COAL SEAM GAS WATER AND SALT MANAGEMENT STRATEGY

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1. INTRODUCTION

1.1 Purpose

The purpose of this strategy is to define and communicate the management framework for coal seam gas (CSG) water, groundwater and salt to be implemented by Arrow Energy Pty Ltd (Arrow). This strategy has been developed within the regulatory framework to ensure that Arrow's management of water and salt are conducted at, or above, the legal requirements and standards expected by stakeholders and the broader community.

The strategy outlines the:

- Principles Arrow applies to assessing and identifying the most appropriate management option for CSG water and salt produced as a result of Arrow's operations (from the point of production through to beneficial use or disposal); and
- Framework for assessing, modelling and managing groundwater.

This strategy is to be implemented in conjunction with CSG water and groundwater management plans and standard operating procedures (SOPs) developed for Arrow's operations.

1.2 Objectives

The objectives of this strategy are to:

- Communicate corporate policy and principles for the management of CSG water and salt;
- Describe the regulatory framework that applies to the:
  - Gathering, treatment, storage, distribution, beneficial use and disposal of CSG water and salt;
  - Monitoring and management of groundwater and predicted impacts to groundwater level changes in quality;
- Facilitate management of CSG water and salt in a manner that maximises beneficial use and minimises the potential for environmental impacts; and
- Establish a framework for development of both aquifer and infrastructure groundwater monitoring programs.

2. ARROW OPERATIONAL AREAS

Arrow Energy Pty Ltd (Arrow) holds a large number of CSG exploration and production tenures in Queensland.

2.1 Surat Basin

The existing Surat Basin development, known as the Dalby Expansion Project, is located approximately 200 km west of Brisbane and includes the Petroleum Leases (PL) 194, 198, 230, 238, 252, 258 and 260. Arrow has proposed further expansion of CSG operations in the Surat Basin through the Surat Gas Project. The project is expected to cater to the growing demand for gas in the Australian market, and the global liquefied natural gas (LNG) export market. The tenure within the Surat Gas Project development area covers approximately 6,100 km^2 and extends from the township of Wandoan in the north towards Millmerran in the south, in an arc through Dalby. The towns of Wandoan, Chinchilla, Kogan, Dalby, Cecil Plains, Millmerran and Miles are located in, or adjacent to, the project development area (see Figure 1).

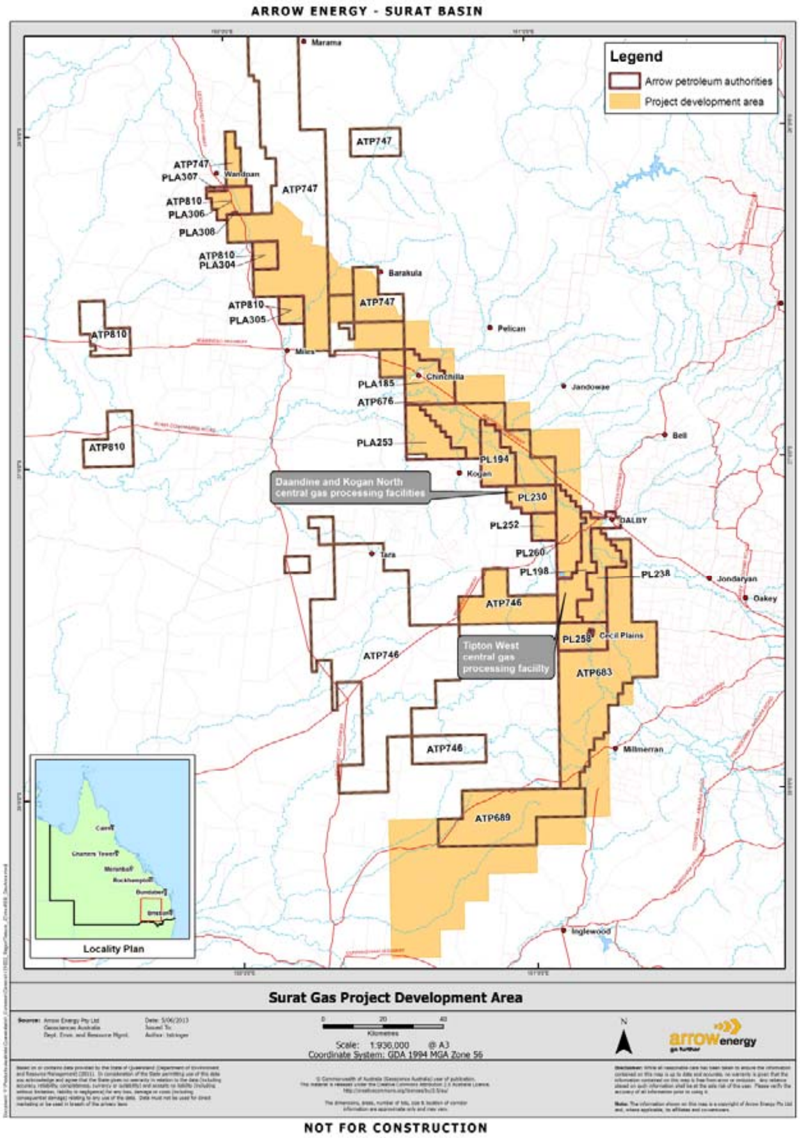


Figure 1. Surat Gas Project development area (including PLs and ATPs)

2.2 Bowen Basin

The existing Bowen Basin development, known as the Moranbah Gas Project (MGP), is located near Moranbah and includes the Petroleum Leases (PL) 191, 223, 224 and 196. As in the Surat Basin, Arrow is also working to expand its CSG operations in the Bowen Basin through the Bowen Gas Project. The Bowen Gas Project covers an area of approximately 8,000 km^2 within Arrow's exploration and production acreage, approximately 200 km south west of Mackay, with the bulk of the area extending from 100km north of Moranbah to 100km south of Moranbah (see Figure 2).

