FINAL REPORT

GLNG Environmental Impact Statement – Associated Water Management Strategy

Prepared for

Santos Ltd

Santos House
Level 14
60 Edward Street
Brisbane QLD 4000

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42626220

URS

Project Manager:

....
Paul Wilkinson
Principal Water Engineer

Project Director:

....
Michel Raymond
Principal Water Engineer

Author:

(Optional)

....
Paul Wilkinson
Principal Water Engineer

URS Australia Pty Ltd

Level 16, 240 Queen Street
Brisbane, QLD 4000
GPO Box 302, QLD 4001
Australia
T: 61 7 3243 2111
F: 61 7 3243 2199

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1.1 Background to the Strategy

Santos Ltd (Santos) has appointed URS Australia Pty Ltd (URS) to carry out an Environmental Impact Statement (EIS) for its proposed Gladstone Liquefied Natural Gas (GLNG) project in Central Queensland. The proposed project encompasses three major components including the development of:

- Upstream gas fields in the Roma, Fairview and Arcadia Valley regions (referred to as the Coal Seam Gas (CSG) Fields);
- A gas transmission pipeline linking the upstream gas fields around Roma to a liquefaction plant and export facility for LNG (LNG Facility) located on Curtis Island, near Gladstone; and
- The LNG Facility on Curtis Island (with an initial capacity of 3.5Mtpa, increasing to 10Mtpa over the course of the GLNG project), plus associated infrastructure including a transport corridor comprising a bridge and access road and services corridor. The bridge will span the Narrows separating Curtis Island from the mainland.

The primary objective of the GLNG project is to enable Santos to commercialise its CSG resources.

A primary by-product of CSG production is water. In the Petroleum and Gas (Production and Safety) Act 2004 'associated water' is used to describe this and is defined as '*underground water taken or interfered with, if the taking or interference occurs during the course of, or results from, the carrying out of another authorised activity for the tenure*'.

Coal seam gas production involves extracting water from coal seams (referred to as dewatering) to reduce the groundwater pressure that keeps the gas trapped in the coal. Managing the resultant water is challenging due to its variable quality and often large quantity. Poor quality (high concentration of salts, high Sodium Adsorption Ratio and other parameters) commonly makes the water unsuitable for release to the environment or for many beneficial uses without treatment. As such, historically a common management technique has been to dispose of the water through evaporation ponds. Given the recent focus in Queensland and more widely across Australia on water conservation (primarily driven by the recent drought and future climate change concerns), there is now significant interest in using associated water for beneficial purposes, as opposed to disposal. This change in philosophy is the primary driver of the proposed strategy aimed at sustainably managing associated water produced throughout the lifetime of the GLNG project.

During the GLNG project, which is expected to extend from 2010 to approximately 2035, it is expected that between the three existing major field areas of Fairview, Arcadia and Roma, an upper bound total of 386 Giga litres (GL) of associated water could be produced with a peak production of around 70 Mega litres per day (Ml/d)[1]. This represents a significant water resource, and whilst the quality of water is expected to be highly variable, it is likely that with appropriate treatment and early planning, a variety of beneficial uses can be realised. This is of particular relevance in an area such as this which is subject to periods of extended drought, and where the lack of water constitutes a significant socio-economic constraint both at a community and individual scale. It is acknowledged within this strategy that whilst the long term supply of water cannot be assured and the water supply may only be available for a period of 20 years or so, this still presents a significant

[1]Note: this estimate does not include the other areas in the CSG study area which are not planned to be developed in the near future, e.g. Dennison, Mahalo, Scotia etc. and are not the focus of this report or overall EIS.

opportunity to take the pressure off existing water supplies (from groundwater and surface water resources), enhance the environment and add value to the local economy.

With this in mind, Santos have established a steering committee group tasked with co-ordinating the planning and implementation of the associated water management strategy presented within this report, including undertaking consultation with government bodies, local communities and other key stakeholders.

At this preliminary stage of the GLNG project, the Associated Water Management Strategy presented in this report is at the *Concept Evaluation* stage. By the end of 2009, a number of on-going feasibility studies (recommended in this report) will have been completed which will inform the strategy and allow Santos to progress to the *Concept Selection* stage.

