Sodium-bicarbonate-chloride to sodium-chloride-bicarbonate	1211	7.7	The EIS nominated a sodium-chloride dominant groundwater composition however the EIS water quality assessment was based on a single sample from the Springbok Sandstone therefore the SREIS dataset is considered to better represent aquifer conditions.

Table 8.5 Summary of Surat Basin groundwater chemistry (cont'd)

Groundwater System	Formation[1]	Number of Samples	Dominant Groundwater Composition	Median TDS concentration (mg/L)	Median pH	Comments
Coal seam gas groundwater system	Walloon Coal Measures (coal seam)	302	Sodium-bicarbonate to sodium-chloride-bicarbonate	2741	8.0	Generally consistent with the water quality information presented in EIS. The EIS did not separate water quality of coal seams from sandstone sub-units.
	Walloon Coal Measures (sandstone sub-units)	83		1685	8.1	
	Eurombah Formation	10	Sodium-bicarbonate to sodium-bicarbonate-chloride	760	8.2	Water quality information for this unit was not presented in the EIS.
Deep groundwater system	Hutton Sandstone/Marburg Subgroup	234	Sodium-bicarbonate to sodium-chloride-bicarbonate	752	8.1	Generally consistent with the water quality information presented in EIS.
	Evergreen Formation (aquitard unit)	33	Sodium-bicarbonate	787	8.0	Water quality information for this unit was not presented in the EIS.
	Evergreen Formation (sandstone sub-units)	82		252	7.6	Water quality information for this unit was not presented in the EIS.
	Precipice Sandstone	113	Sodium-bicarbonate	151	7.4	Water quality information for this unit was not presented in the EIS.

1. The geological formations presented in this table represent key formations within the project development area and form a sub-set of those formations represented in the Activity 1.2 database (WP, 2012).

Groundwater Use

Groundwater within the Surat CMA has historically been used for a wide variety of non-petroleum and non-gas purposes, including irrigation, agriculture, grazing, industry and urban supply. Groundwater extraction associated with the petroleum and gas industry has increased in the last 5 to 10 years with the expansion of coal seam gas production within the Surat CMA. Groundwater extracted as part of petroleum and gas activities is defined in the Surat CMA UWIR as groundwater extracted during 'conventional' oil and gas production (i.e., usually from sandstone formations) or from coal seam gas production (sometimes termed 'unconventional' gas production).

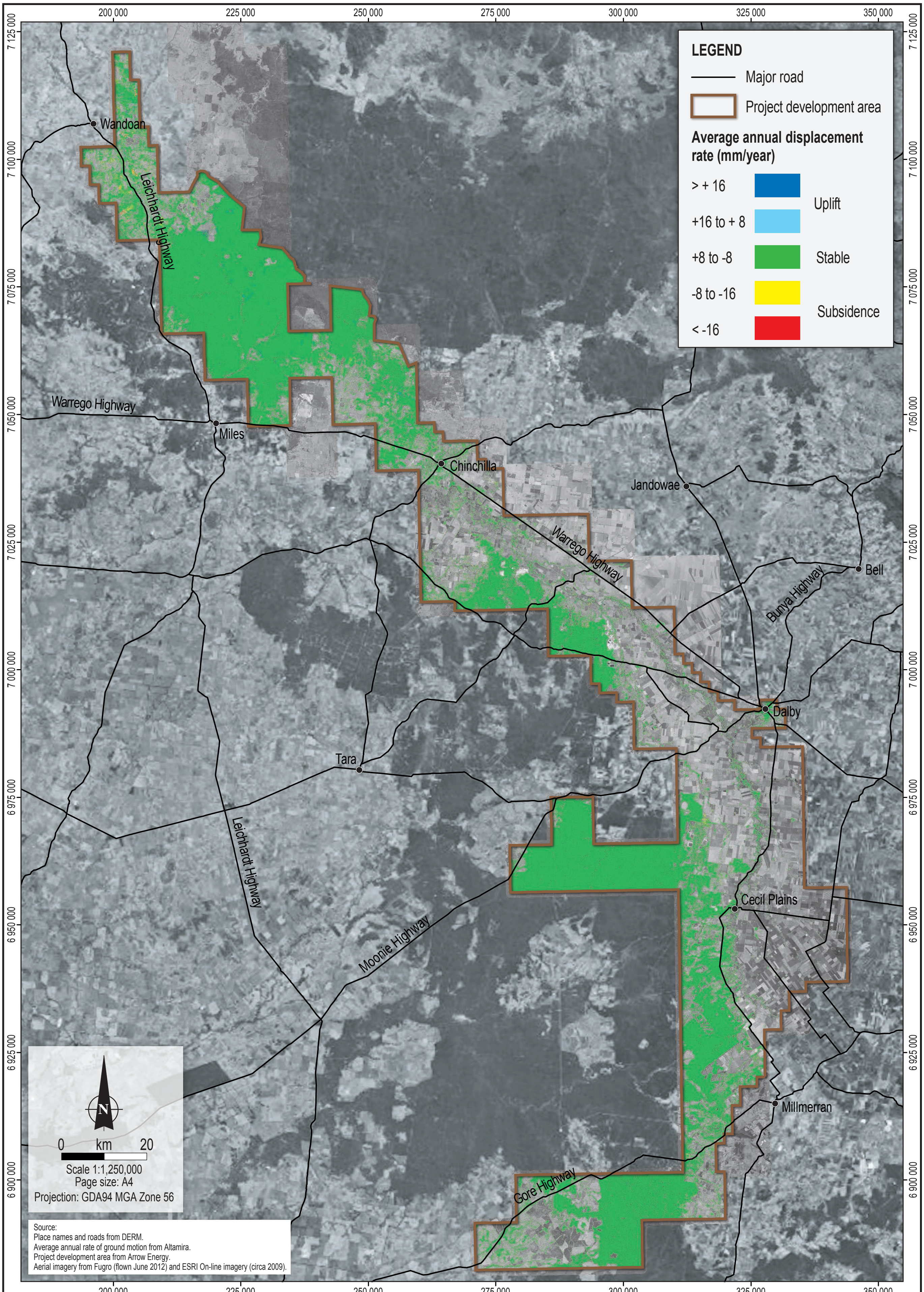
An inventory of groundwater use is presented in the UWIR for the Surat CMA (OGIA, 2012) and is summarised below:

- Non-petroleum and gas groundwater bores:
  - There are over 21,000 water bores within the Surat CMA with a combined water extraction in the order of 215,000 megalitres per annum (ML/a). Of this, around 85,000 ML/a is sourced from Great Artesian Basin formations and 130,000 ML/a is sourced from other aquifers, including 55,000 ML/a from the Condamine Alluvium.
  - Aquifers having the greatest number of groundwater bores and extraction volume include the Condamine Alluvium and Main Range Volcanics, and to a lesser extent the Walloon Coal Measures and Hutton Sandstone.
- 'Conventional' oil and gas wells:
  - In early 2011 there were 154 'conventional' oil and gas wells extracting groundwater from the Surat and Bowen basins within the Surat CMA. The majority of groundwater has been extracted from aquifers of the Great Artesian Basin.
  - Current annual water extraction is approximately 1,800 ML/a. This rate has not been significantly exceeded over the past 30 years.
- Coal seam gas wells:
  - In early 2011, 1,160 coal seam gas wells were extracting groundwater.
  - Total groundwater extraction from coal seam gas wells reported to the OGIA in 2011 was approximately 18,000 ML.

Subsidence

Review of information sources relevant to subsidence indicates that from 2006 to 2011 ground motion within the project development area has been minimal. The area is classified as stable in the Altamira Information study (Altamira Information, 2012a; 2012b) (Figure 8.9). Within this time frame, some coal seam gas extraction has occurred in relation to Arrow's current activities, including Arrow's Dalby Expansion Project. Notable ground motion in these areas was not observed. Some areas of localised motion were identified, and these were noted in the Altamira Information reports to be associated primarily with irrigation dams and an open pit coal mine.

The link between coal seam gas extraction and the potential for surface subsidence has been an area of further study since finalisation of the EIS. A report prepared for the Australian Council of Environmental Deans and Directors in October 2012 (Williams, 2012), reflects the general understanding across the industry that subsidence within a landscape will occur to some degree following extraction of water from aquifers.



Source:
Place names and roads from DERM.
Average annual rate of ground motion from Altamira.
Project development area from Arrow Energy.
Aerial imagery from Fugro (flown June 2012) and ESRI On-line imagery (circa 2009).

coffey environments	Date: 27.06.2013 MXD: 7040AF_GW03_GIS012_v1_3 File Name: 7040_GW03_F08.09_GIS_JO	Arrow Energy Surat Gas Project	arrow energy go further	Historical average annual rate of ground motion within the project development area (2006 to 2011)	Figure No: 8.9

A report commissioned by SEWPaC, and undertaken by Geosciences Australia in 2010 (Geosciences Australia and Habermehl, 2010) also notes that groundwater extraction may cause some aquifer compaction that is likely to result in a degree of subsidence. However, the structural integrity of aquifers in relation to their ability to transmit water is unlikely to be significantly impacted by groundwater extraction associated with coal seam gas production.

8.4.2 Comparison of Groundwater Modelling Methods

A numerical groundwater model requires data that conceptualises the stratigraphic and geological profile, the hydraulic parameters of the geological units, and the behaviour of groundwater flow. Estimates of groundwater extraction are also required as a model input to predict groundwater drawdown levels. Other important aspects of numerical groundwater models include the model boundary conditions (a representation of the way groundwater flows into and out from the model extent), the methods used to calibrate the model, and determine the areas of the model sensitive to uncertainty.

A detailed comparison between the Arrow EIS groundwater model and the OGIA Surat CMA model is provided in the supplementary groundwater assessment (Appendix 4). The key similarities and differences are summarised in Table 8.6 and are considered when comparing the results of the Arrow SREIS groundwater model (which is consistent with the approach adopted in the OGIA Surat CMA groundwater model) with the Arrow EIS groundwater model.

Table 8.6 Summary of model comparison findings

Model Aspect	Arrow EIS Groundwater Model	OGIA Surat CMA Groundwater Model	Comments
Stratigraphic and Geological Conceptualisation	• 15 model layers over an area of approximately 450 km by 270 km. • Includes formations in the Surat Basin and western extent of the Clarence-Moreton Basin. • Condamine Alluvium represented as a single layer in the model. • Walloon Coal Measures represented as five layers in the model	• 19 layer model over an area of approximately 580 km by 660 km. • Includes formations in the Surat Basin and underlying Bowen Basin. • Condamine Alluvium represented as a two layers in the model; a wedge of fine-grained material next to the eastern river channel wall (sheetwash) overlying an alluvial layer with more varied grain size. The alluvial layer is located in the western portion of the channel (Figure 8.2). • Walloon Coal Measures represented as three layers in the model. • More recent data on the thicknesses of Hutton Sandstone and Precipice Sandstone obtained through drilling activities that occurred after finalisation of the Arrow EIS (GHD, 2012) was used to revise the thickness of these units.	Overall, the stratigraphic profiles are comparable for regional groundwater models of this scale. The thickness and extent of the Condamine Alluvium are similar, and the Kumbarilla Beds are represented by the Mooga Sandstone, Gubberamunda Sandstone, Westbourne Formation and Springbok Sandstone.
Groundwater flow and aquifer hydraulic parameters	A detailed comparison of the following hydraulic parameters is presented in the supplementary groundwater assessment (Appendix 4): • Average horizontal conductivity: a measure of the rate at which groundwater moves through a geological unit in the direction of groundwater flow (i.e., in a horizontal direction). • Average vertical conductivity: a measure of the rate at which groundwater moves through a geological unit in a direction perpendicular to groundwater flow (i.e., in a vertical direction). • Specific storage: a measure of an aquifer's ability to release groundwater.		The calibrated horizontal conductivity values are similar, and of the same magnitude in both models. The calibrated vertical conductivity values determined by the Arrow EIS groundwater model are more conservative (higher values) than the calibrated parameters determined by the OGIA Surat CMA groundwater model. These higher values permitted greater levels of vertical groundwater movement between units in the Arrow EIS groundwater model. Specific storage values are very similar.