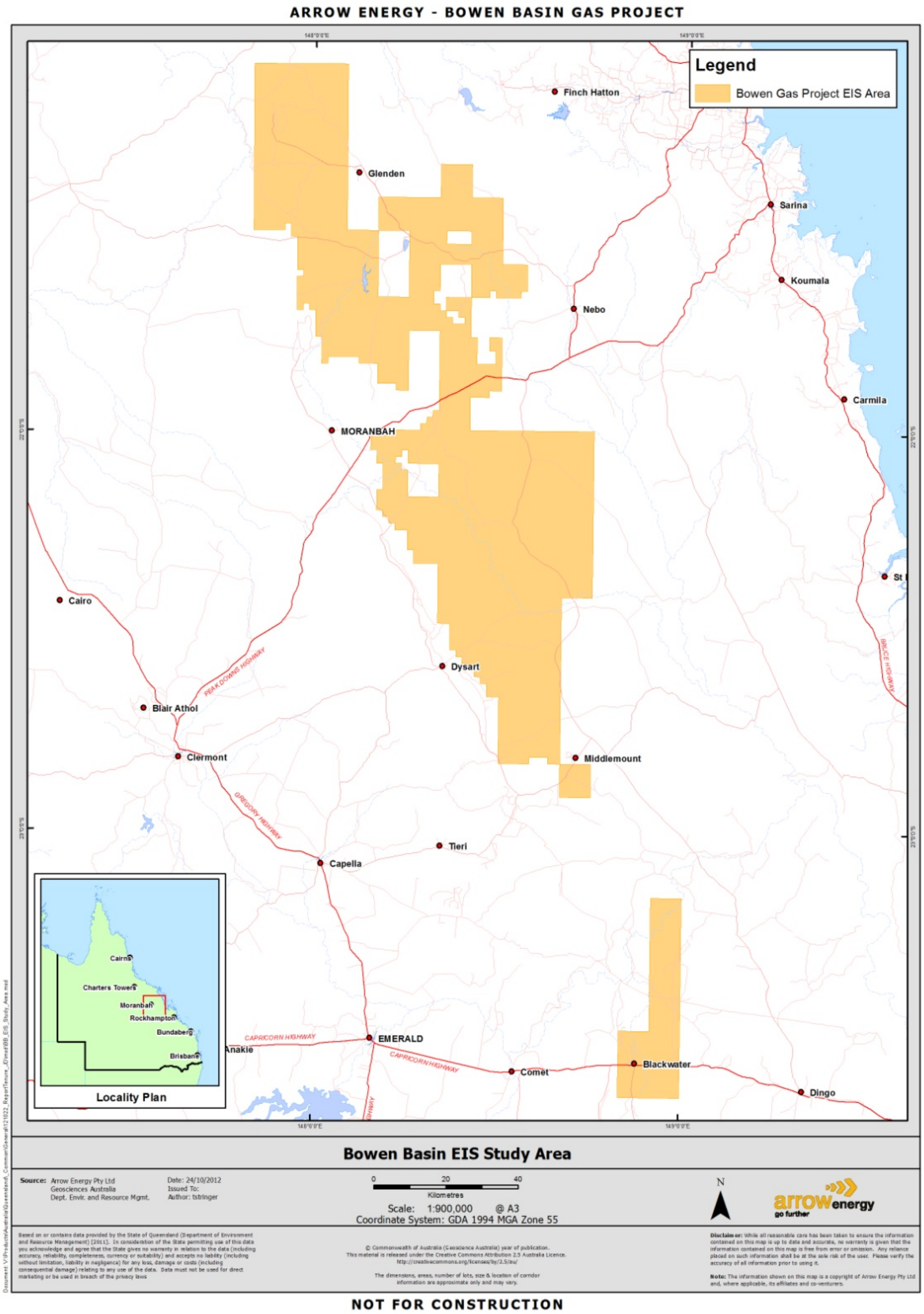


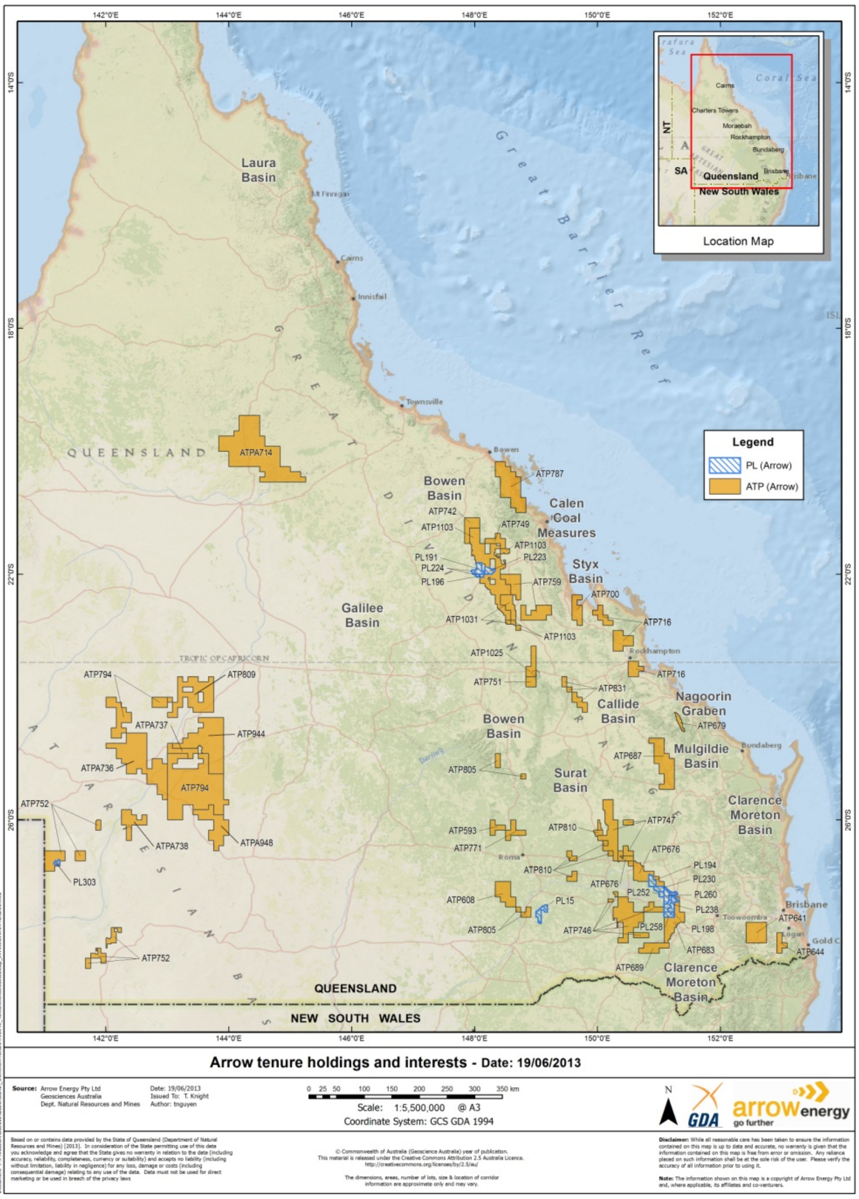
Figure 2. Proposed Bowen Gas Project development area

2.3 Other Queensland Basins

In addition to the above basins, exploration activities are being undertaken in the following basins for the purposes of gathering information for planning, assessing resources and reserves maturation (see Figure 3):

- Clarence Moreton Basin
- Hillsborough Basin
- Nagoorin Graben

- Styx Basin
- Capricorn Basin
- Galilee Basin
- Cooper Basin
- Mulgildie Basin



NOT FOR CONSTRUCTION

Figure 3. Arrow tenure holdings and interests in Queensland

3. REGULATORY FRAMEWORK

Petroleum tenure is required to produce petroleum, including coal seam gas, in Queensland. The Queensland Petroleum Act (1923) and Petroleum and Gas (Production and Safety) Act (2004) provide for petroleum tenures, Authorities to Prospect (ATPs) and Petroleum Leases (PLs), to be granted. These Acts also afford petroleum tenure holders underground water rights i.e. the right to take water as part of petroleum production or testing. Underground water rights are subject to the tenure holder complying with underground water obligations. The activities to be conducted on a tenure (e.g drilling of wells, construction of pipelines and associated gas and water infrastructure) are also authorised under these Acts.

The Environmental Protection Act (1994) requires that an Environmental Authority (EA) is obtained for each tenure (or group of tenures comprising a single project) to regulate and condition the activities to be conducted on that tenure.

The regulatory framework that applies to the extraction and management of CSG water is described in the table below. The framework includes relevant legislation in conjunction with government policies, guidelines and procedures that must be referred to and corresponding plans and/or activities that must be prepared and/or implemented by tenure holders.

Activities	Statutory Obligation/Guideline/Policy	Responsible Regulator
Extraction of CSG Water	• Underground water obligations defined in Water Act including: - Baseline Assessments of landholder bores - Underground Water Impact Reports including: o Prediction (through groundwater modelling) of area of aquifers where water level will decline by more than bore trigger threshold: ▪ In next three years i.e. Immediately Affected Areas, and ▪ At any time i.e. Long-Term Affected Areas. o Water Monitoring Strategy including monitoring of: ▪ Quantity of water extracted, ▪ Changes in water level and water quality of aquifers (through installation and sampling of groundwater monitoring network), ▪ Land access arrangements consistent with other activities (including Notice of Entry/Conduct & Compensation Agreement), and ▪ A Water Monitoring Authority must be obtained for installation of groundwater monitoring bores off tenure. o Springs Impact Management Strategy including: ▪ Predicted risk and likely impact on spring, and ▪ Strategy for preventing or mitigating predicted impacts. o Identification of responsible tenure holder. o A program for conducting an annual review of predictions, and o Prepared (and reissued every three years) by: ▪ Office of Groundwater Impact Assessment for Cumulative Management Areas (CMA) declared by DEHP, and ▪ Tenure holder for tenures outside of CMAs. - Bore Assessments & Make Good o When CMA declared and 'immediately affected area' (IAA) identified in UWIR, tenure holder must undertake a 'Bore Assessment' of all landholder bores in IAA o Where potential for impact on bore in the IAA (within 3 years) or where impaired capacity observed, tenure holder to negotiate a 'Make Good' Agreement with the bore owner • Impacts to springs in the Surat CMA associated with species listed as MNES and the listed ecological community: 'The community of native species dependent on the discharge of groundwater from the Great Artesian Basin' regulated by EPBC Act • Other impacts to springs regulated by EP Act (EA): 'Extraction of CSG water must not directly or indirectly cause environmental harm to any spring, wetland or other surface waters' - Where springs exist, implement Springs Impact Management Strategy referred to above	DEHP