1.2 Why a Strategy?

The purpose of the Associated Water Management Strategy is to ensure that water produced throughout the lifetime of the project is managed on a sustainable and integrated basis, with the aim of maximising beneficial use and minimising the potential for environmental harm.

To date a number of separate associated water management studies and reviews have been commissioned by Santos, primarily for immediate to short term requirements for existing operations. Whilst these address current (i.e. short term) needs and concerns for particular locations, the studies are unlikely to meet the needs of the recently published Queensland Environmental Protection Agency (EPA) Operational Policy for the management of associated water which requires consideration of a modified waste hierarchy (see Section 1.3).

As part of the planning phase of the GLNG project, URS and Santos therefore identified the need to develop a long term associated water management strategy, which can be adapted throughout the life of the field and be used to support the decision making process. Coupled with this, the final Terms of Reference for the GLNG Environmental Impact Statement (EIS) (published August 2008) included the following (see Terms of Reference, Section 2.5.2.1). A reference to the appropriate section in this report is included.

1) *The EIS should review the management of associated water in Santos' CSG field development area in terms of the EPA Operational Policy 'Management of water produced in associated with petroleum activity (associated water). In particular, the EIS should clearly investigate each method of management as well as investigating the potential beneficial reuses of associated water.*

   This is covered in **Section's 3 & 4** of this report.

2) *Associated water discharged to streams must consider; a review of risks, hydrological modelling, development of a risk management framework, development of an adaptive water management plan and monitoring and review.*

   This is summarised in **Section 4** of this report. A full report on the discharge to grade water management option is provided in the Appendix O1 of the main EIS report, EIS technical report entitled '*GLNG Gas Field Development - Associated Water Discharge Study*'.

3) *The preferred management method should be identified taking into considerations environmental, social, technical, economic and regulatory constraints. The EIS should clearly document and provide sufficient information to justify the preferred approach.*

   This is covered in **Section 5** of this report.

4) *The EIS should develop an Associated Water Management Plan that will form part of the required Environmental Management Plan (EMP). The Plan should set specific performance measures or goals to be achieved to maximise the beneficial reuse of associated water and minimise the generation or emission of contaminants to the receiving environment.*

   This is covered in **Section 5** of this report and a separate EMP submitted as part of the EIS.

5) *The EIS should determine the most appropriate methodology to be used for constructing containment facilities, that is based on best practice environmental management and engineering principles and include performance measures and rehabilitation criteria.*

   This is covered in **Appendix C** of this report.

An associated water management strategy is therefore considered an important input to the EIS to demonstrate that a range of water management options have been identified and several option combinations would be appropriate for the sustainable development of the project. It is also of fundamental importance to Santos' CSG field operations, since the absence of a viable water management strategy could cause potential delays to the project with significant financial implications.

The integrated associated water management strategy proposed in this document aims to meet the needs of the Queensland EPA and other key regulators and, where possible, add value to the regional environment and economy.

1.3 How was the Strategy Prepared?

The strategy has been prepared through a partnership process comprising Santos, URS, GHD and Matrix Plus (all of whom have undertaken individual water management studies), and included the following management arrangements:

- A steering committee comprising representatives from each of the firms listed above, to provide direction to the technical teams and ensure that short/medium term operational needs are compatible with the overall long term strategy for the GLNG project;
- An expert panel, comprising technical experts across a wide range of fields, to provide input to the risk assessment process and development of the overall strategy and implementation plan; and,
- Consultation with the community via workshops and surveys.

The core study and development of the draft strategy has been led by URS as part of the EIS process. It is expected that beyond the EIS period, Santos will be the primary driver of the long term strategy and will engage a wider stakeholder group within the strategy development and implementation process.

1.4 Aims and Objectives

The primary objective of this study is to develop an adaptive long-term Associated Water Management Strategy that considers a range of water management options that can be adapted relative to variability in quality and quantity of associated water produced from wells in different areas and continual improvement in best practice water management for coal seam gas operations. The guiding principal of the strategy is to maximise use for beneficial purposes and minimise environmental harm.

A key foundation of the strategy has involved the development of a knowledge base of advantages, disadvantages, and risks of various water management options and a framework to select appropriate water management approaches at various stages of the GLNG project life. It is envisaged that the strategy will allow informed decisions to be made throughout the lifetime of the field and help meet the needs for regulatory approvals, negotiations, and compliance with EPA requirements.