Table 8.6 Summary of model comparison findings (cont'd)

Model Aspect	Arrow EIS Groundwater Model	OGIA Surat CMA Groundwater Model	Comments
Groundwater Extraction	• The Modflow Multi-Node Well package was used to simulate drawdown in aquifers based on an anticipated volume of groundwater extracted over time from an arbitrary grid of production wells located across the project development area. • The model predicted drawdown from Arrow-only extraction and from cumulative coal seam gas extraction. • Production data used to simulate groundwater drawdown was sourced from publically available information. • Did not simulate a scenario without coal seam gas extraction (i.e., a scenario with only irrigation, stock, town supply etc.).	• Uses an evapotranspiration (EVT) package to generate the volume of groundwater that needs to be extracted to reach a certain pressure target in the aquifers. This method generally results in an over-estimate of the water extraction volume. Groundwater drawdowns were predicted for two scenarios: • Base Run Scenario: Estimates water extraction for non-coal seam gas groundwater users within the Surat CMA. • Petroleum and gas production run scenario: Relies on more recent production data obtained from all coal seam gas proponents in the Surat CMA. Groundwater extraction from the Condamine Alluvium groundwater model was based on a Multi Node Well No.2 and Fracture Well package.	The difference between the modelled groundwater extraction rates presented in the Arrow EIS and the OGIA Surat CMA groundwater models is a reflection of the methods used. The over-estimation of modelled groundwater extraction volumes produced through the use of the EVT package by the OGIA allows a more conservative approach to the assessment of groundwater drawdown impacts as actual impacts are likely to be lower than modelled.
Model Boundary Conditions	Constant head boundaries (where groundwater is either flowing into or out of the model at a constant rate) were applied along portions of the eastern edge and the western edge of the model extent to allow for regional inflow (from the east) and outflow (to the west). These constant head boundaries represented the regional groundwater flow regime from east to west across the Surat Basin.	• General head boundaries (where the rate of groundwater flow into or out of the model can vary depending on pressure changes in the model) were applied in key aquifers only. • All constant head boundary conditions were removed. • Aquitards were assigned a default 'no flow' boundary condition. • Five conceptual general head boundaries were adopted in the Condamine Alluvium groundwater model to account for the mechanisms through which groundwater flows into and out of the Condamine Alluvium.	Despite the use of varied boundary conditions, the model function and predictions from the Arrow EIS and the OGIA Surat CMA groundwater models are comparable and represent the understanding of regional groundwater flow through the system.

Table 8.6 Summary of model comparison findings (cont'd)

Model Aspect	Arrow EIS Groundwater Model	OGIA Surat CMA Groundwater Model	Comments
Recharge Rates	• A recharge rate of 1 mm/a was applied to aquifer outcrop areas defined in the Arrow EIS groundwater model based on Kellett et al., 2003. • Where confining layers outcropped at the surface, no recharge was applied. • The foot of the Main Range Volcanics were assigned a recharge rate of 5 mm/a to reflect enhanced recharge associated with this recharge zone of the Great Artesian Basin.	• Recharge rates were allocated to zones defined across the model extent. • In most zones, recharge was allowed to vary between 1 and 30 mm/a based on the range of long-term average estimates included in Kellett et al., (2003). • The majority of the area to the west of Dalby was allocated a recharge rate of between 0 and 3 mm/a. • The average long-term average net recharge to the Main Range Volcanics was defined as 5.2 mm/a. • In the more detailed Condamine Alluvium groundwater model, a range of recharge values were calculated during the calibration process, and reflect the variety of recharge mechanisms associated with this aquifer.	The recharge rates assigned in the models are comparable.
Model Calibration	The model was calibrated by manually varying hydraulic properties, within the documented ranges, to improve the alignment between simulated (both historical and current) and observed (both historical and current) groundwater levels.	Calibration was undertaken using the Parameter Estimation Code of software (Doherty, 2010). This system is designed specifically to assist with optimising parameters in a groundwater model.	The comparison indicates that calibration of the models with observed conditions meets a similar standard in both models and that they are both suitable for use as regional groundwater models.

Table 8.6 Summary of model comparison findings (cont'd)

Model Aspect	Arrow EIS Groundwater Model	OGIA Surat CMA Groundwater Model	Comments
Sensitivity and Uncertainty Analysis	• Analysis focused on the specific storage of all layers and the vertical hydraulic conductivity of some of the key model layers. • A total of 15 sensitivity runs were simulated. • The findings showed that there was little difference between the sensitivity run values compared with the calibrated case. • The model was calibrated to a satisfactory level.	• Generation of 200 model predictions based on 200 different statistically generated parameter sets, resulting in 200 different predictions of groundwater level impacts. • Generates an abundance of outputs, which were analysed statistically. • The model was calibrated to a satisfactory level. • The Condamine Alluvium groundwater model was subjected to a qualitative sensitivity analysis during model development and manual calibration. A complete sensitivity analysis of all major model components was not undertaken.	Different methods for sensitivity and uncertainty analyses were used, and show that the models were calibrated to a satisfactory level.

8.4.3 Arrow SREIS Groundwater Modelling Results

The Arrow SREIS groundwater model simulates Arrow's current development case in the OGIA Surat CMA groundwater model with the following key changes:

- A different set of predictive extraction scenarios. For the purposes of the supplementary groundwater assessment, the predicted drawdowns associated with the following modelling scenarios have been used to evaluate the potential impacts of the project on groundwater values:
  - Non Coal Seam Gas Case, to evaluate the drawdown associated with extraction that is not associated with petroleum and gas activities from 1995 onwards.
  - Arrow-only case, to determine the contribution of Arrow's current development case to groundwater drawdown impacts in the Surat CMA.
  - Cumulative case, to evaluate cumulative drawdown impacts predicted by the OGIA for the Surat CMA in response to Arrow's current development case.
  - Substitution case, to determine the response of the Condamine Alluvium to 'virtual injection' via substitution of treated coal seam gas water.
- Incorporation of Arrow's current development plan. Using the EVT package, the Arrow SREIS groundwater model simulates a water production volume of 702 GL with a peak extraction rate of 140 ML per day (ML/day) anticipated between 2021 and 2024.

The outputs of the calibrated case from the Arrow SREIS groundwater model are presented and summarised below.

Arrow-Only Case

Arrow-only outputs from the calibrated case are presented for the aquifer units within each groundwater system most likely to experience the greatest drawdown impacts, and include the following:

- Condamine Alluvium from the shallow groundwater system.
- Springbok Sandstone from the intermediate groundwater system.
- Walloon Coal Measures from the coal seam gas groundwater system.
- Hutton Sandstone from the deep groundwater system.

The following characteristics of the groundwater drawdown profile in each aquifer were considered:

- The degree of groundwater drawdown as a function of minimum, maximum and average drawdown values.
- The spatial extent of drawdown.
- The duration of drawdown effects observed in the aquifer and the modelled recovery profile after coal seam gas water extraction ceases.

Characteristics of groundwater drawdown in the key aquifer units identified are summarised in Table 8.7 below. A comparison of the results from the Arrow SREIS groundwater model with the Arrow EIS groundwater model is also provided.

Table 8.7 Summary of Arrow SREIS groundwater model results

Groundwater System and Aquifer	Arrow Groundwater Model	Modelled Drawdown	Extent of Drawdown	Duration and Recovery	Summary and Model Output Comparison
Shallow groundwater system: Condamine Alluvium	SREIS	**Drawdown:** • Average drawdown: 0.18 m • Maximum drawdown: 0.5 m, 105 years after the commencement of modelling. **Flux impacts:** • 63 GL over 100 years	Maximum drawdown is located in the vicinity of Dalby. (Figure 8.10).	Peak drawdown predicted to occur approximately 105 years (2100) after commencement of groundwater modelling. The shallow aquifer system including the Condamine Alluvium is dynamic with several recharge mechanisms and is expected to recover when groundwater extraction associated with coal seam gas activities is removed. Recovery of groundwater levels in response to substitution of groundwater allocations from the Condamine Alluvium are presented in Figure 8.10 and discussed in relation to the outputs from the substitution case below.	Comparison of the model outputs shows: • Flux estimates are similar. • Groundwater drawdown is reduced under Arrow's current development case, as predicted by the Arrow SREIS groundwater model. • Peak drawdown is predicted by the Arrow SREIS groundwater model to occur later than the peak predicted by the Arrow EIS groundwater model.
	EIS	**Drawdown:** • Average drawdown: <0.5 m • Maximum drawdown: 1 m, 48 years after the commencement of modelling. **Flux impacts:** • 62 GL over 60 years	Maximum drawdown of just over 1 m indicated to occur in the vicinity of Dalby, along the western extent of the Condamine Alluvium.	Peak drawdown predicted to occur in 2059. Groundwater levels not returning to initial levels by 2071, the temporal extent of this model.	

Table 8.7 Summary of Arrow SREIS groundwater model results (cont'd)

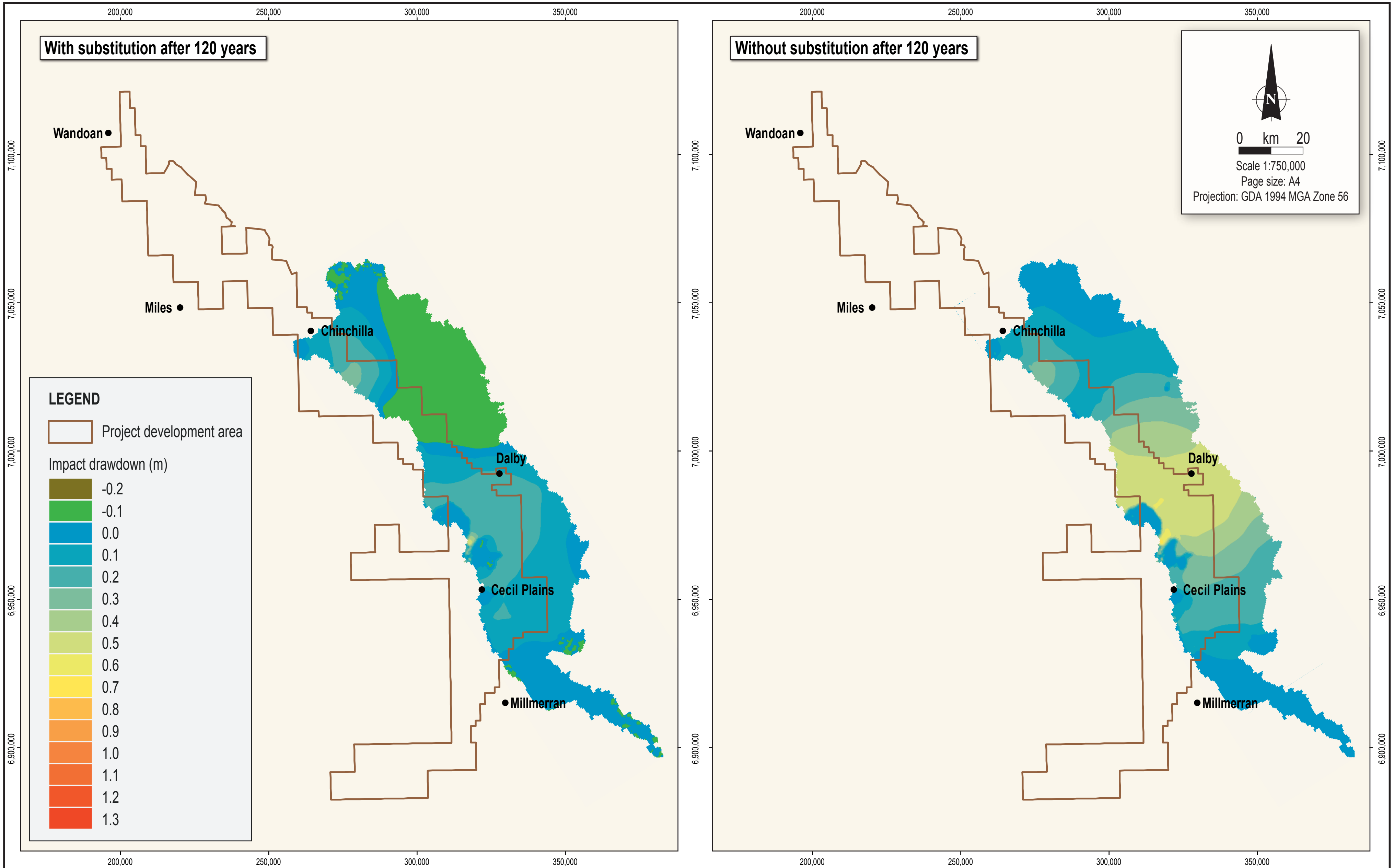
Groundwater System and Aquifer	Arrow Groundwater Model	Modelled Drawdown	Extent of Drawdown	Duration and Recovery	Summary and Model Output Comparison
Intermediate groundwater system: Springbok Sandstone	SREIS	**Drawdown:** • Average drawdown: <2 m • Maximum drawdown: 10 m, 50 years after the commencement of modelling.	Maximum drawdown is located to the west of Dalby, with a second area of drawdown west of Cecil Plains (Figure 8.11).	Peak drawdown to the west of Dalby is expected to occur in 2050. While drawdown in the area to the west of Cecil Plains peaks later in time, at approximately 2094. Water levels in the Springbok Sandstone recover to around 50% of maximum drawdown after approximately 50 to 250 years, depending on the location of drawdown.	Comparison of the model outputs shows: • Groundwater drawdown is reduced and more localised under Arrow's current development case, as predicted by the Arrow SREIS groundwater model. • Peak drawdown is predicted by the Arrow SREIS groundwater model to occur later than the peak predicted by the Arrow EIS groundwater model. • Following peak drawdown, the Arrow SREIS groundwater model predicts slower recovery rates in comparison with the Arrow EIS groundwater model.
	EIS	**Drawdown:** • Average drawdown: <5 m • Maximum drawdown: 30 m, 13 years after the commencement of extraction.	Maximum drawdown of 30 m indicated to occur in the vicinity of the Dalby area.	Peak drawdown predicted to occur in 2024. By 2061 (20 years after the cessation of groundwater extraction) drawdowns recover to approximately 70% of maximum drawdown (equivalent to approximately a 5 m drawdown) in the Goondiwindi area, and along the eastern extent of the unit.	