Activities	Statutory Obligation/Guideline/Policy	Responsible Regulator
	• Minimum Construction Requirements for Water Bores in Australia • Minimum Standards for the Construction and Reconditioning of Water Bores that intersect the Sediments of Artesian Basins in Queensland	
Treatment and Storage of CSG Water and Brine	• Environmental Protection Act 1994 (EP Act) • Dam design, construction, operation and monitoring requirements. Defined in Environmental Authority including: - Dam design report and Operating Plan (including maintenance, decommissioning and rehabilitation), and - Dam monitoring and auditing program (including infrastructure groundwater monitoring program), - Leakage detection for surface infrastructure (eg dams) o infrastructure groundwater monitoring program o Seepage detection and return system for brine dams • Guideline for Structures which are dams or levees constructed as part of environmentally relevant activities • Manual for Assessing Hazard Categories and Hydraulic Performance of Dams (Guideline)	DEHP
Distribution and Supply of CSG Water for Direct Beneficial Use	• Supply untreated or treated water to a third party (on tenure) regulated by: - Water Act which requires: o Water Supply Licence o Waste Reduction and Recycling Act 2011 Beneficial Use Approval – general or specific - Environmental Authority which requires: o Water Off-Take Agreement between Arrow and with third party o Coal Seam Gas Water Management Plan, and - Sustainable Planning Act 2009 necessitates a Development Approval (off tenure). • If charging for supply untreated or treated CSG water to a third party (on or off tenure) - Water Act o Water Service Provider's Licence - Waste Reduction & Recycling Act 2011 o Beneficial Use Approval – general or specific o Water Off-Take Agreement between Arrow and third party. • Supply of CSG water to a drinking water service provider (direct or indirect augmentation) - Water Supply (Safety & Reliability) Act 2008 o Coal seam gas water defined as 'recycled water' o Recycled water management scheme, including appointment of scheme manager • Beneficial use of CSG water: - Waste Reduction & Recycling Act 2011 o No application required for General Beneficial Use Approval, only provide notification to DEHP o Application required for Specific Beneficial Use Approval, including extensive water and other analyses o For irrigation: a Resource Management Plan is required • 'Virtual Injection' (Substitution of groundwater allocations): - Water Act o Water Supply Licence o Waste Reduction & Recycling Act 2011 o Beneficial Use Approval - general or specific - Water Off-Take Agreement between Arrow and third party – includes commercial arrangements to effect substitution - P&G Act o Land Access, including monitoring arrangements for bore/s	DEHP DIP DEWS
Discharge of CSG Water into Watercourse	• EP Act (EA) - Environmental Impact Assessment to achieve EA approval (site specific conditions) - Receiving Environment Monitoring Program - Water Release Reduction Strategy • Queensland Government Coal Seam Gas Water Management Policy (2012)	DEHP DEWS

Activities	Statutory Obligation/Guideline/Policy	Responsible Regulator
	• Water Supply (Safety & Reliability) Act 2008 - Recycled water management scheme, including appointment of scheme manager - *Note: coal seam gas water is assumed to directly or indirectly augment a drinking supply and is therefore automatically captured under the Water Supply (Safety & Reliability) Act 2008, however application for exemption can be made to the Office of the Water Supply Regulator in DEWS. Extensive monitoring, analyses, modelling and risk assessment are required for exemption to be granted.*	
Injection into an aquifer used or potentially used as a source of supply for drinking	• P&G Act - Authorised petroleum activity - Land Access • EP Act (EA) - Application for approval to undertake injection trial - Application to include extensive monitoring, analyses, investigations and risk assessments - DERM specifications for injection well - Aquifer groundwater monitoring program • Water Supply (Safety & Reliability) Act 2008 - Recycled water management scheme, including appointment of scheme manager • Queensland Government Coal Seam Gas Water Management Policy (2012) - *Note: coal seam gas water is assumed to directly or indirectly augment a drinking supply and is therefore automatically captured under the Water Supply (Safety & Reliability) Act 2008, however application for exemption can be made to the Office of the Water Supply Regulator in DEWS. Extensive monitoring, analyses, modelling and risk assessment are required for exemption to be granted.*	DNRM DEHP DEWS
Salt or brine disposal	• Waste Reduction & Recycling Act 2011 • Queensland Government Coal Seam Gas Water Management Policy (2012) • EP Act (EA) - Coal Seam Gas Water Management Plan (including brine management plan) - Regulated waste management and tracking system - No encapsulation of brine dams on site - Regulated waste management facility • Commercial agreement with regulated waste service provider	DEHP
Beneficial use of salt or brine	• Waste Reduction & Recycling Act 2011 - Beneficial Use Approval – specific • EP Act (EA) • Queensland Government Coal Seam Gas Water Management Policy (2012) • Commercial contract between Arrow and third party	DEHP
Land access, including compensation for pipelines and Notice of Entry, ecology and cultural heritage clearances	• P&G Act • Land Access Procedure (99-V-PR-0025)) • EP Act (EA) • Environment Protection and Biodiversity Conservation Act 1999 (Federal) • Nature Conservation Act 1992 • Vegetation clearing permit	DNRM SEWPaC

4. CSG WATER INFRASTRUCTURE, MONITORING AND COMPLIANCE

4.1 Source of Coal Seam Gas Water

CSG is the name given to any naturally occurring gas trapped in underground coal seams by water and ground pressure. The gas lines the open fractures between the coal (called cleats) and the inside of the pores within the coal (the matrix).

Coal seams store both gas and water. The water, which is under pressure from the weight of overlying rock material, holds the gas in place. When the water pressure is reduced, the gas is released. In the production process, the water pressure is reduced when a well is drilled into a coal seam and the water is gradually pumped out of the seam. This allows the gas to flow to the surface via the well.

Once a well has been drilled, it becomes the only conduit for gas and water to reach the surface. The two products are separated below ground, with water transferred to centralised collection and treatment facilities, and the gas transferred to production facilities where it is dried, compressed and piped to market.

CSG water can vary from fresh water (water with very few other elements) to saline or highly turbid. CSG water from the Surat or Bowen Basins typically has the following characteristics:

- pH of approximately 7 to 11;
- Salinity generally ranging from 3,000 to 8,000 mg/L (i.e., brackish) and total dissolved solids (TDS) including sodium salts, bicarbonate salts, chlorides and others;
- Suspended solids from the well that will usually settle out over time;
- Other ions including calcium, magnesium, potassium, fluoride, bromine, silicon and sulphate (as SO_4); and
- Trace metals and low levels of nutrients.

The beneficial use of this water is constrained by the salt content, often requiring treatment and/or amendment prior to use. It is understood that CSG water quality typically varies over the life of a well and can also vary between wells in the same location.

4.2 Coal Seam Gas Water Production Forecasting

The water production profiles and assumptions for well counts are obtained from reservoir engineering based on current and proposed field development plans (FDP). Dynamic reservoir modelling and the development of low, mid and high (P_{10}, P_{50} and P_{90}) case production scenarios for both gas and water are developed from this information.

The process for reservoir modelling includes the following key steps:

- Establishing key assumptions such as expansion areas, gas sales targets and gas usage for production activities;
- Developing a well maintenance program for production forecast timing;
- Simulating the required production rates using the reservoir model; and
- Reviewing model performance against actual production data and history matching.

The water forecasting process occurs monthly as a minimum to account for changes to the field development plan, updated reservoir data or identified production constraints.

Water balance models are maintained by the Water Operations Team and used for short, medium and long term planning of water management and supply infrastructure, including water supply and end use.

The model simulates expected dam storage capacity based on forecast production rates, climatic data and anticipated water usage rates. The following items have been incorporated into the model:

- Forecast water production;
- Dam storage capacity, surface area and current levels;
- Rainfall and evaporation based on dam surface area and local historical meteorologic conditions;
- Evaporation factors comprised of surface area and salinity factors;
- Beneficial use off-takes and disposal; and
- Treatment capacity, including allowances for plant availability and recovery.