The specific objectives of the strategy are therefore:

1. To develop a viable long term strategy that provides the best net environmental, social and economic outcomes for the region.
2. To develop a consistent and transparent decision support tool to assist Santos' internal management processes and aid negotiations with regulatory authorities throughout the EIS period and beyond.
3. To develop an adaptive associated water management strategy that can be updated periodically and continually improved with new monitoring data and with advances in science and technology (e.g. emerging water treatment technologies).
4. To promote and adopt EPA preferred uses of associated water and only use non-preferred uses as a temporary measure.
5. To maximise opportunities for local community use of associated water and, where ever possible, add value to the local environment and economy.
6. To identify who will be responsible for implementing components of the strategy and timeframes in which they will be delivered to ensure that the supply of associated water does not exceed the established demand. This will include undertaking early negotiations with potential end-users, establishing contracts, completing the necessary approvals process required under the *Environmental Protection Act 1994* and constructing infrastructure to deliver the strategy over the next 20 years.

1.5 Legislation and Regulatory Bodies

The key legislation governing the management of associated water includes:

- Water Act 2000
- Environmental Protection (Water) Policy 1997 (EPP Water)
- Petroleum and Gas (Production and Safety) Act 2004
- Petroleum Act 1923
- Environmental Protection Act 1994
- Environmental Protection (Waste Management) Policy 2000
- Environmental Protection (Waste Management) Regulations 2000
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC 2000)
- Australian Drinking Water Guidelines (NHMRC and ARMCANZ 1996)

These legislative documents provide the basis on which negotiations, compliance and approvals are undertaken with four key regulatory bodies, the Department of Mines and Energy (DME), the Environmental Protection Agency (EPA), Natural Resources and Water (NRW) and Queensland Government Department of Infrastructure and Planning (DIP). An overview of each regulatory body and administrative responsibilities is provided in Sections 1.5.1 to 1.5.4.

The long term water management strategies for the GLNG Project have been developed in accordance with current legislation and best practice outlined in Section 1.5.1 to 1.5.4.

1.5.1 Department of Mines and Energy (DME)

The *Petroleum and Gas (Production and Safety) Act 2004 (P&G Act)* and the *Petroleum Act 1923* provide the framework for accessing land to explore and develop petroleum and gas resources in Queensland. The Department of Mines and Energy (DME) is the regulatory authority responsible for administering these Acts.

The *P&G Act* replaces the *Gas (Residual Provisions) Act 1965* and amends the *Petroleum Act 1923, Mineral Resources Act 1989, Water Act 2000 and other legislation.* The purpose of the *P&G Act* is to facilitate and regulate the carrying out of responsible petroleum activities and the development of a safe, efficient and viable petroleum and fuel gas industry. The following key points are made in relation associated water:

- A petroleum tenure holder may take or interfere with underground water if taking or interference happens during the course of, or results from, the carrying out of another authorised activity for the tenure (i.e. petroleum tenure holders have an entitlement to associated water).
- A petroleum tenure holder may use associated water for the carrying out of another authorised activity for the tenure. If the holder wishes to use associated water for another purpose, the holder must obtain a water licence in accordance with the *Water Act 2000*.
- A petroleum tenure holder may allow an owner or occupier of land in the area of the tenure or land that joins the area of the tenure and is owned by the same person, to use, on that land, associated water taken by the tenure holder for domestic purposes or stock purposes.

1.5.2 Environmental Protection Agency (EPA)

The Environmental Protection Agency (EPA) is responsible for the environmental management and regulation of petroleum activities, including the management of associated water. The recently published Queensland Government *EPA Operational Policy* entitled ‘ *Management of water produced in association with petroleum activities (associated water)*’, applies to associated water produced from any type of petroleum activity and applies to all new applications for non-code compliant environmental authorities (petroleum activities). The *Operational Policy* provides a framework for consistent application and interpretation of legislation by the EPA, and in this case relates to the regulation of petroleum activities under the *Environmental Protection Act 1994 (EP Act)*.

The overall aim of the *EPA's Operational Policy* is to promote the beneficial use of associated water in accordance with the waste management hierarchy set out in the *Environmental Protection (Waste Management) Policy 2000 (EPP Waste)* and minimise potential environmental harm.