Table 8.7 Summary of Arrow SREIS groundwater model results (cont'd)

Groundwater System and Aquifer	Arrow Groundwater Model	Modelled Drawdown	Extent of Drawdown	Duration and Recovery	Summary and Model Output Comparison
Coal seam gas groundwater system: Walloon Coal Measures	SREIS	**Drawdown:** • Average drawdown: <50 m • Maximum drawdown: 350 m, 30 years after the commencement of modelling.	Maximum drawdown of 350 m is located to the west of Cecil Plains, where the coal seam formation is relatively deep. This area of maximum drawdown is generally contained within the project development area. In the Wandoan and Chinchilla areas, drawdown levels reach between 50 and 100 m along the western extent of the project development area (Figure 8.12).	Peak drawdown to the west Cecil Plains is expected to occur in 2030. Where the greatest drawdown impact is predicted, impact drawdown is expected to recover by 30% within 30 years of peak drawdown being observed, and 50% recovery within around 60 years.	Comparison of the model outputs shows: • The peak groundwater drawdown is increased and is more localised under Arrow's current development case, as predicted by the Arrow SREIS groundwater model. • Peak drawdown is predicted by the Arrow SREIS groundwater model to occur at a similar time to the peak predicted in the EIS. • Following peak drawdown, the Arrow SREIS groundwater model predicts slower recovery rates in comparison with the Arrow EIS groundwater model.
	EIS	**Drawdown:** • Average drawdown: <2 m • Maximum drawdown: 75 m, 13 years after the commencement of extraction.	Maximum drawdown of 75 m indicated to be generally confined to the project development area.	Peak drawdown is predicted to occur in 2024. By 2061 (20 years after the cessation of groundwater extraction) drawdowns recover to approximately 90% of maximum drawdown (equivalent to less than 10 m drawdown).	

Table 8.7 Summary of Arrow SREIS groundwater model results (cont'd)

Groundwater System and Aquifer	Arrow Groundwater Model	Modelled Drawdown	Extent of Drawdown	Duration and Recovery	Summary and Model Output Comparison
Deep groundwater system: Hutton Sandstone	SREIS	**Drawdown:** • Average drawdown: <5 m • Maximum drawdown: 8 m, 105 years after the commencement of modelling.	Maximum drawdown of 8 m is expected to occur in the area between Dalby and Cecil Plains (Figure 8.13).	Peak drawdown is expected to occur in 2154. Water levels in the Hutton Sandstone recover to around 50% of maximum drawdown after approximately 300 to 400 years.	Comparison of the model outputs shows: • Groundwater drawdown is reduced and more localised under Arrow's current development case, as predicted by the Arrow SREIS groundwater model. • Peak drawdown is predicted by the Arrow SREIS groundwater model to occur later than the peak predicted by the Arrow EIS groundwater model. • Following peak drawdown, the Arrow SREIS groundwater model predicts slower recovery rates in comparison with the Arrow EIS groundwater model.
	EIS	**Drawdown:** • Average drawdown: <10 m • Maximum drawdown: 30 m, 16 years after the commencement of extraction.	Maximum drawdown of 30 m is indicated to occur in the Wandoan area, confined to the project development area.	Peak drawdown occurs in 2027, with the exception of drawdowns in the former Goondiwindi development region, which was anticipated to commence water extraction after all other development regions. Given the relinquishment of land parcels within this area, no comparison can be made for this portion of the project development area. By 2061 (20 years after the cessation of groundwater extraction) drawdowns recover to approximately 80% of maximum drawdown (equivalent to approximately 15 m drawdown).	



Source:
Place names from DERM.
Drawdown contours from GHD.
Project development area from Arrow Energy.

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Date: 27.06.2013
MXD: 7040AF_12_GIS152_v1_1
File Name: 7040_12_F08.10_GIS_VS

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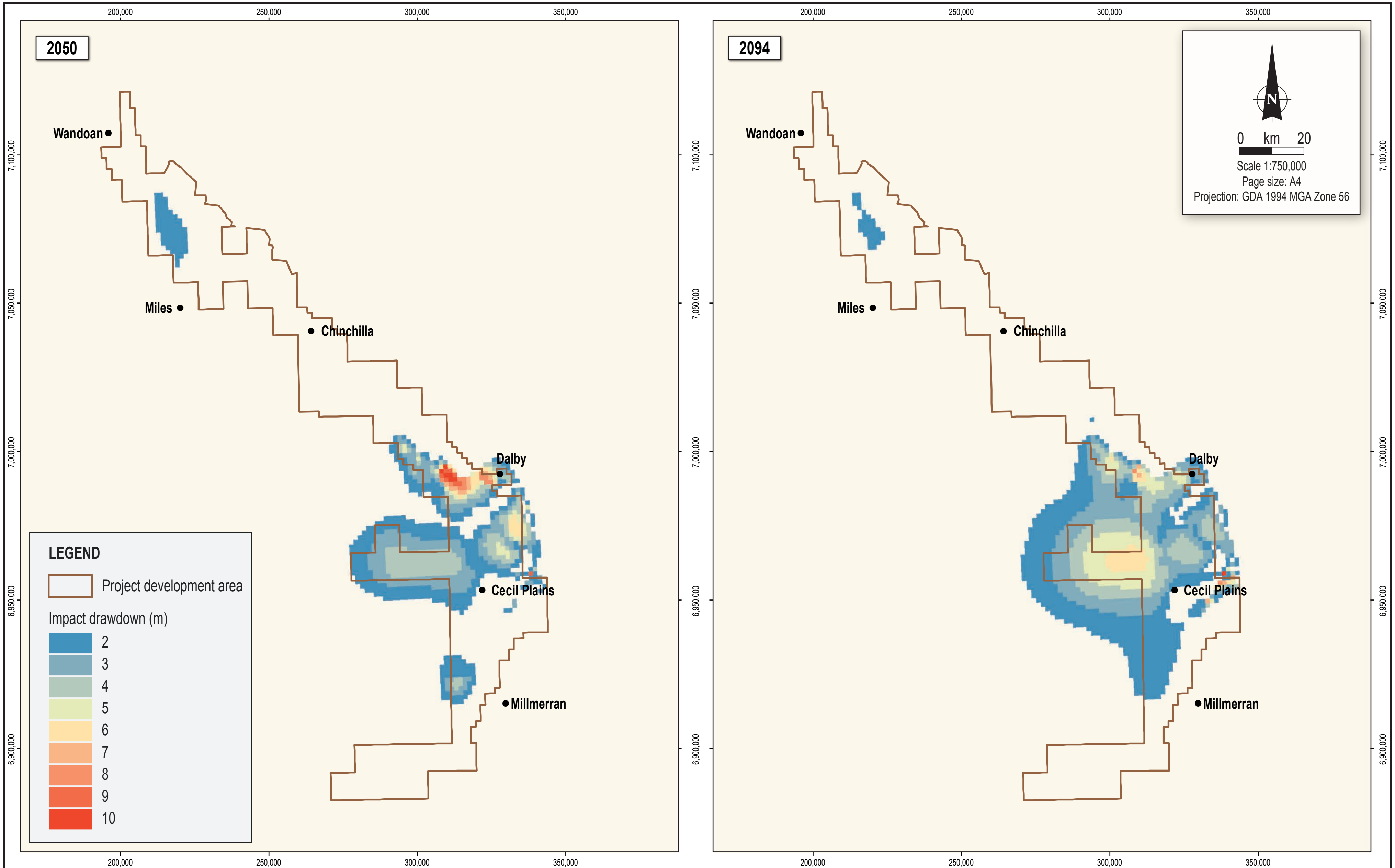
Predicted Arrow-only drawdown in theCondamine Alluvium (calibration realisation) with and without offsetting via substitution

Figure No: 8.10



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Drawdown contours from GHD.
Project development area from Arrow Energy.

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Date: 24.06.2013
MXD: 7040AF_GW03_GIS081_v1_2
File Name: 7040_12_F08.11_GIS_GL

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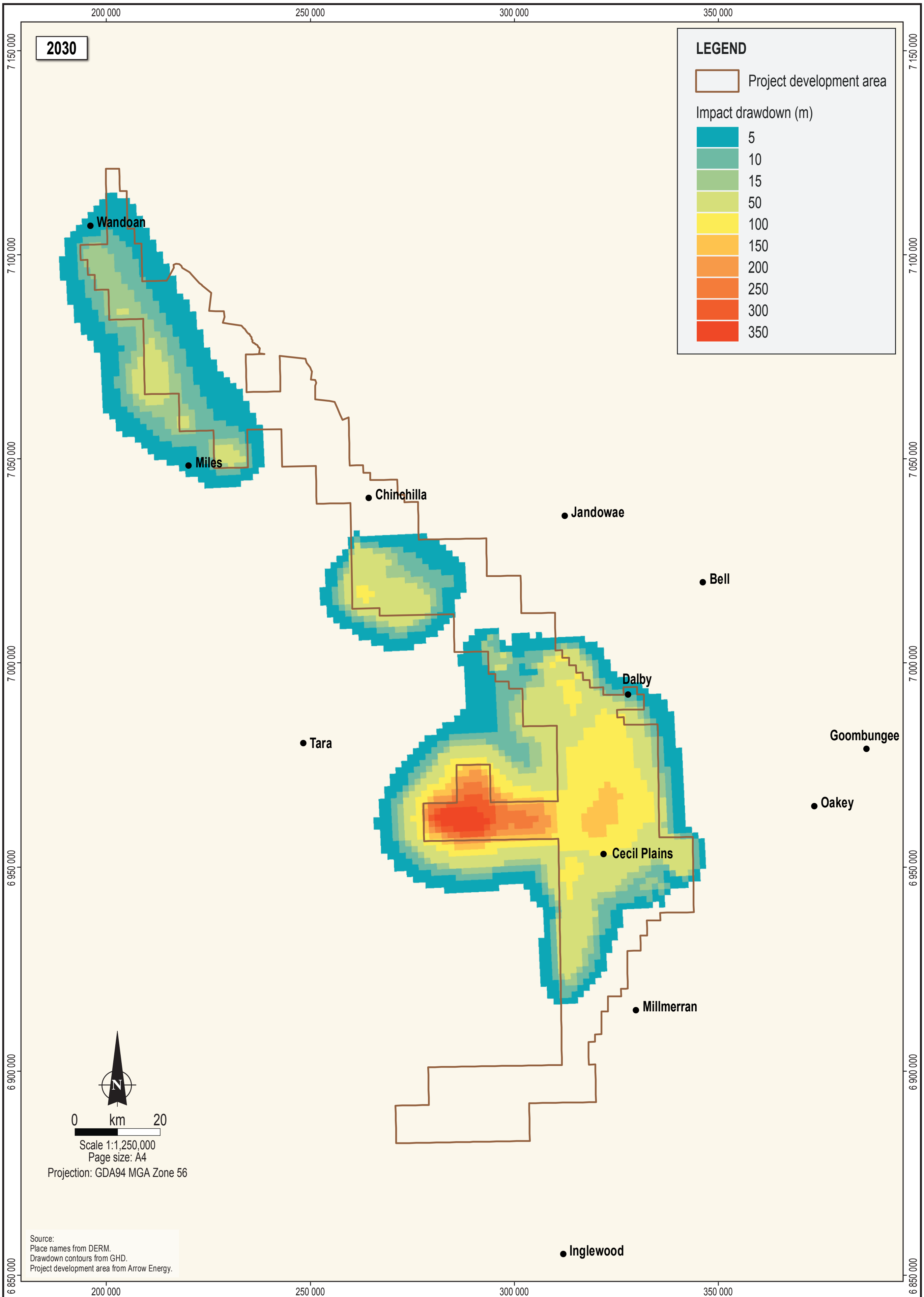
Predicted Arrow-only drawdown in the Springbok Sandstone (calibration realisation)