4.3 Groundwater Modelling

Where the tenure is not within a CMA, Arrow undertakes groundwater modelling to evaluate and predict groundwater drawdown as a result of CSG water extraction. The following hierarchy will guide application of groundwater modelling:

- Collect relevant geological and hydrogeological data from:
  - Existing and future production or exploration wells;
  - Monitoring of Arrow, government and landholder bores; and
  - Collaborative sharing of information with other proponents and regulatory authorities;
- Construct or update the geological 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; and
  - Observed responses in monitoring wells that reflect aquifer behaviour during CSG water extraction;
- Employ the updated numerical groundwater model (if required) 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; and
  - Evaluate water management strategy options by modelling the effectiveness of substitution and/or injection (where conducted) in offsetting impacts of depressurisation;
- The complexity of groundwater modelling used to make predictions is consistent with the volume of water production from each tenement. For example, where:
  - Relatively little groundwater is extracted during exploration and appraisal activities, a relatively simple groundwater model is developed to assess the impacts of these activities;
  - Groundwater is extracted during the production phase, the complexity of the groundwater model produced is increased to better predict the impacts of these activities;
- Groundwater modelling incorporates historical, current and forecast non-CSG groundwater extraction within the tenure.

4.4 Infrastructure

4.4.1 Water Management Dams

Dams are an integral part of the water management system, providing operational storage or water balance capacity to ensure the containment of CSG water. Existing dams that are not currently connected to the water treatment system are identified as either:

- Key infrastructure for integration into future water treatment networks; or
- Surplus to requirements, in which case a decommissioning and rehabilitation plan will be developed.

The types of dams required to manage the production, treatment and distribution of CSG water are:

- **Aggregation Dams** – contain coal seam water from gathering network. Aggregation dams provide a buffer between variations in CSG water production and water treatment flows;
- **Treated Water Dams** – contain treated coal seam water. Treated water dams provide a buffer between treatment output and beneficial use demand;
- **Utility Dams** – contain waste lubricants and chemicals used in water treatment and gas compression systems; and
- **Brine Dams** – contain brine produced during the reverse osmosis water treatment process.

All dams are hazard category assessed to determine the design and compliance requirements of each structure. In order to determine the hazard categorisation of its storage dams, Arrow Energy implements the assessment procedure outlined in the latest version of the DEHP *Manual for Assessing Hazard Categories and Hydraulic Performance of Dams*[1].

All Arrow Energy storages are designed, built, operated and decommissioned in accordance with the DEHP guideline and the current EA.

Dam size is optimised to ensure that an appropriate buffer capacity is provided to allow for variation in:

- Daily flows from the field;
- Development of the field to accommodate new wells as required for initial field development and future maintenance wells;
- Availability of off-takes and/or downstream processes due to maintenance and other factors;
- Levels due to long periods of rain and/or evaporation; and
- Treatment plant availability and optimisation.

Exploration and appraisal activities are generally undertaken in areas remote from existing water management and treatment infrastructure. Hence dams associated with exploration activities are considered temporary and due to distance are not economically feasible to connect to gathering and treatment facilities at that particular stage in the development. Consequently, relatively small aggregation dams may be constructed. At the conclusion of the activities these dams are determined as either:

- Inherent to the water management infrastructure for future development and maintained for integration into the future water management network;
- A dam to be transferred to the landholder (at their request) with approval from the administering authority; or
- A dam that is to be decommissioned (to commence within the timeframe specified in the EA after completion of exploration activities).

4.4.1.1 Regulated Dam Register

Arrow maintains a Regulated Dam Register that contains information including, but not limited to:

- Dam name, location and date of entry into Register;
- Description of dam purpose and contents;
- Hazard category;
- Details of composition and construction of any liner;
- Dimensions and surface area;
- Maximum operational volume;
- Design Storage Allowance at Nov 1st each year;
- Mandatory Reporting Level;
- Date construction certified;
- Name and qualifications of certifier;
- Dates on which dam was inspected for structural and operational adequacy; and

[1] *Queensland Department of Environment and Heritage Protection, 2012. Manual for Assessing Hazard Categories and Hydraulic Performance of Dams, DEHP, Queensland, Australia.*

- Date on which annual inspection report was provided to administering authority.

4.4.1.2 Dam Operating Plans

The procedures and criteria to be used for operating dams, including management, maintenance and monitoring are defined in regional asset operating plans. These operating plans include:
- Dam details;
- Operating guidelines;
- Inspections checklists;
- Regulatory reporting requirements; and
- Surface water monitoring programs.

4.4.1.3 Annual Dam Inspections

An annual audit is undertaken to ensure that dams are assessed as structurally sound and compliant with current performance standards. During the audit process, dams are assessed for the following:
- Hazard category in accordance with the most recent version of DEHP's *Manual for Assessing Hazard Categories and Hydraulic Performance of Dams*;
- Condition and adequacy for dam safety; and
- Its structural, geotechnical and hydraulic performance against the criteria contained in the design plan.

If the structural integrity of any dam is identified to be deficient, a management plan will be developed defining safe operating parameters and any remediation requirements.

All new dams will be designed and constructed by a suitably qualified and experienced person in accordance with the hazard assessment and hydraulic performance standards prescribed by DEHP (*Manual for Assessing Hazard Categories and Hydraulic Performance of Dams*) and with Arrow's standard specification for the construction of regulated dams for the CSG industry.

4.4.1.4 Dam Decommissioning and Rehabilitation

A Decommissioning and Rehabilitation Management Plan will be developed as part of the initial dam design plan for approval by DEHP. The plan is specific to the project and is established based on the timeframes for construction, operation and decommissioning of each facility.

At the end of the life of a dam:
- All liquid and solid material must be removed from the dam prior to rehabilitation;
- Where used, artificial liners must be removed and transported to a regulated waste facility for disposal; and
- Brine must be evaporated and the solid salts must be removed from the dam for:
  - Appropriate disposal to a regulated waste disposal facility designed for that purpose;
  - Further treatment; or
  - Use as an input into another production process.

4.4.2 Water Treatment Facilities

Arrow has undertaken a comprehensive assessment to evaluate the various technologies available for the treatment of coal seam gas water. Reverse osmosis (RO) has been selected as the treatment technology of choice for CSG water.

The water treatment plant includes the following four processes:
- Pre-treatment: consisting of activated carbon filtration to remove residual organics in the feed water;

- Micro Filtration: a microporous membrane separation process that removes particulates to sizes 0.1 to 3 microns;
- Reverse Osmosis: the separation of salts from solution by driving a fluid through a semi permeable microporous membrane under elevated hydrostatic pressure; and
- Amendment:
  - Ionic Amendment – the reduction of SAR by dosing with calcium chloride; or
  - Blending – mixing of treated and untreated water to ensure the appropriate water quality specification for end use.

Future treatment facilities will generally include ion exchange between the pre-treatment and the RO process to increase recovery and reduce the size of brine dams. Facilities will also be identified for enhanced evaporation and/or crystallisation of brine.

The need for and capacity of an RO plant is determined through the infrastructure planning process using the water forecast and balance models outlined above. Treatment facilities may be constructed in a modular fashion to ensure flexibility in capacity and mobility of units across projects. The treatment facilities will be designed and constructed to accommodate the variation in water volumes predicted through modelling.

4.4.3 Gathering and Distribution Systems

The types of pipelines required to manage the production, treatment and distribution of CSG water are:

Water gathering lines – a low pressure water gathering system is installed from each well head to aggregation dams at each treatment facility;

Transfer pipelines – a transfer pipeline, including associated pumps and controls is constructed to connect dams within and between project treatment facilities to ensure that variations in CSG water production and field development phasing can be managed. A transfer pipeline may also be used to move brine from the water treatment facility to brine treatment facilities; and

- **Distribution pipelines** – a network of distribution pipelines, including associated pumps and controls, conveys treated water to end users in the region.