The specific objectives are:

1. To provide consistency, certainty and transparency in decision-making about appropriate management strategies for associated water during the pre-design phase of application for non-code compliant environmental authorities.

2. To promote, where feasible, beneficial use or injection in preference to any disposal options for the management of associated water.

3. To achieve the best net environmental, social and economic outcomes for the management of associated water whilst providing flexibility in how the outcome is achieved.

These objectives are in direct alignment with the overall study objectives stated in Section 1.3 of this document.

To facilitate the beneficial use of associated water, the EPA has granted a general approval under section 66F of the *Environmental Protection (Waste Management) Regulation 2000 (Waste Reg.)* for certain stated types of uses (see Table 1-1). The approval and conditions are within the Notice of decision to approve a resource for beneficial use (referred to as the General Notice). If the associated water complies with the conditions of the General Notice, then the water is not classified as a waste and can be reused.

Table 1-1 Water quality criteria for stated types of use

Stated Types of Uses	Water Quality Criteria
Irrigation and general use	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000) Volume 1: Chapter 4.2 and Volume 3: Chapter 9.2
Livestock drinking water	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000) Volume 1: Chapter 4.3 and Volume 3: Chapter 9.3
Aquaculture and human consumption of aquatic foods	Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000) Volume 1: Chapter 4.4 and Volume 3: Chapter 9.4
Drinking water	Australian Drinking Water Guidelines (NHMRC and ARMCANZ 1996)
Dust suppression	Total dissolved solids < 2000mg/L and pH 6-9
Landscaping and re-vegetation	Total dissolved solids < 1000mg/L and pH 6-9

Alternatively, if the water does not comply with the conditions of the general approval, an application may be made under section 66F of the *Waste Reg.* for a specific approval of a resource for beneficial use, of which only a stated person and stated use has the benefit. The applicant can be the environmental authority holder (the producer of the resource), or another person that has the consent of the environmental authority holder. The specific approval would contain conditions particular to the specific beneficial use project (referred to as a Resource Utilisation Plan or RUP), particularly in reference to ensuring that the applicant's proposed use of water is not likely to result in environmental harm. The RUP is consistent with the requirements of a Land and Water Management Plan (see Section 1.5.3), is assessed by both the EPA and DNRW (as an Advice Agency to the EPA) and forms part of, or a condition of, a Beneficial Reuse Approval. As long as these conditions are adhered to then the water is not classified as a waste and hence does not need to be licensed as such.

The *EPA Operational Policy's* waste hierarchy defines two categories for waste water management:

- Category 1 (preferred options) includes injection into aquifers, direct use (livestock watering, aquaculture, mining etc.) and treated use (potable water, irrigation etc.); and
- Category 2 (non-preferred options) includes disposal via evaporation, disposal via injection after surface storage or into better quality groundwater, and disposal via discharge to grade.

The *EPA Operational Policy* states that petroleum producers must determine their method of managing associated water in accordance with this hierarchy. If category 2 options are proposed then the application must include a statement to demonstrate that category 1 management options are not feasible. Furthermore, a re-evaluation of the feasibility of category 1 options must be undertaken by the administering authority on an annual basis. Scope also exists to stage water management strategies, whereby in the short term, category 2 options may be adopted pending the outcome of pilot studies for category 1 management options.

The various options are described fully in Section 4.3, including an assessment of their constraints, opportunities, potential impacts and mitigation strategies across the GLNG field.

1.5.3 Department of Natural Resources and Water (DNRW)

A Land Water Management Plan (LWMP) for approval by the Department of Natural Resources and Water (DNRW) can provide CSG producers with a means of using associated water to irrigate preferred species. A LWMP consists of a property map, overlays showing relevant detailed information (e.g. topography, soils, and land use) and a supporting technical document. Under the current regulatory system, there is no trigger for a LWMP under the Water Act 2000. However, the format, rationale and content of a LWMP are appropriate for assessing these types of proposals.

The purpose of a LWMP is to ensure that irrigation water-use practices are environmentally sustainable. With respect to associated water, this primarily relates to ensuring that potentially high levels of salinity and Sodium Adsorption Ratios do not detrimentally impact soil structure or receiving waters (groundwater or surface water).