Figure No: 8.11



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Date: 24.06.2013
MXD: 7040AF_GW03_GIS079_v1_2
File Name: 7040_GW03_F08.12_GIS_GL

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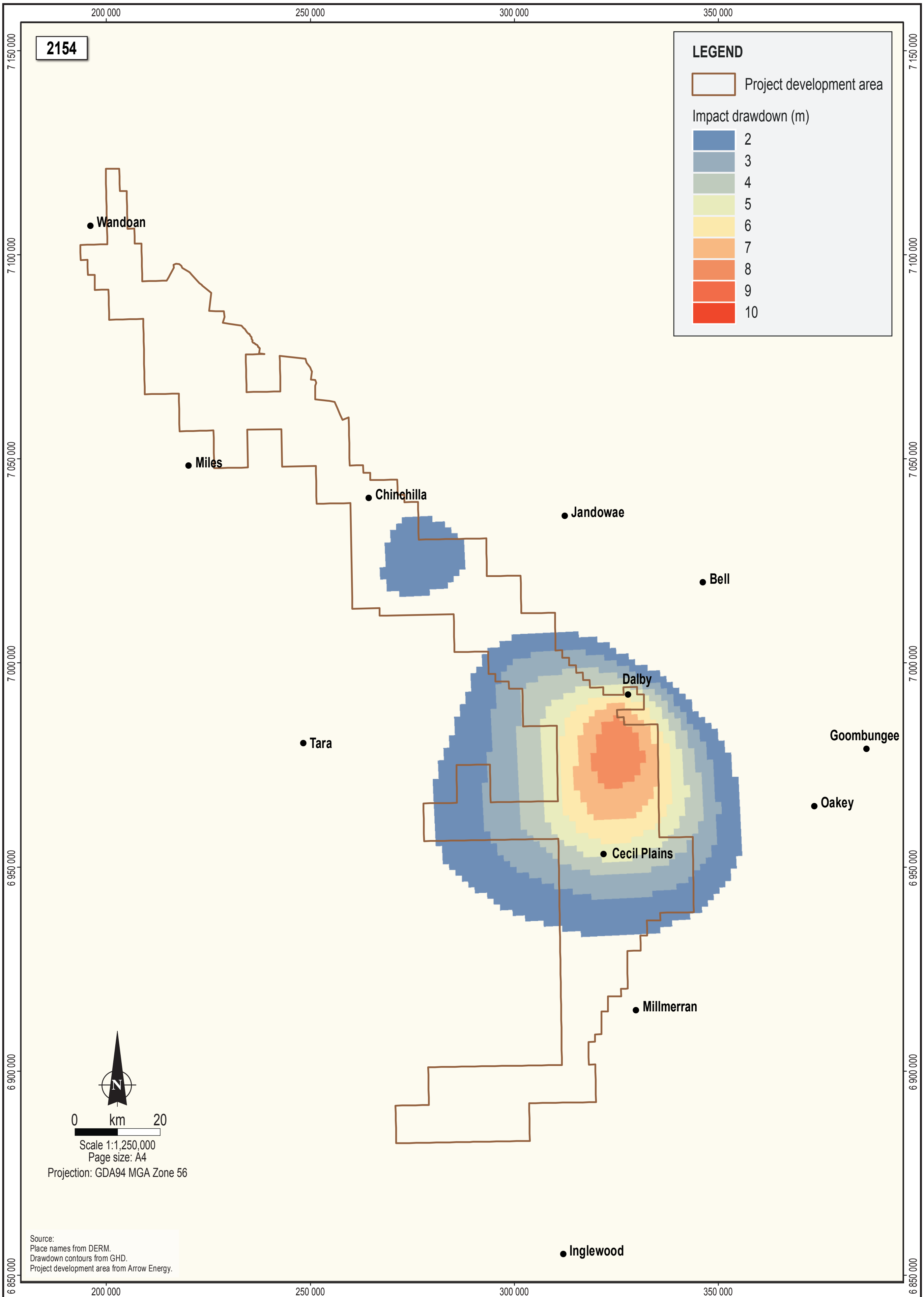
Predicted Arrow-only drawdown in the Walloon Coal Measures (calibration realisation)

Figure No: 8.12



coffey environments	Date: 24.06.2013 MXD: 7040AF_GW03_GIS080_v1_2 File Name: 7040_12_F08.13_GIS_GL	Arrow Energy Surat Gas Project	arrow energy go further	Predicted Arrow-only drawdown in the Hutton Sandstone (calibration realisation)	Figure No: 8.13

Overall, the drawdown levels predicted by the Arrow SREIS groundwater model are smaller than those predicted by the Arrow EIS groundwater model. Key differences are observed in the extent and duration of groundwater drawdown impacts predicted by each model. These differences are expected due to the following:

- Different development case information used by each model. The plan determines the volume of groundwater extracted, and the order in which this occurs across the project development area. The OGIA had access to more up to date coal seam gas production data than was available to Arrow during the preparation of the EIS. Arrow relied on publically available information, while the OGIA was able to request specific information from proponents.
- The modelling methods used. The Arrow EIS and SREIS groundwater models were generated using different methodologies, impacting on the way groundwater extraction is simulated. An example of this is the use of the EVT package in the Arrow SREIS groundwater model results in increased drawdown levels predicted for the Walloon Coal Measures.
- The availability of additional (more recent) data utilised in the Arrow SREIS groundwater model.
- Detailed differences in the model conceptualisations of the groundwater system. Both conceptualisations represent regional groundwater models with comparable characteristics, although detailed differences in the conceptualisation of the geology and hydrogeology will determine how the model simulates actual conditions.

Cumulative Case

The Arrow SREIS groundwater model is based on Arrow's current development case. This development case has a reduced development footprint and groundwater extraction volume (over equivalent time periods) in comparison with the development case used to generate the Arrow EIS groundwater model. The objective of the supplementary groundwater assessment is to evaluate whether the impact predictions reported in the EIS and the SREIS for Arrow-only production are consistent. If confirmed to be consistent, it is inferred that the cumulative impacts have not been underestimated.

All groundwater drawdown levels predicted by the Arrow SREIS groundwater model are reduced when compared with the Arrow EIS groundwater model, with the exception of drawdown in the Walloon Coal Measures (Table T140). As described above, this increase is a function of the use of the EVT package, and the resultant over-estimate of groundwater extracted from this unit.

Since submission of the EIS, the OGIA developed an independent numerical groundwater model (OGIA Surat CMA groundwater model) in order to predict the cumulative impacts of all coal seam gas developments. Arrow is obligated to monitor groundwater aquifers and manage cumulative impacts under the requirements and direction of the OGIA, for which existing modelling has already been undertaken.

Arrow's statutory obligations have previously been determined in the Surat CMA UWIR. Nevertheless, cumulative impacts have been modelled for the current development case in the Arrow SREIS groundwatermModel, and detailed results are presented in the supplementary groundwater assessment (Appendix 4). Key findings of the calibrated outputs from the cumulative case include:

- Groundwater extraction under the cumulative case peaks in 2015 at approximately 550 ML/day.

- The maximum drawdown in the Condamine Alluvium is predicted to be 0.9 m in the vicinity of Dalby, with an average drawdown of 0.24 m (Figure 8.14, right-hand panel)
- Peak impacts in the Springbok Sandstone are predicted to occur approximately 100 years after the peak drawdown impact is observed in the underlying Walloon Coal Measures.
- Peak impacts in the Hutton Sandstone are predicted to occur approximately 100 years after the peak drawdown impact is observed in the overlying Walloon Coal Measures.

Modelled Flux Changes to the Condamine Alluvium

The Condamine Alluvium groundwater model was used to predict impacts caused by groundwater level changes in the Condamine Alluvium, based on modelled flux changes from the OGIA Surat CMA groundwater model. Modelled interlayer fluxes between the Condamine Alluvium and the underlying strata are initially extracted from the OGIA Surat CMA groundwater model. These modelled flows are then incorporated into the more detailed Condamine Alluvium groundwater model to calculate coal seam gas related impacts within the Condamine Alluvium.

Predicted interlayer fluxes for the Non-coal seam gas case are into the Condamine Alluvium (i.e. upward flow). Model predictions indicate that interlayer fluxes will remain upward, but reduced as a result of coal seam gas development. Net interlayer flux changes are therefore a reduction in upward flux (GHD, 2013).

The Arrow SREIS groundwater model has modelled the flux impacts to the Condamine Alluvium as a result of coal seam gas water extraction from the Walloon Coal Measures:

- **Arrow-only Case**: The flux impacts to the Condamine Alluvium under the Arrow-only case (calibration realisation) is 63 GL over a 100 year period.
- **Cumulative Case:** The flux impacts to the Condamine Alluvium under the cumulative case (calibration realisation) is 79 GL over a 100 year period.

Substitution Case

Model runs were performed to assess the impacts on the Condamine Alluvium with and without ‘virtual injection’ of treated coal seam gas water via substitution in the area of predicted maximum drawdown. The results are summarised below.