4.5 Groundwater Management

Arrow manages potential impacts on groundwater resources as a result of CSG water extraction and storage through the following framework:

- Development of a groundwater monitoring program based on a risk assessment to detect any impacts from:
  - Authorised petroleum activities which pose a significant risk to groundwater quality; and
  - Seepage from any regulated dam.
- Identification of existing groundwater ‘users’ and springs in, or in the vicinity of, Arrow operated petroleum tenure to facilitate updates to existing databases of:
  - Groundwater bores (through baseline assessments described in Section 4.5.2); and
  - Springs (through completion of spring monitoring surveys as described in Sections 4.5.3.2 and 4.5.5 respectively);
- Development of a groundwater model (detailed in Section 4.3) to predict groundwater drawdown as a result of CSG water extraction, including identification of:
  - Areas of each aquifer in the tenure where groundwater drawdown is predicted to exceed the bore trigger threshold in the next three years and at any time; and
  - Potentially affected springs;
- Description and implementation of monitoring strategies for:
  - Groundwater level and quality (detailed in Section 4.5.3.1);
  - Springs (detailed in Sections 4.5.3.2 and 4.5.5); and
  - Subsidence (detailed in Section 4.5.6);

These strategies will also seek to:
- Verify and improve groundwater modelling; and
- Identify unpredicted impacts;

- Management of impacts on:
  - Water bores located in Immediately Affected Bores by:
    - Undertaking detailed Bore Assessments (detailed in Section 4.5.4) to evaluate whether the predicted drawdown is likely to result in an inadequate quantity and/or quality of groundwater to fulfil the bore's authorised purpose; and
    - Entering into a Make Good Agreement (detailed in Section 4.5.4) with the owner of the water bore, including Make Good Measures if required;
  - Potentially affected springs by:
    - Implementing a program of spring monitoring;
    - Undertaking assessments of the connectivity of the spring to the underlying aquifers and the risks to the springs;
    - If required, developing a strategy to mitigate impacts to the spring based on information gathered from the aforementioned studies.

4.5.1 Groundwater Monitoring Program

A Groundwater Monitoring Program is developed for each EA based on the findings of a site specific risk assessment. The assessment considers risks to groundwater associated with petroleum activities authorised under the EA. The risk assessment involves determination of risk by considering the site setting, authorised petroleum activities, pathways for groundwater impact, the consequence of the impact and the likelihood (including control measures).

The Program includes installation of a network of groundwater monitoring bores (if required) around relevant infrastructure in accordance with the tenure specific EA. The Program includes:

- An appropriate groundwater monitoring network associated with site infrastructure that poses a significant risk to groundwater quality and satisfies the relevant Environmental Authority conditions;
- Identification of background groundwater quality;
- Monitoring points, parameters to be measured, frequency of monitoring, and monitoring methodology;
- Trigger values, or the process for developing trigger values, for the measured parameters;
- Assessment of the potential for and level of impact caused in the event of contamination to underlying groundwater from the monitored infrastructure;
- Details of additional hydrogeological investigations to assess the extent and significance of potential contamination, e.g. geodetic survey, aquifer testing, groundwater flow mapping; and
- Considers local biological, groundwater and surface water conditions when identifying sites for CSG water and brine storage dams.

4.5.2 Baseline Assessments

In accordance with the Water Act (2000), a baseline assessment plan (BAP) will be developed for each tenure in which production of CSG, or production testing (during exploration) occurs.

- The BAP includes a baseline assessment timetable (BAT) which details when an assessment of each bore in the tenure will be undertaken;
- Assessments of bores in closest proximity to production of CSG or production testing are undertaken first;
- Assessments are undertaken in accordance with the DEHP's Guideline for Baseline Assessments to obtain information about the bore, including:
  - The location of the bore;
  - The level and quality of water in the bore;
  - Historical water use;

  - How the bore is constructed including the aquifer into which the bore is drilled; and
  - The type of infrastructure used to pump water from the bore;
- Both registered and un-registered bores are assessed, hence reasonable endeavours are made to contact all landholders in each tenure that may own a water bore;
- Completion of baseline assessments provides information to update existing databases of groundwater bores to enable identification of bores which may be impacted by extraction of CSG water in the future.

4.5.3 Underground Water Impact Report

The Water Act (2000) requires an Underground Water Impact Report (UWIR) to be prepared for each tenure in which production of CSG, or production testing (during exploration) occurs. Arrow prepares a UWIR for an individual tenure, or:

- Where a number of tenements are located in close proximity to one another in the same basin, Arrow may prepare a single UWIR which covers all Arrow operated tenure in the basin; or
- Where a Cumulative Management Area (CMA) is declared, the Queensland Office of Groundwater Impact Assessment (OGIA) prepares the UWIR. A CMA has been declared in the Surat Basin (the Surat CMA).

The contents of the UWIR required under the Water Act are:

- Description of petroleum and gas production within the tenure;
- Description of the regional geology and hydrogeology (including aquifers, their quality and connections to formations from which CSG water is extracted) based on the existing information;
- Prediction of groundwater drawdown (detailed in Section 4.3) as a result of CSG water extraction taking into consideration historical, current and forecast non-CSG groundwater extraction within the tenure;
- Identification of:
  - Areas of each aquifer in the tenure where groundwater drawdown is predicted to exceed the bore trigger threshold (defined in the Water Act as 2m for an unconsolidated aquifer and 5m for a consolidated aquifer):
    - In the next three years (an Immediately Affected Area); and
    - At any time (a Long-term Affected Area);
  - Potentially affected springs where drawdown is predicted to exceed the spring trigger threshold (defined in the Water Act as 0.2m) at any time;
- A groundwater monitoring strategy (described in Section 4.5.3.1), including:
  - Monitoring of the quantity of CSG water extracted;
  - A regional monitoring network to collect data on, and identify changes in, groundwater levels and groundwater quality;
  - Specification of:
    - The parameters to be measured;
    - Locations for installation of monitoring bores; and
    - The frequency of measurements;
- A Spring Impact Management Strategy (SIMS, explained in Section 4.5.3.2), including:
  - Details of potentially affected springs in the tenure;
  - Assessments of the connectivity of the spring to the underlying aquifers and the risks to the springs;
  - Development of a strategy (where required) to mitigate impacts to the spring based on information gathered from the aforementioned studies;
- If the report is prepared for a CMA, assignment of responsible tenure holder for monitoring and make good obligations, and
- A program for annual review.

4.5.3.1 Groundwater Monitoring

Hydrogeological data is collected throughout project development and operation, from a number of sources:

- Exploration, appraisal and production wells, including detailed geological descriptions of the aquifers overlying target coal seams;
- Landholder bores in the vicinity of CSG production testing and production wells, collected during baseline assessments and bore assessments;
- Government monitoring bores installed in the vicinity of CSG operations;
- Collaborative sharing of information with other CSG operators and other stakeholders; and
- Dedicated groundwater monitoring bores installed as part of the WMS (that satisfy Arrow's obligations as described in each UWIR) to:
  - Establish current groundwater level and groundwater quality conditions;
  - Assess natural variation (i.e. seasonal variations) in groundwater levels;
  - Monitor groundwater levels during the operational phase;
  - Monitor groundwater quality during the operational phase;
  - Establish suitable datum levels for each aquifer system;
  - Focus on sensitive areas where more frequent monitoring and investigation is required (e.g. groundwater-dependent ecosystems);
  - Address basin-specific questions or gaps identified during preceding phases of study or modelling, such as the degree of vertical connectivity between target coal seams and over- or underlying aquifers;
  - Provide new data on aquifer properties such as conductivity, storage and water quality (particularly in areas of highest uncertainty);
  - Enable regular updating/refinement of the existing groundwater model as new data is recorded or observations are made; and
  - Provide sufficient spatial coverage to identify unpredicted impacts to water bores and/or springs.

4.5.3.2 Spring Monitoring

Where the tenure is not within a CMA, Arrow will develop a strategy to manage impacts to potentially affected springs, including:

- Identification and review of information on springs from existing datasets;
- Identification of springs that overly aquifers where groundwater drawdown in excess of 0.2m is predicted to occur at any time;
- Field surveys (including ecological and hydrogeological components) of identified potentially affected springs that have not previously been surveyed;
- Surveys for new springs not previously recorded in areas where potentially affected springs may occur;
- Assessment of the connectivity of springs to underlying aquifers by using information from:
  - Existing datasets;
  - Field surveys; and
  - Evaluations of the likely source aquifer for each spring;
- Evaluation of available knowledge about the identified springs and the groundwater flow model developed for the tenure to assess the risk that potentially affected springs will be impacted, including:
  - Likelihood of reduction in flow of water at the spring; and
  - Consequences on spring ecology if a reduction in flow was to occur;

  In many cases the relationship between groundwater level, water flow at the spring and ecology of the spring will only be understood through analysis of detailed monitoring data. This understanding may not be achieved in the short-term (such as the typical timeline for the preparation of management plans and approvals processes) and may take years to decades of research and monitoring;
- Development of a spring monitoring program to identify changes to the:

  - Volume and chemistry of water flowing to a spring;
  - General character of springs; and
  - Ecology of the spring including the assemblages present;

  The spring monitoring program will not include groundwater level monitoring in underlying aquifers as this will provided for by the groundwater monitoring network referred to in Section 4.5.3.1;
- Development of a strategy to mitigate impacts to springs once sufficient data has been collected from the spring monitoring program:
  - To confirm that mitigations are required; and
  - Evaluation of potential mitigations and their effectiveness.