1.5.4 Queensland Government Departure of Infrastructure and Planning (DIP)

In response to the significant quantities of associated water currently being produced across Queensland as a result of CSG exploration and production, the Queensland Government Departure of Infrastructure and Planning (DIP) has developed its own Policy (Queensland Coal Seam Gas Water Management Policy). This is now State Policy.

The key features of the new policy framework are:

- Discontinuing the use of evaporation ponds as a primary means of disposal of CSG water. Remediation of existing evaporation ponds should occur within three years; and
- Making CSG producers responsible for treating and disposing of CSG water. CSG water must be treated to a standard as defined by the EPA before disposal or supply to other water users.

The policy represents a balanced response to the need for CSG producers to dispose of CSG water appropriately, while also considering the need for environmental protection and the interests of regional communities and agricultural stakeholders. The policy firmly aims to maximise the beneficial use of CSG water, and considers the following options to be acceptable solutions:

1) Injection of untreated CSG water into aquifers of equal or poorer quality without needing surface storage;
2) Direct use of CSG water without treatment (subject to water quality and intended use);
3) Injection of treated CSG water;
4) Beneficial use of treated CSG water; and
5) If CSG water must be treated then brine must be injected or disposed of in lined evaporation ponds.

The policy also incorporates a number of changes to current requirements including:

- Ponds necessary for water aggregation and the storage of brine from treatment facilities are to be fully lined to a standard determined by the EPA; and

Section 1 Introduction

- An associated CSG water management plan is to be incorporated into the Environmental Management Plan (EMP) for a Level 1 Environmental Authority application.