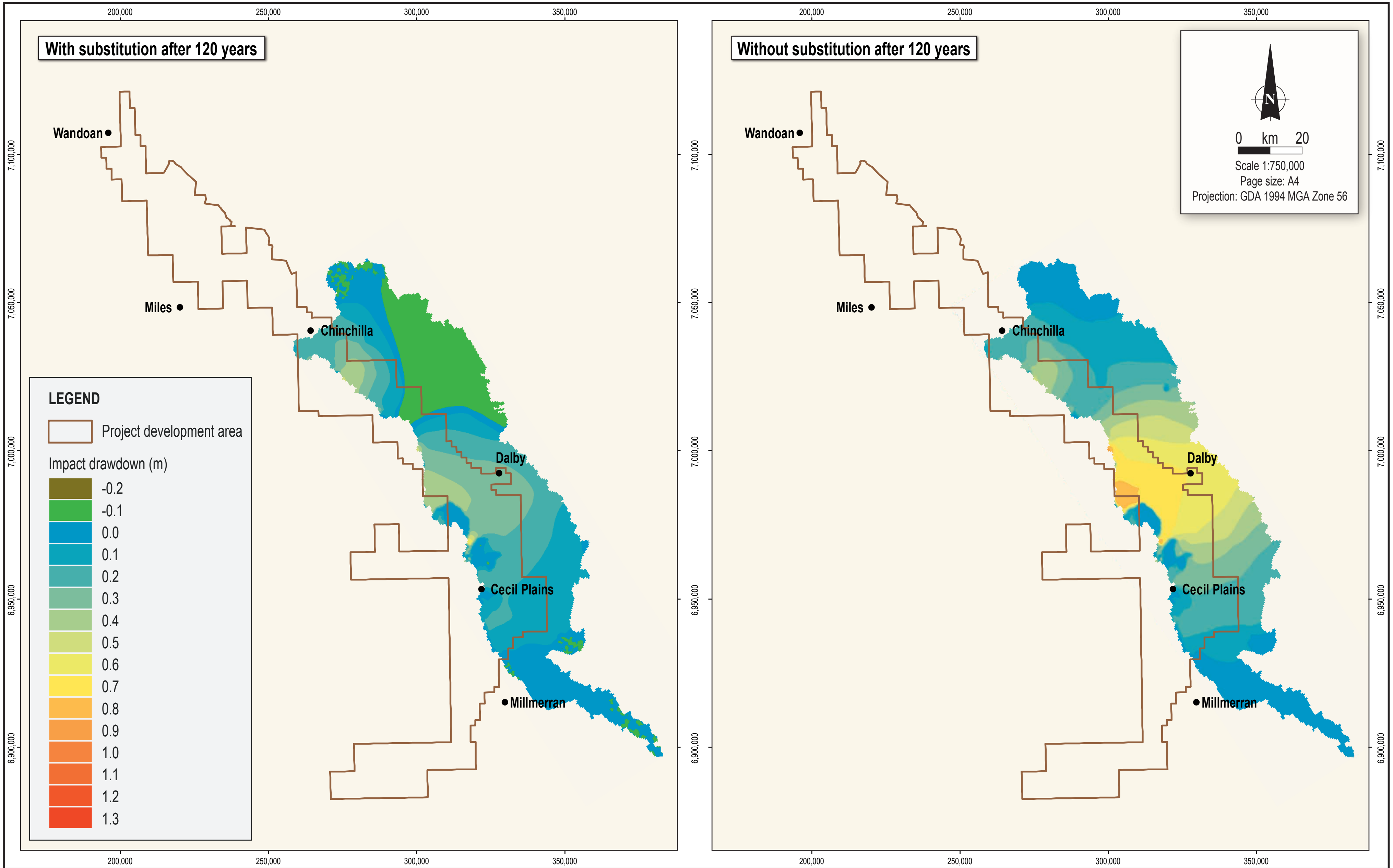
Modelled Response in the Condamine Alluvium (Arrow-only Case)

Figure 8.10 shows the predicted Arrow-only drawdown levels in the Condamine Alluvium in 120 years with and without ‘virtual injection’ of treated coal seam gas water via substitution.

Without substitution, predicted drawdowns in the area west of Dalby are up to 0.5 m and predicted average drawdown over the Condamine Alluvium is 0.18 m.

When substitution is applied, the model results indicate the following:

- There are net positive impacts in some areas with groundwater levels increasing by up to 0.2 m in the modelled substitution area.
- Average drawdowns over the Condamine Alluvium reduce from 0.18 to 0.03 m. On average, predictions indicate a 0.03 m net decrease in groundwater levels (groundwater levels become shallower) in the Condamine Alluvium as a result of offsetting.



Source:
Place names from DERM.
Drawdown contours from GHD.
Project development area from Arrow Energy.

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File Name: 7040_12_F08.14_GIS_VS

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Predicted cumulative drawdown in the Condamine Alluvium (calibration realisation) with and without offsetting via substitution

Figure No: **8.14**

Modelled Response in the Condamine Alluvium (Cumulative Case)

Figure 8.14 shows the predicted cumulative drawdown levels in the Condamine Alluvium in 120 years with and without ‘virtual injection’ of treated coal seam gas water via substitution.

Without substitution, predicted drawdowns in the area west of Dalby are up to 0.9 m and predicted average drawdown over the Condamine Alluvium is 0.24 m.

When substitution is applied, the model results indicate the following:

- There are net positive impacts in some areas, with groundwater levels increasing by up to 0.2 m in the modelled substitution area.
- Average drawdowns over the Condamine Alluvium reduce from 0.24 to 0.09 m. On average, predictions indicate a 0.09 m net decrease in Condamine Alluvium groundwater levels as a result of offsetting.

Benefits and Limitations of Substitution

As discussed in Section 8.4.1 the Condamine Alluvium and its tributaries are characterised by over-development and over-allocation with respect to the productive yield of the groundwater system (DNRM, 2012c). Current estimates of water extraction from the Condamine Alluvium by non-coal seam gas groundwater users is identified by DNRM (2012c) to be 40.4 GL more than the sustainable diversion limit defined for the Central Condamine Alluvium in the *Basin Plan 2012* (Cwlth) (Murray-Darling Basin Plan) prepared under the *Water Act 2007* (Cwlth). It is therefore likely that additional drawdown as a result of non-coal seam gas extraction will occur.

The predicted likely Arrow component of flux reduction from the underlying strata to the Condamine Alluvium is 63 GL over 100 years (GHD, 2013).

To offset this flux reduction (and associated groundwater level drawdown) Arrow propose to substitute groundwater allocations to the west of Dalby, in the area of maximum predicted drawdown as a result of coal seam gas activities. This area constitutes a small portion of the entire Condamine Alluvium. Given that the proposed substitution scenario assumes that Arrow will supply water for substitution over a 25 year period, the volumes that can be supplied are equal to approximately 2.5 GL/a (or 6.9 ML/day). The modelling outputs show the following information in relation to substitution:

- Drawdown is reduced to 0.03 m on average over the 100 year period considered (GHD, 2013).
- The volumes applied in substitution are sufficient to offset Arrow’s component of flux impact to the Condamine Alluvium.
- The associated drawdown in the Condamine Alluvium due to flux reduction is relatively small when compared to the observed groundwater drawdown attributable to non-coal seam gas extraction (Section 8.4.1).

Based on the relatively high magnitude drawdown to the Condamine Alluvium from non-coal seam gas extraction, it is apparent that substitution could not be used to offset non-coal seam gas related drawdown impacts to the Condamine Alluvium.

8.5 Review and Update of the EIS Impact Assessment

The updates made to the EIS impact assessment are detailed below and are based on the updates to the description of the existing environment and the results of the Arrow SREIS groundwater model.

8.5.1 Overall Sensitivity Rankings

The overall sensitivity rankings assigned to each groundwater system within the project development area remain unchanged from those presented in the EIS.

The sensitivity of groundwater systems supporting groundwater dependent ecosystems was reviewed taking into account additional information on these systems available for the project development area. The biological component of the conservation status assigned to the intermediate and deep groundwater systems has been increased to account for the nomination of the Gubberamunda Sandstone, and the Hutton Sandstone and the Precipice Sandstone as a spring source aquifers respectively. The conservation status, and therefore sensitivity of the immediate and deep groundwater systems has increased, but does not increase the overall sensitivity ranking applied to either system.

Details on the sensitivity ranking system applied to groundwater dependent ecosystems are set out in the supplementary groundwater assessment (Appendix 4).

8.5.2 Confirmation of Potential Impacts

All potential impacts identified in the groundwater impact assessment prepared for the EIS remain relevant to the supplementary assessment. Some impacts were reviewed to account for:

- Changes to the project description, specifically Arrow's revised current development case that could result in a varied impact profile by way of location (spatial extent) or timeframe, with the requirement for new mitigation measures to be implemented to manage these impacts.
- Additional information that updates the understanding of the existing environment and definition of environmental values and associated sensitivity rankings.

The potential impacts identified in the EIS triggered for review as part of the supplementary groundwater assessment are presented in Table 8.8 below:

Table 8.8 Potential impacts identified for review

Potential Impact	Groundwater System	Trigger for Review of EIS Assessment
Direct impacts from depressurisation of the Walloon Coal Measures		
Groundwater drawdown resulting in reduced supply to existing or future groundwater users.	Coal seam gas groundwater system	Revised project description and updated groundwater model predictions.
Groundwater drawdown resulting in reduced supply to groundwater-dependent ecosystems fed by the Walloon Coal Measures.		Revised project description, updated groundwater model predictions and additional information on groundwater-dependent ecosystems.
Indirect Impacts from depressurisation of the Walloon Coal Measures		
Groundwater flux between adjacent aquifers above and below the Walloon Coal Measures causing groundwater quality impacts.	Shallow, intermediate and deep groundwater systems. (Coal seam gas groundwater system impacts identified as direct impacts).	Revised project description and updated groundwater model predictions.
Groundwater drawdown in adjacent aquifers causing reduced supply to existing or future groundwater users.		Revised project description and updated groundwater model predictions.

Table 8.8 Potential impacts identified for review (cont'd)

Potential Impact	Groundwater System	Trigger for Review of EIS Assessment
Indirect Impacts from depressurisation of the Walloon Coal Measures (cont'd)		
Groundwater drawdown in adjacent aquifers causing reduced groundwater availability for groundwater-dependent ecosystems.	Shallow, intermediate and deep groundwater systems. (Coal seam gas groundwater system impacts identified as direct impacts).	Additional information on the location and attributes of groundwater-dependent ecosystems.
Groundwater drawdown in adjacent aquifers due to leakage through coal seam gas wells (well failure) causing groundwater quality impacts from inter-aquifer flows.		Revised project description, additional information on groundwater quality and changes in groundwater flux impacts.
Inter-aquifer flows between adjacent aquifers above and below the Walloon Coal Measures causing subsidence.	Loss of structural integrity may affect all groundwater systems where significant pressure reduction occurs.	Additional information is available on baseline conditions and the mechanisms for coal seam gas extraction to result in subsidence.

Potential impacts associated with the installation of production wells, monitoring bores and other subsurface and surface infrastructure, storage of chemicals and fuels, and management of coal seam gas water and brine/salt remain as presented in the EIS. Aspects of the project description that would influence the magnitude of these impacts have not changed, including the following:

- The composition of drilling muds.
- The methods used to install subsurface infrastructure remain the same, and the footprint area of surface infrastructure (i.e. production facilities) remain proportionally small in relation to the overall project development area.
- Methods for the handling, storage and disposal of fuels, chemical and other wastes.
- Methods used to install, maintain and monitor coal seam gas water and brine/salt storage facilities.

Groundwater-dependent Ecosystems

A significant volume of information regarding springs within the Surat CMA has been reviewed as part of the supplementary groundwater assessment. This information was not available at the time of the EIS. For the purposes of reviewing the EIS findings, springs and watercourse springs presented in the Surat CMA UWIR that are within 30 km of the project development area were identified for more detailed consideration of potential impacts related to Arrow's current development case.

Information considered in relation to springs within 30 km of the project development area is provided below:

- Spring complex 584 (Wambo) is considered to be supported by a localised groundwater flow system from a source aquifer within the shallow groundwater system or the Orallo Formation (which is an upper formation of the intermediate groundwater system). Groundwater drawdown impacts are not predicted to occur in the shallow or the upper sections of the intermediate groundwater systems at this location, and this spring is not considered further in the review of the EIS assessment.

- Spring complex 585 (Bowenville) is associated with outcropping basalt on the boundary of the Condamine Alluvium. Drawdown is predicted in the Condamine Alluvium at this location and spring complex 585 is considered as part of the review of the EIS assessment.
- Spring complexes 601 (Main Range Volcanics 3) and 602 (Main Range Volcanics 4) are associated with outcropping basalt supported by localised groundwater flow systems disconnected from groundwater flow in the underlying formations of the Great Artesian Basin (OGIA, 2012). These spring complexes are located beyond the area of groundwater drawdown predicted by the model for the shallow groundwater system, and are not considered further in the review of the EIS assessment.

Watercourse springs presented in Surat CMA UWIR identified within 30 km of the project development area were also identified. Information on these watercourse springs is provided below:

- Watercourse spring sites W14 and W15 are interpreted to be supported by groundwater sourced from the Hutton Sandstone and are located beyond the extent of predicted drawdown in this formation. These watercourse springs are not considered further in the review of the EIS assessment.
- Watercourse spring sites W77 and W78 are interpreted to be supported by groundwater sourced from the Mooga Sandstone or the Gubberamunda Sandstone. The Arrow SREIS groundwater model predicts no drawdown in these formations at these locations, and are not considered further in the review of the EIS assessment.
- Watercourse spring site W100 is interpreted to be supported by groundwater sourced from sediments in the shallow groundwater system. The watercourse spring is located beyond the extent of modelled drawdown in this system and is not considered further in the review of the EIS assessment.
- Watercourse spring site W160 is interpreted to be supported by groundwater sourced from the Kumbarilla Beds. It is located 10 km beyond the 0.2 m predicted modelled drawdown extent for this aquifer and is not considered further in the review of the EIS assessment.