Management of GDEs that are not covered in the Surat CMA UWIR SIMS (i.e. those dependent on the subsurface presence of groundwater) will be undertaken using the same conceptual framework adopted for the SIMS. This framework includes:

- Identification of potential GDE landscapes,
- Use of modelling to predict impact,
- Undertaking a risk assessment to identify GDEs at risk of impact. Where GDEs are identified as being at risk of impact, further assessment is warranted, including detailed field studies and monitoring to ascertain connectivity of GDE to underlying aquifers,
- Monitor and manage impacts as required, including further research, and
- Routinely update/refine conceptual understanding of GDEs in vicinity of project development area as additional data is obtained. This will inform the need for impact mitigation and the selection of mitigation measures that are likely to be most effective.

4.5.4 Make Good Framework

Arrow manages the impacts of CSG water extraction on existing landholder groundwater bores by undertaking Bore Assessments of Immediately Affected Area bores. These assessments are used to evaluate whether the predicted drawdown is likely to result in an inadequate quantity and/or quality of groundwater to fulfil the bores authorised purpose. The assessments will be undertaken by third party specialist hydrogeologists in accordance with DEHP's Bore Assessment Guideline and Arrow's Bore Assessment Procedure. The Bore Assessments involve determination of:

- The yield of the bore by, for example, pumping. The maximum yield of a bore is a function of the aquifer properties, bore efficiency, pumping test rate, pumping test duration and water level in the bore;
- An 'authorised' or 'reasonable' yield which depends on the:
  - Aquifer properties;
  - Bore efficiency;
  - Water level in the bore;
  - Climatic conditions (such as wind speed); and
  - Use of the bore (stock watering or a drought relief bore that may only be pumped sporadically);

  The 'authorised' or 'reasonable' yield for an equipped bore is likely to be lower than the maximum yield for that bore. For bores not equipped with motorised pumps, an actual record of the volumes of groundwater produced over a range of weather conditions will be obtained in order to establish the 'authorised' or 'reasonable' yield;
- Whether impaired capacity is likely to occur, i.e. a reduction in the yield for that bore (as a result of the predicted reduction in groundwater level in the bore) to less than the 'authorised' or 'reasonable' yield for that bore.

Arrow makes all reasonable endeavours to enter into a Make Good Agreement with the owner of any bore where a Bore Assessment is undertaken. The outcome of the Bore Assessment, i.e. whether an impaired capacity is likely to occur or not, is documented in the Make Good Agreement. The Make Good Agreement also documents Make Good Measures that will be implemented if an impaired capacity is likely.

Make Good Measures are evaluated on a case by case basis by considering:
- The existing infrastructure used to pump water from the bore;
- The existing construction of the bore;
- The predicted decline in groundwater level in the bore;
- The current and authorised use of the bore;
- The geology in the vicinity of the bore; and
- Other existing or potential sources of water in the vicinity of the bore.

Make Good Measures to be implemented will be negotiated between Arrow and the bore owner and may include:
- Modifying the pumping infrastructure of the bore;
- Modifying or deepening the bore;
- Installing a new bore into the same aquifer;
- Installing a new bore into another aquifer;
- Supplying an alternative source of water; or
- Monetary compensation.

4.5.5 EPBC Spring Monitoring

The Environment Protection and Biodiversity Conservation (EPBC) Act is Commonwealth legislation that provides for the protection of Matters of National Environmental Significance (MNES), including the community of native species dependent on natural discharge of groundwater from the GAB, or listed threatened species that are reliant on springs.

Where potentially affected springs include MNES, Arrow will, in collaboration with holders of adjacent and nearby petroleum tenures (to the extent possible), develop a plan to provide an early warning system for the monitoring and management of these springs. This plan will:
- Detail the monitoring that will be undertaken for each spring including:
  - Work that will be performed as part of the SIMS;
  - Baseline sampling to establish the pattern of seasonal variation in spring presence, extent, physical characteristics and ecology; and
  - Ongoing sampling;
- Propose an early warning system monitoring network including groundwater monitoring bores detailed in the Water Monitoring Strategy; and
- Identify trigger levels and specific actions to avoid, minimise and manage impacts to these springs from CSG water extraction.

4.5.6 Subsidence Monitoring

Where required Arrow undertakes baseline and ongoing monitoring to quantify surface deformation within its tenures in collaboration (to the extent possible) with holders of adjacent and nearby petroleum tenures, including:
- Collection and analysis of satellite interferometry;
- Establishment of a baseline to quantify deformation at the ground surface across the tenure prior to significant expansion of coal seam gas production; and
- Ongoing collection and analysis of additional satellite interferometry to identify deformation at the land surface.

5. CSG WATER AND SALT MANAGEMENT OPTIONS

5.1 DEHP CSG Water Management Policy

The DEHP *CSG Water Management Policy (2012)* sets out the Queensland Government's position on the management of CSG water and salt. It aims to encourage the beneficial use of CSG water in a way that protects the environment and that maximises its productive use as a valuable resource. To achieve this, the policy outlines a prioritisation hierarchy for managing and using CSG water, and for managing saline waste. These priorities are depicted in Figure 4.

Alongside the hierarchy, DEHP also defines management principles and management criteria to be used as the basis for developing CSG water management options.

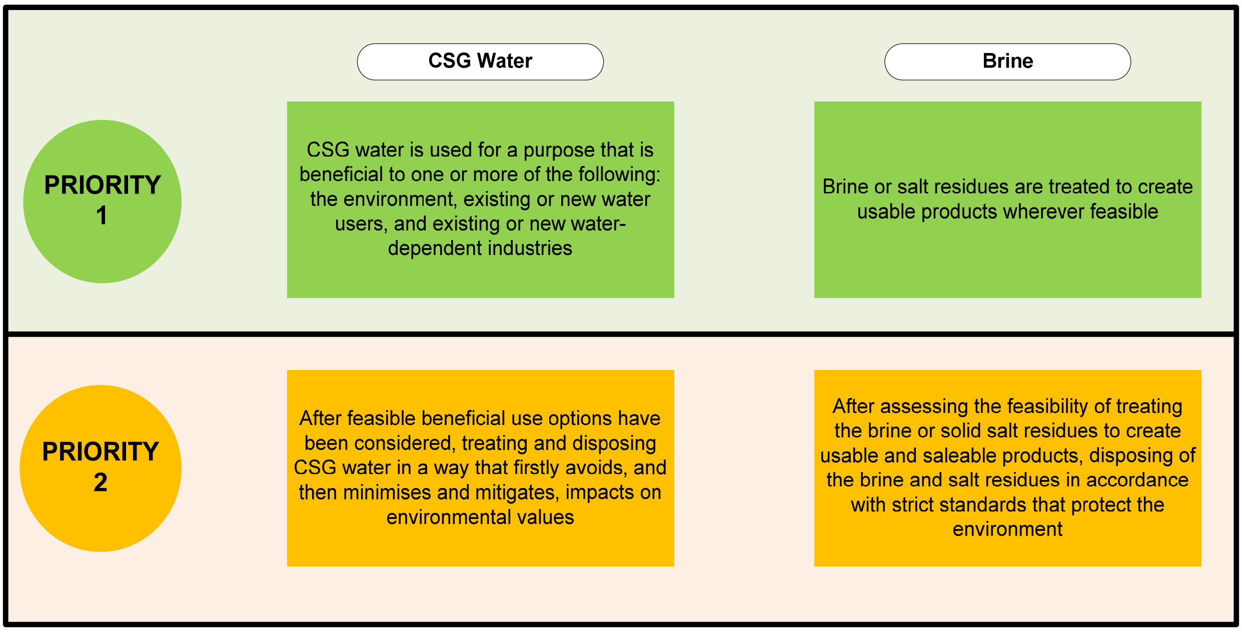


Figure 4. DEHP Priority for CSG Water and Brine Management

5.2 CSG Water and Salt Management

In line with the DEHP CSG Water Management Policy, Arrow's CSG Water and Salt Management Strategy seeks to manage CSG water and salt in a manner that maximises beneficial use and minimises the potential for environmental impacts. In order to achieve the objectives of this strategy, Arrow will manage CSG water, groundwater and salt through a hierarchy of management options that form the basis for an adaptive management framework. These options are shown in Figure 5.