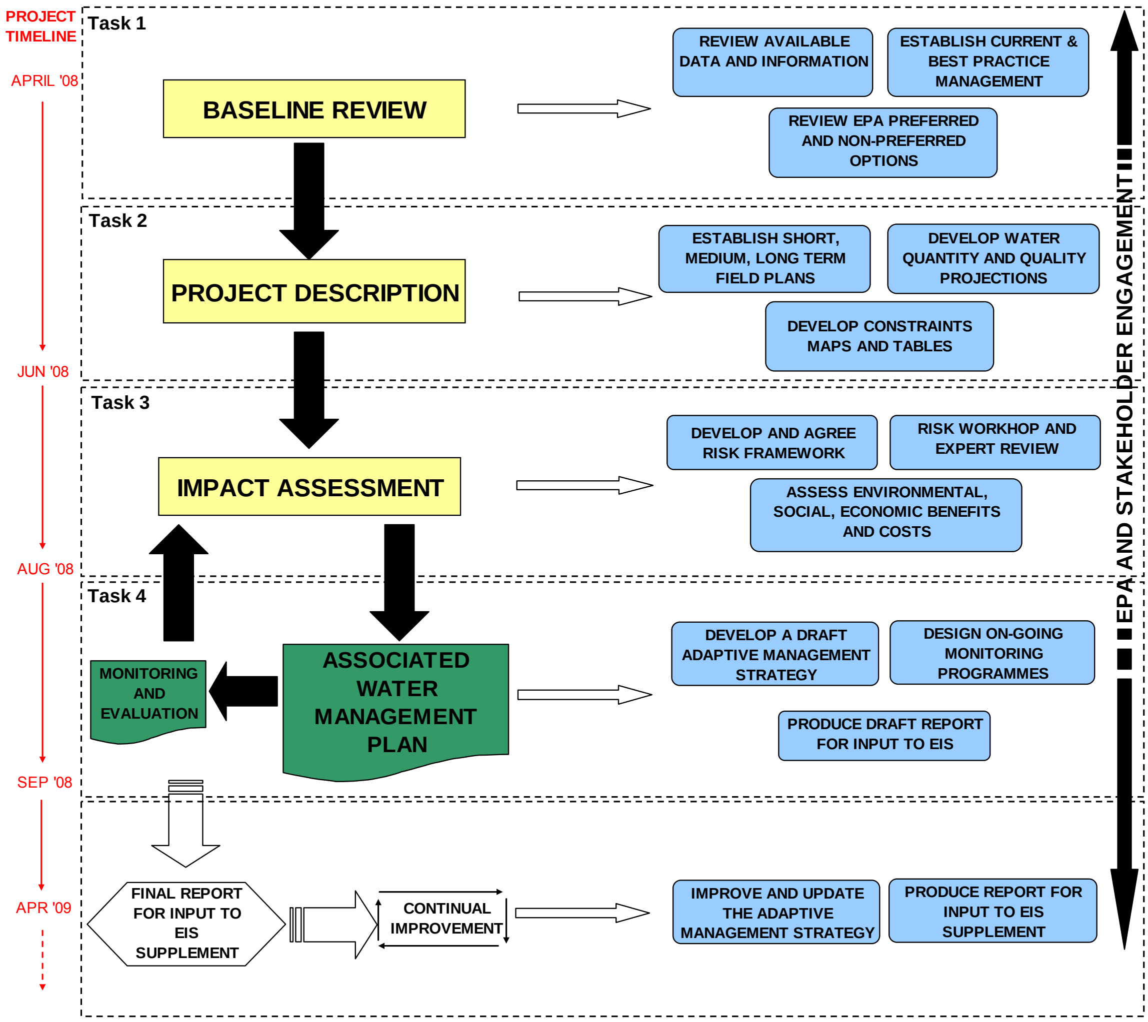
2.1 Study Area

For the purpose of this strategy the GLNG CSG field study area has been divided into 3 sub-regions, namely Fairview, Roma and Arcadia Valley. Given the distinct geographical (physical and socio-economic) characteristics of the three field areas, the associated water management strategy has been developed on a field-by-field basis. It is these three areas that will be developed in the foreseeable future, with the extent to which other CSG development areas in the study area are developed being dependent on the outcomes of ongoing appraisal/exploration programs over the coming years. A full description of the development of the gas fields and likely quantity and quality of associated water over the lifetime of the field is provided in Chapter 3.

2.2 Methodology

The steps in developing the strategy and meeting the needs of the Terms of Reference for the GLNG EIS are shown in Figure 2-1.

Figure 2-1 Strategy Development Process



2.2.1 Task 1 - Baseline Review

- Carrying out a desktop review of existing operations management practices/studies and a review of similar best practice projects beyond Santos operations.
- Identifying missing data through gap analysis and defining additional data needs (monitoring programmes) and working assumptions.
- Identifying and quantifying existing beneficial use demands and identifying the potential for additional uses above current demand.
- Undertaking an initial options assessment of associated water management strategies (Category 1 and 2) including identifying key opportunities and constraints to implementation.
- Undertaking a series of meetings with key Santos and URS personnel to explain the objectives, methodology and desired outcomes and their role in the strategy development process. This included the development of a preliminary risk register with the following objectives:
  - Defining water management options for each field area;
  - Identifying risks for the management options and assessing whether these impacts represented a risk or opportunity cost to the project;
  - Planning the risk profiling exercise; and
  - Providing the preliminary risk register for the preferred options to the expert panel prior to a workshop in which detailed risk-profiles were developed.

2.2.2 Task 2 - Project Description

- Consulting with Santos to develop agreed long term scenarios for the projected development of the field from 2010 to 2034.
- Estimating the change to water quantity production rates and quality over the lifetime of the fields.

2.2.3 Task 3 - Impact Assessment

- Developing a quantitative risk assessment methodology (based on the RISQUE methodology developed by URS) to provide a comprehensive, rigorous and defensible platform from which Santos can reasonably determine their preferred water management strategy, identifying which risk issues are significant, and which risk issues need further investigation to comply with organisational policies, standards and external criteria. The RISQUE method has been audited against AS/NZS 4360 (the Australian and New Zealand standard for Risk Management) and has been successfully used on a range of projects to assist decision-makers gain an appreciation of risk (including the overall GLNG project Hazard and Risk Assessment).
- Using an experienced and qualified panel of experts during a 2-day workshop to identify the risks to the initial strategy, including commercial and legal liabilities, political and reputation impacts, human health and safety impacts and environmental impacts. The workshop participants used their collective expert knowledge and experience to quantify (estimate) the likelihood (frequency of occurrence) and the consequences (expressed in terms of environmental, social, health and safety and economic impacts) of the relevant issues.

- Developing an adaptable risk assessment framework which can be updated throughout the lifetime of the field as more data and information becomes available from monitoring programmes and modelling studies. The outputs from the risk modelling provides a consistent and transparent basis on which to compare the economic, social and environmental benefits and costs of associated water management options, and support the decision making process (see Appendix D).