8.5.3 Review of Magnitude Rankings

The magnitude of potential impacts prior to the implementation of mitigation and management measures has been determined for the impacts requiring review. The review considers the severity, duration and geographical extent of the potential impact. The results of the review are presented in Table 8.9 below.

Table 8.9 Review of Magnitude Rankings – Pre-mitigation and Management

Potential Impact	Groundwater System	Magnitude Ranking		Summary and Comparison
		EIS Assessment	SREIS Assessment	
Direct impacts from depressurisation of the Walloon Coal Measures				
Groundwater drawdown resulting in reduced supply to existing or future groundwater users.	Coal seam gas groundwater system	Very high	Very high	The magnitude ranking remains unchanged, and the very high ranking reflects the severity, extent and duration of the drawdown impacts in the Walloon Coal Measures, as indicated by the Arrow SREIS groundwater model outputs: • Maximum drawdown of 350 m is predicted in the Walloon Coal Measures at around 2030, with an average drawdown of <50 m. • Maximum drawdown is centred on DA11, and the extent of 5 m drawdown extends beyond the project development area boundary. • In the area of maximum drawdown, groundwater levels are expected to recover by 30% within 30 years of peak drawdown being observed, and 50% recovery within approximately 60 years.
Groundwater drawdown resulting in reduced supply to groundwater-dependent ecosystems fed by the Walloon Coal Measures.		Moderate	Very low	The magnitude ranking has reduced to very low, and reflects reductions in the severity, duration and extent of impacts based the Arrow SREIS groundwater model outputs and the availability of new information: • No springs or watercourse springs are identified as having the Walloon Coal Measures as their source aquifer. The EIS conservatively assumed the Coal Seam Gas groundwater system supported springs, however currently available information indicates it does not support known springs. • There are no mapped potential ecosystems dependent on the subsurface presence of groundwater in areas where the Walloon Coal Measures outcrop and could be impacted by drawdown near the surface.
Indirect Impacts from depressurisation of the Walloon Coal Measures				
Inter-aquifer flows between adjacent aquifers above and below the Walloon Coal Measures causing groundwater quality impacts.	Shallow groundwater system	High	Low	The magnitude ranking has reduced to low, and reflects the process by which any inter-aquifer flows caused by the extraction of poorer quality water from the Walloon Coal Measures will not involve flow of poor quality water into better quality aquifers. While outputs from the Arrow SREIS model do not specifically predict changes in groundwater quality, it does indicate that prior to coal seam gas extraction, inter-layer fluxes within the Surat CMA are predominantly upwards (GHD, 2013), including from the Walloon Coal Measures to the Condamine Alluvium (OGIA, 2012; GHD, 2013).

Table 8.9 Review of Magnitude Rankings – Pre-mitigation and Management (cont'd)

Potential Impact	Groundwater System	Magnitude Ranking		Summary and Comparison
		EIS Assessment	**SREIS Assessment**	
Indirect Impacts from depressurisation of the Walloon Coal Measures (cont'd)				
Inter-aquifer flows between adjacent aquifers above and below the Walloon Coal Measures causing groundwater quality impacts.	Intermediate groundwater system	High	Low	Depressurisation of the Walloon Coal Measures would reduce this flux to aquifers above the Walloon Coal Measures and increase flux to the Walloon Coal Measures from underlying aquifers. This will act to reduce the potential for contamination of over or underlying aquifers from poorer quality water of the Walloon Coal Measures.
	Deep groundwater system	High	Low	
Groundwater drawdown in adjacent aquifers causing reduced supply to existing or future groundwater users.	Shallow groundwater system	High	Moderate	The magnitude ranking has reduced to moderate, and reflects reductions in the severity of the drawdown impacts, however the duration and extent of impacts have increased based the Arrow SREIS groundwater model outputs: • Modelling predicts a maximum drawdown in the Condamine Alluvium of 0.5 m with an average across the whole of the Condamine Alluvium of 0.18 m. • Drawdown is predicted across the Condamine Alluvium and extends beyond the project development area. The shallow aquifer system including the Condamine Alluvium is dynamic with several recharge mechanisms and is expected to recover when groundwater extraction associated with coal seam gas activities is removed.
	Intermediate groundwater system	High	High	The magnitude ranking remains unchanged, and the high ranking reflects the severity, extent and duration of the drawdown impacts as indicated by the Arrow SREIS groundwater model outputs: • Modelling predicts a maximum drawdown in the Springbok Sandstone of 10 m with an average drawdown of <2 m. The extent of drawdown impact is centred on drainage areas 7, 8 and 11. • Drawdown impact extends beyond the project development area, mainly to the west. • Where maximum drawdown is observed in the Springbok Sandstone, groundwater levels recover to around 50% of maximum drawdown after approximately 50 to 250 years, depending on the specific location. • There is minimal drawdown (<1 m) predicted in the overlying Gubberamunda Sandstone, or Mooga Sandstone and Bungil Units.

Table 8.9 Review of Magnitude Rankings – Pre-mitigation and Management (cont'd)

Potential Impact	Groundwater System	Magnitude Ranking		Summary and Comparison
		EIS Assessment	SREIS Assessment	
Indirect Impacts from depressurisation of the Walloon Coal Measures (cont'd)				
Groundwater drawdown in adjacent aquifers causing reduced supply to existing or future groundwater users.	Deep groundwater system	High	High	The magnitude ranking remains unchanged, and reflects reductions in the severity of the drawdown impacts, however the duration and extent of impacts have increased based the Arrow SREIS groundwater model outputs: • Modelling predicts maximum drawdown of 8 m and an average of <5 m in the Hutton Sandstone. • The extent of drawdown in the Hutton Sandstone is centred on drainage areas 8 and 9, extending beyond the project development area to the east and west. • Where maximum drawdown is observed in the Hutton Sandstone, groundwater levels recover to around 50% of maximum drawdown after approximately 300 to 400 years, depending on the specific location. • Significant water extraction by existing users occurs from the Hutton Sandstone and a maximum drawdown of 8 m may impact existing or future groundwater users.
Groundwater drawdown in adjacent aquifers causing reduced groundwater availability for groundwater-dependent ecosystems.	Shallow groundwater system	Very low	Moderate	The magnitude ranking has increased to moderate, due to the availability of new information indicating a spring complex 585 that may be impacted by groundwater drawdown in excess of the spring trigger threshold, as predicted by the Arrow SREIS groundwater model outputs: • Modelling predicts maximum drawdown in the Condamine Alluvium of 0.5 m with an average drawdown of 0.18 m. • A single spring complex is located within the region of predicted Condamine Alluvium drawdown (spring complex 585). This is a non-Great Artesian Basin recharge spring, no EPBC Act listed species or communities have been identified at the spring complex location. • The spring complex is associated with local groundwater flow systems (as opposed to regional groundwater flow), on the boundary of the Main Range Volcanics and the Condamine Alluvium. • The maximum drawdown predicted in the Condamine Alluvium at the spring location as a result of Arrow-only impacts is 0.3 m, which is above the spring trigger threshold.

Table 8.9 Review of Magnitude Rankings – Pre-mitigation and Management (cont'd)

Potential Impact	Groundwater System	Magnitude Ranking		Summary and Comparison
		EIS Assessment	SREIS Assessment	
Indirect Impacts from depressurisation of the Walloon Coal Measures (cont'd)				
Groundwater drawdown in adjacent aquifers causing reduced groundwater availability for groundwater-dependent ecosystems. (cont'd)	Shallow groundwater system (cont'd)	Very low	Moderate	Additional information available in relation to groundwater-dependent ecosystems also informs the revised magnitude ranking: • There is a general absence of mapped potential groundwater-dependent ecosystems within the area of the Condamine Alluvium. Where the Condamine River is likely to receive groundwater baseflow south of Chinchilla the Condamine Alluvium has a predicted drawdown of <0.1m. • Also in the Condamine Alluvium some ecosystems potentially dependent on the subsurface presence of groundwater coincide with regions of predicted drawdown, however depth to water information suggests that groundwater is typically beyond the rooting depth of plants therefore will be unaffected by drawdown in the Condamine Alluvium. • At the margins of the Condamine Alluvium where depth to the watertable may be shallower and there may be ecosystems dependent on the subsurface presence of groundwater, in particular in the northern parts, the predicted drawdown is <0.2 m.
	Intermediate groundwater system	Low	Moderate	The magnitude ranking has increased to moderate based on the potential for modelled drawdown to impact on aquifers that support ecosystems dependent on the subsurface presence of groundwater: • Modelling predicts maximum drawdown in the intermediate groundwater system of 10 m (Springbok Sandstone). • The Springbok Sandstone is expected to outcrop to the west of the Condamine Alluvium, and along much of the western boundary of the project development area. Differentiation between the Springbok Sandstone and other of the Kumbarilla Beds is difficult in this area.

Table 8.9 Review of Magnitude Rankings – Pre-mitigation and Management (cont'd)

<table>
<tr><th rowspan="2">Potential Impact</th><th rowspan="2">Groundwater System</th><th colspan="2">Magnitude Ranking</th><th rowspan="2">Summary and Comparison</th></tr>
<tr><th>EIS Assessment</th><th>SREIS Assessment</th></tr>
<tr><td colspan="5">Indirect Impacts from depressurisation of the Walloon Coal Measures (cont'd)</td></tr>
<tr><td rowspan="2">Groundwater drawdown in adjacent aquifers causing reduced groundwater availability for groundwater-dependent ecosystems. (cont'd)</td><td>Intermediate groundwater system (cont'd)</td><td>Low</td><td>Moderate</td><td>• Immediately west of the Condamine Alluvium, where the Springbok Sandstone may outcrop, there is a general absence of mapped ecosystems potentially dependent on both the surface expression of groundwater and subsurface presence of groundwater, however further west there is some potential for ecosystems potentially dependent on the subsurface presence of groundwater to be impacted by drawdown in the Springbok Sandstone, depending on the extent of Springbok Sandstone outcrop.
• No springs with a source aquifer from the intermediate groundwater system (Gubberamunda and Springbok Sandstone) are located within 10 km of the predicted area of 0.2 m drawdown in those formations.</td></tr>
<tr><td>Deep groundwater system</td><td>High</td><td>Very Low</td><td>The magnitude ranking has decreased to very low, due to additional information on the location and source aquifers of groundwater dependent ecosystems within and surrounding the project development area and the outputs of the Arrow SREIS groundwater model:
• Modelling predicts maximum drawdown of 8 m and an average of <5 m in the Hutton Sandstone.
• No springs with a source aquifer from the deep groundwater system are located within 10 km of the predicted 0.2 m drawdown extent.
• The Hutton (and Marburg equivalent) Sandstone does not outcrop where there is predicted drawdown in the aquifer and is not considered to be a source aquifer for ecosystems potentially reliant of the subsurface presence of groundwater or other potential groundwater dependent ecosystems supported by groundwater expressed at the surface.</td></tr>
</table>

Table 8.9 Review of Magnitude Rankings – Pre-mitigation and Management (cont'd)

Potential Impact	Groundwater System	Magnitude Ranking		Summary and Comparison
		EIS Assessment	SREIS Assessment	
Indirect Impacts from depressurisation of the Walloon Coal Measures (cont'd)				
Groundwater drawdown in adjacent aquifers due to leakage through coal seam gas wells (well failure) causing groundwater quality impacts from inter-aquifer flows.	Shallow groundwater system	Low	Low	The magnitude ranking remains unchanged, and considers updated and additional information on groundwater quality and inter-aquifer fluxes: • The potential inter-aquifer well fluxes that would be caused by the failure rate of a small percentage of wells is not considered to be hydrologically significant compared to inter-aquifer fluxes through confining layers over large regional areas. • Inter-aquifer fluxes that occur locally due to failed wells are expected to decline rapidly, as pressure equilibrium is approached between the formations in the vicinity of the wells. • In the longer term as aquifer pressures recover after the cessation of coal seam gas water extraction, modelling shows that pressure differences observed between to formations reduce, further limiting the potential for adverse impact.
	Intermediate groundwater system	Low	Low	
	Deep groundwater system	Low	Low	
Inter-aquifer flows between adjacent aquifers above and below the Walloon Coal Measures causing subsidence and loss of aquifer structural integrity.	Shallow groundwater system	N/A, no ranking provided in the EIS	Very low	The loss of an aquifer's structural integrity would require significant levels of subsidence to occur on a localised scale, at differing rates. As subsidence is not expected to be significant (Geoscience Australia, 2010), and is expected to be widespread, differential movement is not expected. The magnitude of impact to the structural integrity of depressurised formations which might occur due to the physical effects of subsidence is therefore considered to be very low.
	Intermediate groundwater system		Very low	
	Deep groundwater system		Very low	

8.5.4 Mitigation, Management and Monitoring Measures

The mitigation measures identified in the EIS remain relevant for the management of groundwater-related impacts associated with the Surat Gas Project. The management of cumulative groundwater impacts within the Surat CMA is defined by the Surat CMA UWIR and compliance with the requirements assigned to responsible tenure holders is enforced by EHP. Arrow is already regulated by this process.