5.2.1 CSG Water

Management of CSG water will consist of a combination of management options which address Arrow's statutory obligations and commitments within the context of the key assumptions. For each project, Arrow will seek to beneficially use or (where necessary) dispose of coal seam gas water in the most cost effective manner that limits its exposure to residual liability. This necessitates that use and/or disposal of water is managed in proximity to the point of treatment. The development sequence for each project will determine the timing, combination and implementation of the management options. The field development plan for any given project will be refined over time to incorporate learnings and improvements as the project develops. Therefore, it is necessary to retain flexibility in the options for management of coal seam gas water to ensure that the most appropriate suite of management options is identified and implemented at each stage of a project's lifecycle.

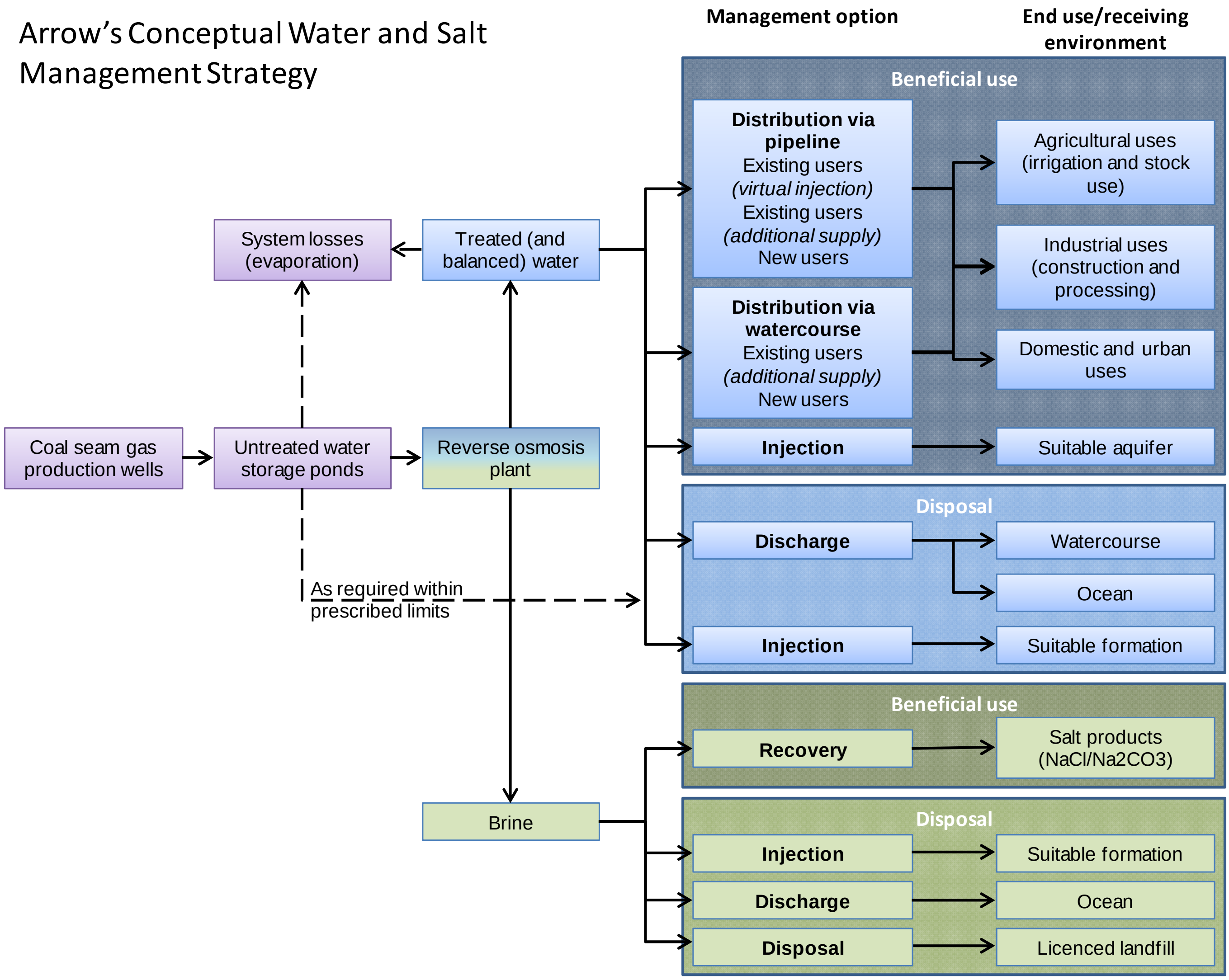


Figure 5. Arrow's Conceptual Water and Salt Management Strategy

Opportunities afforded by collaboration with other coal seam gas developers or service providers will be maximised where they result in a material benefit to Arrow, and such opportunities have the potential to reduce costs and the lead time to obtain approval for, and establish, the infrastructure required for a particular project.

5.2.2 Groundwater

As listed in Section 3, the Water Act (2000) imposes the requirement on CSG companies to 'make good' any impacts of their CSG activities on other groundwater users. Once the groundwater impacts in a given aquifer as a result of CSG water extraction (if any) have been predicted (see also Section 4.5), a decision must be made as to whether Arrow will attempt to offset those potential impacts proactively or choose to make good. In order to make this decision, Arrow will assess:

- The predicted impacts of CSG activities on that aquifer;
- The make good liability ensuing from those impacts;
- Whether it is feasible / practical to use CSG water to offset the potential impacts;

- The cost of using CSG water to offset the potential impacts; and
- The cost of the alternative CSG water management option(s).

If the resulting decision is to offset potential groundwater impacts, two of the CSG water management options in Figure 5 can be used to achieve this:

- Reducing existing extraction from the impacted aquifer to effectively offsets potential flux from that aquifer as a result of depressurisation in the coal seams through:
  - ‘Virtual Injection’ (substitution of groundwater allocations) – provision of CSG water by Arrow to groundwater users, in return for which those users agree to cease taking groundwater;
  - Purchasing groundwater allocations from the impacted aquifer; and
- Injection – injecting CSG water of a suitable quality into target aquifers (if proven feasible) may offset groundwater depressurisation impacts in those aquifers.

The effectiveness of these management options in offsetting the impacts of depressurisation is verified through modelling. In the Surat Basin, virtual injection is currently being considered as a way to offset the potential groundwater impacts of CSG extraction to the Condamine Alluvium.

5.2.3 Brine and Salt

Brine is a significant by-product of the water treatment process, which also requires specific measures to manage its storage, use and/or disposal. Assuming the average salt concentration of 4,500 mg/L experienced by Arrow’s operations in the Surat Basin, Arrow expects that treatment of CSG water will generate in the order of 4.5 tonnes of salt per megalitre of CSG water. Concentrations may vary across projects, and may also change over time within a given CSG field.

The brine management option(s) selected for a particular project will be dependent on both the concentration and the total volume of water expected for that development, as well as the feasibility of processing the brine to produce beneficial or saleable products. Figure 5 displays the hierarchy of brine management options.

5.3 CSG Water and Salt Management Options

The management options presented below apply to treated and untreated water and brine/salt. Note that untreated water may be suitable for any of the beneficial use options identified in Figure 6, depending upon the water quality requirements of the end user and the defined limits/conditions of the relevant approval.

5.3.1 Beneficial Use Management Options

Beneficial use is defined in DEHP’s *Coal Seam Gas Water Management Policy (2012)* as the use of CSG water for a purpose that is beneficial to one or more of the following:

- The environment;
- Existing or new water users; and
- Existing or new water-dependent industries.

In this context, CSG water can be supplied to end users or a receiving environment via a range of mechanisms for a variety of uses including:

- Agriculture (irrigation and livestock);
- Industrial (including power station cooling, coal washing and use by Arrow for construction and operational purposes);
- Domestic and urban (potential for supplies to towns such as Moranbah and Dalby); and
- Injection into depleted aquifers for recharge purposes.