2.2.4 Task 4 – Draft Associated Water Management Strategy

- Developing a draft long term water management strategy (combination of preferred options) for each field area on the basis of Tasks 1 to 3. The strategy has been designed to provide a flexible decision support framework which can be adapted to the likely schedule of water production and changes in water quality.
- Providing recommendations for additional longer term water studies and monitoring programmes which will be required to refine and continually improve the water management strategy.

2.3 Key Study Challenges

The key challenges in developing the associated water management strategy have included the following:

- *Lack of water quality characterisation data* – at this early stage of the GLNG project, there is a general lack of groundwater quality monitoring data (coal seam and non-coal seam aquifers) (especially the Arcadia CSG field). As such, where appropriate, conservative assumptions have been made for the purpose of developing the draft strategy.
- *Uncertainty in water quantity predictions* – there is uncertainty over the likely volumes and rates of associated water from each field. In order to account for inherent uncertainty associated with this as well as many other aspects of the strategy, an adaptive water management (decision support) tool has been developed which can be updated and re-run as more information becomes available during the course of the GLNG Project.
- *Balancing current operational needs with the longer term objectives of the strategy* – current water management needs during the field appraisal stage need to be compatible with the longer term strategy objectives. To ensure that this is the case, a steering committee has been formed to coordinate the various on-going and planned water management studies.
- *Competition with other producers for end users in the region* – within the GLNG CSG field study area other producers are also likely to be exploring opportunities for supplying their associated water to end users. This represents a potential key risk to the strategy given that the guiding principle is to maximise beneficial (in particular community) uses.

With these challenges in mind, the strategy has been developed so as to be adaptable to the prevailing physical and socio-economic conditions. Recommendations have been provided to periodically review and update the strategy to ensure that the best available information underpins preferred water management options (see Section 5.6).

Section 3 Project Description

3.1 Overview

This section provides a description of the likely schedule of well development and expected quantity and quality of water produced during the GLNG project between 2010 and 2034. Due to the limited amount of data available to support these estimates and the early stage of the project (which as yet has no finalised field layout plan), it is likely that the estimated quantities of water will change as the project progresses and more field information becomes available. As such, the preferred associated water management strategies put forward in Section 5 will require regular review and updating (at least on a bi-annual basis) as field development plans are progressed.

3.2 Existing Well Development

3.2.1 Roma Field

At present there are no development wells within the Roma field. A number of appraisal wells have been or are in the process of being established. The majority of these are located to the north east of Roma township.

3.2.2 Fairview Field

Within the Fairview field there is an extensive network of development wells which have been established over the past 10 years; although these are not part of the GLNG project. As a result there is a better understanding of likely water quality and quantity schedules. There is also a large network of appraisal wells which are due to be established in the near future, in preparation for the development phase of the project.

In total, more than 110 wells have been drilled in the Fairview area. Of these, 70 are connected to a gathering system with the remainder undergoing dewatering operations and/or awaiting completion and connection. Approximately 50 of the 70 wells are producing associated water. At this point, 4 ML/day of associated water is produced and is either discharged to a creek or to the water gathering system for re-injection. Gas is gathered at two field compressor station sites (CS1 and CS2) where it is compressed and dehydrated before exported as sales gas. Current sales gas production is approximately 45 TJ/day, and is limited by the capacity of the export pipeline and compression systems. Average well productivity is around 0.9 TJ/day, with a number of wells flowing in excess of 5 TJ/day.

3.2.3 Arcadia Valley Field

At present there are no appraisal or development wells within the Arcadia Valley field. As such, there is little or no information available on the likely quantity or quality of associated water (see Section 3.4.3).

3.3 Future Well Development Scenarios

In order to fully establish the potential range and significance of impacts associated with the CSG field development, estimations (minimum and maximum values) have been made of the number of appraisal and development wells that will be drilled in each field area for each year of the GLNG project.