New and revised commitments made by Arrow for the management of potential impacts on groundwater values from the project as a result of the supplementary groundwater assessment are detailed in Table 8.11 and relate to:

- Clarification of the intent of commitments made in the EIS in relation to baseline assessment plans, management options for coal seam gas water and make-good measures.
- Management of potential impacts to groundwater-dependent ecosystems (including spring complexes).
- Compliance with the code of practice for constructing and abandoning coal seam gas wells in Queensland (DEEDI, 2011b).
- Continued provision of information to the OGIA in relation to the Surat CMA and compliance with inspection and monitoring requirements of the UWIR.
- Offsetting the Arrow component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of coal seam gas extraction from the Walloon Coal Measures.

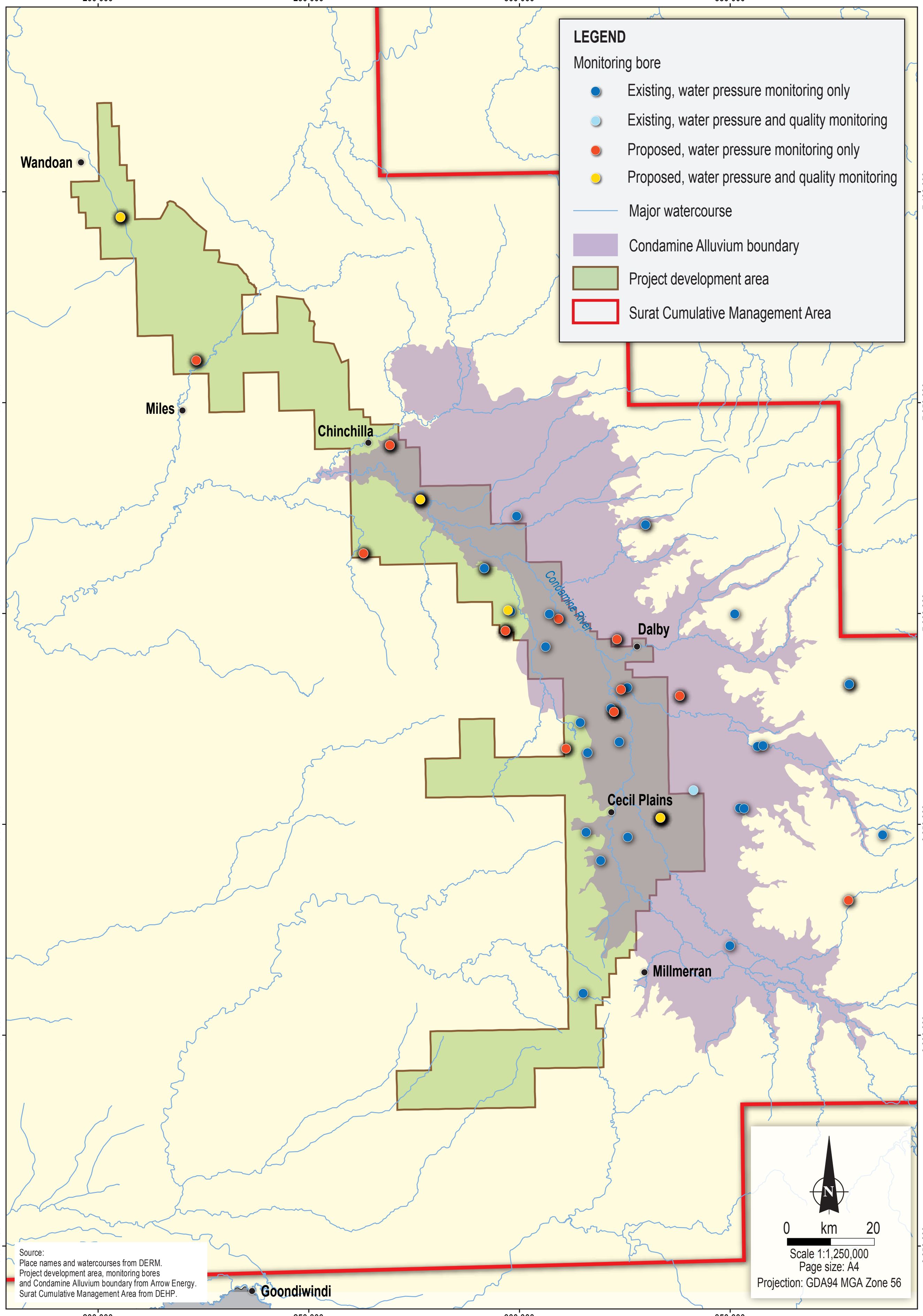
The revised and new commitments identified as a result of the supplementary groundwater assessment are presented in Section 8.9.

Arrow will continue to implement existing monitoring programs, and develop new programs if required. Existing programs are consistent with the requirements set out in the WMS in the Surat CMA UWIR. Figure 8.15 presents the location of Arrow’s existing and proposed monitoring bore locations identified for installation in 2013 by the Surat CMA UWIR.

In the future, should groundwater-dependent ecosystems be identified within Arrow’s tenure, or Arrow is identified as the responsible tenure holder in the Surat CMA UWIR, Arrow will implement the requirements detailed in the corresponding SIMS.

8.5.5 Residual Impacts

The magnitude of potential impacts after the implementation of mitigation and management measures has been determined for the impacts identified for review. The review determines the significance of the residual impacts and makes a comparison with the findings presented in the EIS. The results of the review are presented in Table 8.10. The summary of additional mitigation and management measures presented in Table 8.10 does not include the mitigation and management measures presented in the EIS.



coffey environments

Date: 27.06.2013
MXD: 7040AF_GW03_GIS077_v1_4
File Name: 7040_12_F08.15_GIS_GL

Arrow Energy

Surat Gas Project

arrow energy go further

Arrow's existing and UWIR proposed 2013 monitoring bore locations

Figure No: 8.15

Table 8.10 Residual Impacts

<table>
<tr><th rowspan="2">Potential Impact</th><th rowspan="2">Groundwater System</th><th rowspan="2">Overall Sensitivity Ranking</th><th rowspan="2">Magnitude (pre mitigation and management)</th><th rowspan="2">Summary of Additional Mitigation and Management Measures</th><th colspan="2">SREIS Residual Impact Assessment (post-mitigation and management)</th><th rowspan="2">Change in Residual Significance from the EIS</th></tr>
<tr><th>Magnitude</th><th>Significance</th></tr>
<tr><td colspan="8">Direct impacts from depressurisation of the Walloon Coal Measures</td></tr>
<tr><td>Groundwater drawdown resulting in reduced supply to existing or future groundwater users.</td><td rowspan="2">Coal seam gas groundwater system</td><td rowspan="2">Low</td><td>Very high</td><td>Responsible tenure holder obligations including bore assessment and make good obligations.</td><td>Low</td><td>Low</td><td>No change</td></tr>
<tr><td>Groundwater drawdown resulting in reduced supply to groundwater-dependent ecosystems fed by the Walloon Coal Measures.</td><td>Very low</td><td>Obligations outlined in the Surat CMA UWIR.
Management of other groundwater-dependent ecosystems in addition to springs.
Responsible tenure holder obligations including make good obligations.</td><td>Very low</td><td>Very low</td><td>No change</td></tr>
<tr><td colspan="8">Indirect Impacts from depressurisation of the Walloon Coal Measures</td></tr>
<tr><td rowspan="3">Inter-aquifer flows between adjacent aquifers above and below the Walloon Coal Measures causing groundwater quality impacts.</td><td>Shallow groundwater system</td><td>Moderate</td><td>Low</td><td rowspan="3">Responsible tenure holder obligations including bore assessment and make good obligations.</td><td>Low</td><td>Moderate</td><td>No change</td></tr>
<tr><td>Intermediate groundwater system</td><td>Moderate</td><td>Low</td><td>Low</td><td>Moderate</td><td>No change</td></tr>
<tr><td>Deep groundwater system</td><td>High</td><td>Low</td><td>Low</td><td>Moderate</td><td>No change</td></tr>
</table>

Table 8.10 Residual Impacts (cont'd)

Potential Impact	Groundwater System	Overall Sensitivity Ranking	Magnitude (pre mitigation and management)	Summary of Additional Mitigation and Management Measures	SREIS Residual Impact Assessment (post-mitigation and management)		Change in Residual Significance from the EIS
					Magnitude	Significance	
Indirect Impacts from depressurisation of the Walloon Coal Measures (cont'd)							
Groundwater drawdown in adjacent aquifers causing reduced supply to existing or future groundwater users.	Shallow groundwater system	Moderate	Moderate	Offsetting the Arrow component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of coal seam gas water extraction from the Walloon Coal Measures. Average drawdown across the Condamine Alluvium is reduced from 0.18 m (pre-mitigated) to 0.03 m (substitution case). Responsible tenure holder obligations including make good obligations.	Low	Moderate	No change
	Intermediate groundwater system	Moderate	High	Responsible tenure holder obligations including bore assessment and make good obligations.	Low	Moderate	No change
	Deep groundwater system	High	High		Low	Moderate	No change

Table 8.10 Residual Impacts (cont'd)

Potential Impact	Groundwater System	Overall Sensitivity Ranking	Magnitude (pre mitigation and management)	Summary of Additional Mitigation and Management Measures	SREIS Residual Impact Assessment (post-mitigation and management)		Change in Residual Significance from the EIS
					Magnitude	Significance	
Indirect Impacts from depressurisation of the Walloon Coal Measures (cont'd)							
Groundwater drawdown in adjacent aquifers causing reduced groundwater availability for groundwater-dependent ecosystems.	Shallow groundwater system	Moderate	Moderate	Offsetting the Arrow component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of coal seam gas water extraction from the Walloon Coal Measures. Where ecosystems potentially reliant on the subsurface presence of groundwater have been identified, as well as gaining stream reaches through the Condamine Alluvium, the predicted drawdown under the 'virtual injection' scenario is typically between 0 to 0.2 m, and in some areas an overall reduction in depth to groundwater is predicted (i.e., groundwater level rise). Obligations outlined in the Surat CMA UWIR. Management of other groundwater-dependent ecosystems in addition to springs. Responsible tenure holder obligations including make good obligations.	Very low	Low	No change
	Intermediate groundwater system	Moderate	Moderate	Obligations outlined in the Surat CMA UWIR. Management of other groundwater-dependent ecosystems in addition to springs. Responsible tenure holder obligations.	Very low	Low	No change

Table 8.10 Residual Impacts (cont'd)

Potential Impact	Groundwater System	Overall Sensitivity Ranking	Magnitude (pre mitigation and management)	Summary of Additional Mitigation and Management Measures	SREIS Residual Impact Assessment (post-mitigation and management)		Change in Residual Significance from the EIS
					Magnitude	Significance	
Indirect Impacts from depressurisation of the Walloon Coal Measures (cont'd)							
Groundwater drawdown in adjacent aquifers causing reduced groundwater availability for groundwater-dependent ecosystems. (cont'd)	Deep groundwater system	High	Very low	Obligations outlined in the Surat CMA UWIR. Management of other groundwater-dependent ecosystems in addition to springs. Responsible tenure holder obligations.	Very low	Low	Reduced level of significance based on additional information relating to the presence and characteristics of groundwater-dependent ecosystems since the EIS.
Groundwater drawdown in adjacent aquifers due to leakage through coal seam gas wells (well failure) causing groundwater quality impacts from inter-aquifer flows.	Shallow groundwater system	Moderate	Low	Application of Code of Practice for Constructing and Abandoning Coal Seam Gas Wells in Queensland.	Very low	Low	No change
	Intermediate groundwater system	Moderate	Low		Very low	Low	No change
	Deep groundwater system	High	Low		Very low	Low	No change
Inter-aquifer flows between adjacent aquifers above and below the Walloon Coal Measures causing subsidence and loss of aquifer structural integrity.	Shallow groundwater system	Moderate	Very low	No planned mitigation and management measures.	Very low	Low	Insufficient information available at the time of the EIS, and a ranking was not applied.