The water quality specifications to enable supply to the end user or receiving environment will be prescribed in the relevant approval. The distribution mechanisms for beneficial use include:

5.3.1.1 Distribution of water via pipeline (beneficial use network)

A pipeline is constructed to distribute water to end users to achieve:

- ‘Virtual injection’ (substitution of existing users’ groundwater allocations; e.g. to groundwater users in the Condamine Alluvium in the Surat Basin);
- Additional supply to existing users (volumes in addition to those required for ‘virtual injection’, where economically and technically feasible); and
- New use (supply of volumes over and above those supplied to existing users, where economically and technically feasible).

5.3.1.2 Distribution of water via watercourse

A managed scheme for supply of water to end users via a watercourse where off-takes exist along the pipeline to the watercourse and downstream of the release point into the watercourse. Such schemes are generally managed by an established entity. This can take the form of:

- Additional supply to existing users of the managed scheme (where this is economically and technically feasible); and
- New use (supply of volumes over and above those supplied to existing users or the establishment of a new managed scheme where it does not yet exist, where this is economically and technically feasible).

5.3.1.3 Injection of treated CSG water

Treated (or blended) CSG water is injected into suitable aquifers where these are depleted (whether due to CSG activities or for other reasons, such as non-CSG groundwater extraction).

If Arrow considers that injection may be an appropriate management option for a particular project (based on the identification of a suitable aquifer and resolution of legislative and approval issues), an aquifer injection trial will be conducted. The purpose of the trial is to understand the suitability of the relevant aquifer for injection and to determine the potential volumes and rates of treated or blended CSG water that could be injected.

For the Surat Basin, aquifer injection is currently not considered feasible for the following reasons:

- An appropriate regulatory framework is not in place, including approvals process and provision of an indemnity framework;
- The timeframe for approvals, including completion of trials, would significantly delay project schedules.

Arrow has carried out an injection feasibility study for injection of treated coal seam gas water into the Precipice Sandstone in the Surat Basin, and has submitted environmental authority amendment applications to conduct aquifer injection trials. If the issues mentioned above can be addressed, and these trials prove promising, Arrow will consider further works to define the extent and feasibility of aquifer injection over the Surat Gas Project development area. Further studies and trials would be required to define the extent and feasibility of treated CSG water injection into other aquifers in Arrow’s operational areas.

5.3.1.4 Salt Recovery

The brine produced through the water treatment process is comprised largely of sodium chloride and sodium carbonate salts. Arrow is investigating viable options for the beneficial use of brine as part of the Surat Gas Project. Arrow has undertaken selective salt precipitation trials to:

- Understand the chemical composition of the brine;
- Identify methods to enhance precipitation of the brine; and
- Identify viable chemical processes to transform the brine into commercial products such as salt and soda ash.

5.3.2 Disposal Management Options

Disposal of CSG water and brine/salt may be necessary when beneficial use options are not economically and technically feasible, or in the case of residual volumes (those volumes of coal seam gas water that cannot be feasibly managed through beneficial use due to operational, technical, environmental or economic constraints). These options include:

5.3.2.1 Discharge of water to watercourses

Management of residual volumes via discharge to a watercourse will be necessary to ensure:

- That gas production can continue during times where:
  - Constraints to supply for beneficial use occur; or
  - Unforeseen events occur such as significant weather events or operational upset;
- The structural and operational integrity of dams.

Discharge to watercourses would occur within environmental flow requirements and in accordance with the relevant approval. Potential discharge locations will be identified for the particular project and a site specific impact assessment undertaken to determine the appropriate discharge regime to minimise impact on the environment.

5.3.2.2 Injection of CSG water or brine

Disposal of treated or untreated CSG water via injection is only an option if a suitable formation can be identified. To date, the only formations available for injection that have been identified are aquifers in the Surat Gas Project Area which fall into the beneficial use category, so this disposal option was ruled out for the SGP during the concept select phase.

Disposal of brine via injection is only an option if a suitable formation can be identified. A criterion for brine injection is finding a target formation where the water quality is low enough. To date, no suitable target formations have been identified for any of Arrow's operational areas.

If Arrow considers that CSG water or brine injection is the appropriate disposal management option for a particular project (based on the identification of a suitable formation and economics), an injection trial will be conducted. The purpose of the trial is to understand the suitability of the relevant formation for injection and to determine the potential volumes and rates of CSG water or brine that could be injected.

Further studies and trials would be required to define the extent and feasibility of CSG water or brine injection for disposal purposes in any of Arrow's operational areas.

5.3.2.3 Discharge to Ocean (via pipeline)

Discharge of coal seam gas water to the ocean via a pipeline is considered an option in the absence of an approved alternative, for example:

- Beneficial use (including injection) is not approved or economically or technically feasible; and
- Discharge to watercourses is not approved or available due to environmental flow requirements.

Disposal of brine to the sea via an ocean outfall pipeline is a feasible option for some of Arrow's operational areas. As with CSG water the viability of an ocean outfall would be evaluated at the time of detailed design for the particular project.

5.3.2.4 Landfill (salt)

Disposal of salt to suitably licenced waste disposal facilities, while not the preferred option, may be considered should other brine management options not be available.

5.3.3 Selection of Beneficial Use or Disposal Management Options

To ensure that the most sustainable portfolio of CSG water and brine/salt management options is implemented, Arrow evaluates all potential options in a systematic and transparent multi-criteria assessment (MCA) process. The performance of each option is assessed against the following criteria:

- **Economic** – whole life capital expenditure (CAPEX) and operating expenditure (OPEX) as net present value (NPV) including the degree of confidence in cost assessments;
- **Schedule** – the ability of the option to be delivered on time, as dependent on the forecast rate of CSG water production;
- **Operability** – the ease with which the option can be operated;
- **Size of Demand** – the proportion of the CSG water production curve that can be utilised by the option;
- **Reliability** – the extent to which the water demand arising from the option is reliable and capable of accommodating increases or decreases in the rate of CSG water production;
- **Social Impact** – the impact of the option on the local community (for example in terms of economic benefit) and the extent to which the local community will support the option; and
- **Environmental Impact / Regulatory Compliance** – the level of likely environmental impact that will be caused by the option and the extent to which the option complies with the DEHP *Coal Seam Gas Water Management Policy (2012)*.

To reflect differences in the relative importance of the considered criteria, each is assigned a weighting. Weighted scores are then ranked to categorise options as either ‘preferred’, ‘reserved’ or ‘non-preferred’. Preferred options are prioritised for investment whilst reserved options continue to be evaluated through targeted feasibility studies. Non-preferred options are put on hold.

The following risks and uncertainties are also considered when determining the appropriate management option for a particular project:

- **Production profile** – water volume forecasts vary across basins and the confidence in predictions is dependent on the extent of exploration and appraisal that has occurred. The relevant CSG water management options will be determined by basin-specific conditions, and in some cases, further observations of reservoir behaviour are necessary to better inform the model and increase confidence levels in forecast volumes. Timing and quantity of water production is highly dependent upon the timing and extent of CSG development within each basin. The water management options must be tailored to the development plans and have the flexibility to meet a range of outcomes;
- **Commercial agreements –** to enter into contractual arrangements, a high level of certainty is required, specifically in terms of the following:
  - Available water volumes;
  - The timing and duration of water availability; and
  - The ability to guarantee that water quality characteristics are fit for the intended application, for example for third-party irrigation, where the water quality must be suitable for the soil type and the intended crop;
- **Approvals –** the water management options must meet regulatory requirements into the future, while retaining flexibility to meet a range of outcomes. Long term approvals are a pre-requisite to investment in infrastructure necessary to distribute water to end users, injection sites or discharge points.

5.3.4 Supply of Water for Beneficial Use

Water will be supplied to the end user under the following framework:

- Water Supply Licence;
- Environmental Authority;
- Beneficial Use Approval (where required); and
- Water Supply Agreement.

Currently, there is no regulatory framework to facilitate ‘virtual injection’ and therefore Arrow has developed a commercial framework to support the supply of CSG water (treated or untreated) to groundwater users who hold allocations from the Condamine Alluvium (end users). Under the framework, end users would receive and utilise water supplied by Arrow in lieu of utilising their groundwater allocations. The end user will accept responsibility (legally and practically) for the impacts of his/her use of the water.

Land access and compensation arrangements associated with the supply of water are provided under the Conduct & Compensation Agreement.