Table 8.10 Residual Impacts (cont'd)

Potential Impact	Groundwater System	Overall Sensitivity Ranking	Magnitude (pre mitigation and management)	Summary of Additional Mitigation and Management Measures	SREIS Residual Impact Assessment (post-mitigation and management)		Change in Residual Significance from the EIS
					Magnitude	Significance	
Indirect Impacts from depressurisation of the Walloon Coal Measures (cont'd)							
Inter-aquifer flows between adjacent aquifers above and below the Walloon Coal Measures causing subsidence and loss of aquifer structural integrity. (cont'd)	Intermediate groundwater system	Moderate	Very low	No planned mitigation and management measures.	Very low	Low	
	Deep groundwater system	High	Very low		Very low	Low	

8.5.6 Summary

The review and update of the EIS assessment demonstrates that the impact assessment completed for the EIS did not understate the residual (mitigated) impacts. The review shows that there is no change to the residual impact assessment from that presented in the EIS, with the exception of the residual significance ranking associated with potential impacts to groundwater dependent ecosystems associated with the deep groundwater system. In this instance, the availability of additional information relating to the location of groundwater-dependent ecosystems and the source aquifers supporting those ecosystems and the outputs of the Arrow SREIS groundwater model support a reduction in the significance of residual impacts.

The potential for groundwater extraction leading to physical changes in aquifer structure, resulting in subsidence, was not assigned a significance ranking in the EIS due to insufficient information available at the time. Since the preparation of the EIS, information in relation to baseline conditions and the mechanisms for coal seam gas extraction to result in subsidence has allowed a residual significance ranking of low to be assigned to the shallow, intermediate and deep groundwater systems.

8.6 Future Research Areas

Arrow is undertaking research, or will be involved in a number of research areas that contribute to the understanding of the groundwater system within the project development area and the broader Surat CMA. The OGIA has also identified future research directions as described in the Surat CMA UWIR. These areas of research are described below.

8.6.1 OGIA Future Research Directions

As part of the UWIR, the OGIA has committed to a number of research areas to enhance the OGIA's capacity to predict groundwater impacts and update the Surat CMA UWIR. Key details of these research projects are provided below:

Condamine Interconnectivity Research Project

This project aims to improve the understanding of the interconnectivity between the Condamine Alluvium and the underlying Walloon Coal Measures. The project involves the completion of two activities:

- Activity 1 includes groundwater level monitoring and collection of quality samples from approximately 60 existing private bores. The information collected is to be combined with existing database information.
- Activity 2 involves the installation of new monitoring wells in targeted locations and completion of pumping tests (to be completed by Arrow).

Consistent with commitment C128 in the EIS, Arrow has commenced an investigation that will help quantify the connectivity between the Condamine Alluvium and the Walloon Coal Measures. The scope of the investigative program was developed in collaboration with the OGIA, who has endorsed the scope of Arrow's investigation and its objectives.

The initial scope of work to be completed by Arrow as a component of the OGIA's Condamine Interconnectivity Research Project includes:

- Drilling and installation of monitoring bores at two sites. The position of these monitoring bores is important to obtain the required data. One well will be drilled where the Condamine Alluvium and Walloon Coal Measures are separated by stratigraphic unit(s) (such as the Springbok

Sandstone and the Gubberamunda Sandstone) and groundwater extraction already occurs as part of existing coal seam gas activities. The second well will be drilled where the Condamine Alluvium and Walloon Coal Measures are in direct contact, and pumping from irrigation bores within the Condamine Alluvium occurs.

- Carry out pump testing and groundwater level and quality monitoring to establish the response to pumping in the Condamine Alluvium and the Walloon Coal Measures. Perform aquifer parameter testing and complete an aquifer property report.
- Develop a conceptualisation of the groundwater system and perform local scale numerical modelling based on the results of the pumping and aquifer parameter tests and other desktop information to quantify movement of water between the Condamine Alluvium and Walloon Coal Measures.

The information collected will be provided to the OGIA for inclusion in the Condamine Interconnectivity Research Project and the information will also be used by the OGIA to inform updates to the Surat CMA UWIR.

Influence of geological structures on groundwater flow in the Surat CMA

The OGIA acknowledges that geological structures such as faults can enhance or inhibit groundwater flow and also influence groundwater flow direction. This research project aims to increase understanding of the nature and influence of faults on groundwater flow in the Surat CMA. The project involves the integration of maps, geological and geophysical interpretations (seismic surveys), drill log information, groundwater quality and level information, geochemical data and satellite imagery. Following integration of these datasets, areas that are suitable for targeted geochemical (including isotope analysis) field investigations will be identified. Field investigations will allow the development of a conceptual model that simulates the influence of geological structures on groundwater flow behaviour.

Hydrogeology of the Walloon Coal Measures

This research project aims to gain additional detail on the structure and hydrogeology of the Walloon Coal Measures. Detailed information on the lithology of the Walloon Coal Measures is limited. Data is concentrated in producing tenures within the Surat CMA. Correlation across other areas in the Surat CMA is difficult. The proposed scope of work is focussed on the collection of additional geological and hydrogeological information and development of a representative groundwater block model for the Walloon Coal Measures. The research project also aims to develop techniques to up-scale the block model for use on a regional scale.

Re-conceptualisation of the groundwater systems in the Surat and Bowen Basins in the Surat CMA

This project aims to improve understanding of the hydrogeology of the groundwater systems in the Surat and Bowen Basins to inform future modelling within the Surat CMA. The current conceptualisation of the groundwater systems in the Surat and Bowen basins is based on published literature, government databases and drilling information provided by proponents. Certain assumptions are included in the model to allow regional representation of complex aquifer systems within the Surat CMA. New information identified by the OGIA that would improve future model iterations include water level and pressure maps to generate groundwater flow patterns, hydrogeological characteristics of aquitards, and hydraulic connectivity between the Walloon Coal Measures and underlying and overlying aquifers.

Preparation of second generation regional flow modelling for the Surat CMA

The model used to inform the UWIR will be re-generated every three years. Numerical modelling is a process of ongoing refinement as more information becomes available. As the associated research projects are progressed, this research project will focus on areas for improvement which will be reflected in the next model iteration. These potential model improvements will be informed by exploring options associated with dual phase modelling (i.e., flow of both groundwater and gas from a well), additional sensitivity analyses, alternative uncertainty analysis techniques, and improvement in the understanding of the relationship between the Condamine Alluvium, Walloon Coal Measures and the Main Range Volcanics.

Research to improve knowledge about springs

Additional information associated with the hydrological, ecological and cultural values of springs will be collected as part of this research project. Springs and watercourse springs not yet investigated within the Surat CMA will be the focus of field surveys. Further assessment will be conducted on source aquifers and the level of connectivity between these aquifers and the springs and watercourse springs that they support. Impacts on ecological communities and species associated with water availability will also be assessed, and the research project will investigate the potential for spring monitoring programs to use remote sensing techniques.

8.7 Conclusion

The supplementary groundwater assessment was prepared in response to the comments received on the EIS, and considered updated technical information available since the submission of the EIS, changes to legislation and the regulatory framework, and revisions to the project description.

Further numerical groundwater modelling was undertaken, that was consistent with the approach adopted by the OGIA, and was used to make groundwater drawdown, recovery and flux impact predictions based on Arrow’s current development case.

The impact assessment framework adopted for the EIS was then re-applied in the supplementary assessment and included a review of environmental values, their overall sensitivity, the magnitude of potential impacts on these values and a determination of the residual significance of impacts following the implementation of mitigation and management measures.

The supplementary assessment demonstrates that the assessment completed in the EIS did not understate the significance of residual (mitigated) impacts and that the mitigation measures identified in the EIS remain relevant and appropriate for the management of groundwater-related impacts.

In addition to commitments outlined in the EIS, Arrow has committed to the following:

- Adopt new mitigation and management measures required under the Surat CMA UWIR.
- Offset Arrow’s component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of coal seam gas water extraction from the Walloon Coal Measures.

Arrow is also committed to working with the OGIA and the coal seam gas industry in improving the understanding of the hydrogeology of the Surat Basin through ongoing research.

8.8 Issues Raised in Submissions

Submissions on the EIS raised a range of issues relating to groundwater. The issues fall in broad topics which are listed below.

- Aquifer connectivity, specifically the Condamine Alluvium and the Walloon Coal Measures.
- Arrow's obligations under the P&G Act and the Water Act.
- Definition of groundwater environmental values.
- Enforcement of Arrow's commitments related to groundwater.
- Groundwater monitoring requirements.
- Implementation and enforcement of make good measures.
- Information sources used for the desktop study and research.
- Management of cumulative impacts.
- Management of existing groundwater entitlements.
- Management of groundwater drawdown impacts.
- Potential for coal seam gas extraction to cause subsidence.
- Protection of groundwater quality for a variety of uses.
- Relationship between Arrow and the OGIA.
- Uncertainty associated with the groundwater model.
- Validity of substitution in management of groundwater drawdown.

The topics list is provided to give an idea of the types of issues that have been raised in relation to groundwater and for which responses have been provided under the heading 'Groundwater' in Part B, Chapter 19, Submission Responses.

8.9 Commitments Update

There have been 2 new and 6 updated management measures (commitments) relevant to groundwater identified in the course of the study. These are presented in Table 8.11. Existing commitment C069 has been superseded by the expanded commitment C498.

The full list of commitments, including those that remain unchanged from the EIS and details on those that have changed, are included in Attachment 4, Commitments Update.

Table 8.11 Commitments Update: Groundwater

No.	Commitment	Revised / New
C142	Manage potential impacts to groundwater-dependent ecosystems (including spring complexes) by: • Supporting the identification of specific aquifers that serve as a groundwater source for the groundwater-dependent ecosystem. • Assessing groundwater-dependent ecosystems that are predicted to be subject to unacceptable impacts through the source aquifer. • Developing monitoring and mitigation strategies to avoid or minimise unacceptable impacts.	Clarification of commitment intent.
C120	Prepare a baseline assessment plan to establish benchmark data in registered third-party bores (where possible) prior to the commencement of Arrow extraction activities in accordance with the Water Act.	Clarification of requirements for a baseline assessment plan.
C135	Consider injection of coal seam gas water of a suitable quality (if proven technically feasible) into shallow or deep aquifers to offset depressurisation impacts in aquifers.	Clarification of commitment intent.

Table 8.11 Commitments Update: Groundwater (cont'd)

No.	Commitment	Revised / New
C147	Include where possible make-good measures such as deepening of bores, modification of pumps, or supply of water from an alternative source.	Clarification of commitment intent.
C150	Construct, decommission or repair all coal seam gas production wells in accordance with the code of practice for constructing and abandoning coal seam gas wells in Queensland (DEEDI, 2011b), or relevant code at the time of construction, which details mandatory requirements for well installations, monitoring, management and eventual decommissioning. Should production wells be converted into monitoring bores, do so in accordance with relevant regulations.	Revised to reflect latest edition
C525	Comply with inspection and monitoring requirements of the Surat Cumulative Management Area Underground Water Impact Report administered by the Queensland Government Office of Groundwater Impact Assessment.	Revised to reflect departmental change and release of report.
C564	Arrow will continue to provide information to the Office of Groundwater Impact Assessment (OGIA), as required by the Underground Water Impact Report, to enable continual development and updates to the regional cumulative model administered by OGIA.	New commitment
C565	Arrow is committed to offsetting its component of modelled likely flux impacts to the Condamine Alluvium in the area of greatest predicted drawdown as a result of coal seam gas water extraction from the Walloon Coal Measures.	New commitment. Modelled likely flux impacts are defined as those simulated in the calibrated OGIA Surat CMA Groundwater Model realisation occurring over the period referred to in the UWIR for the Surat CMA (OGIA, 2012) i.e., the next 100 years.