Within the Roma field the number of wells planned ranges from 870 to 970, with the majority being established over the first 5 years of the Project. The number of wells planned for Fairview ranges from 540 to 900, with well development taking place in two phases from 2008 to 2017 and then from 2027 to 2031. Within the Arcadia Valley field the number of development wells is expected to range from 70 to 280. The minimum estimate assumes that the Arcadia Valley field does not progress beyond the appraisal stage (i.e. the reserves are not proven and therefore no development wells are established). Well development for the maximum case is expected to take place over the first 10 years of the project, finishing by 2020. In total, across the entire CSG field area, up to 2600 appraisal and development wells could be established.

It is important to note that these future well development scenarios are at present uncertain as they are based on the limited appraisal well data gathered to date. Final field development plans are expected to be produced by June 2009 following completion of the appraisal stage of the Project. The information presented here was provided by Santos on 29 May 2008.

3.4 Water Quantity and Quality Estimates

The quality and quantity of associated water is primarily dependent upon the geology of the area in which the wells are located, and therefore the management strategies for dealing with the water generally need to be site specific. However, throughout the CSG industry, the presence of total dissolved solids (TDS) is the primary constituent of concern which dictates water management strategies. CSG associated waters typically contain elevated levels of TDS relative to freshwater, with concentrations of between 4,000 and 20,000 mg/L, with sodium, bicarbonate and chloride being primary constituents. Other key water quality parameters of concern in associated water include fluoride and boron. In addition, due care needs to be taken to manage pH, dissolved oxygen, suspended solids, temperature (which can be as high as 40^{0}C) and sodium adsorption ratios (SAR).

An examination of the quality of associated water from the CSG gas fields in the context of overseas developments (see *GLNG Gas Field Development - Associated Water Discharge Study, Section 2*), found that;

- Average salinity and sodium content in GLNG associated water is typically an order of magnitude less than overseas;
- Average chloride and magnesium concentrations are around two orders of magnitude lower than overseas;
- Average sulphate and calcium concentrations are two to three orders of magnitude lower than overseas; and,
- Other water quality parameters are of a similar order of magnitude.

While water production volumes from CSG wells will decline over the life of the well, water quality generally remains consistent (i.e. low temporal variability). Where water quality data is available, the main constituents of concern have been identified and are discussed in Sections 3.4.1 to 3.4.3, along with estimated quantity schedules.

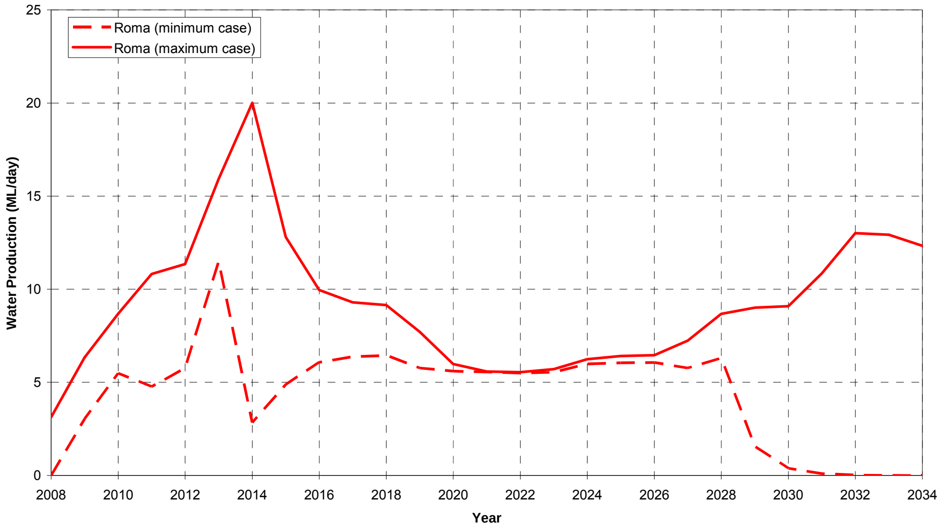
For each year of the CSG field development, estimates have been made of the likely upper and lower bound water production rates based on results from existing wells and the field development plans described above. The dewatering process from an individual well is characterised by high water production rates immediately following well establishment, which reduces linearly over time. Typically, there is an inverse relationship with gas production. An example of this is the first 10 wells in Fairview, which had a combined water production rate of approximately 2 Ml/d in December 1994. Over a 12 year period to December 2006, water production rates decreased by an order of magnitude to around 0.2 Ml/d. Meanwhile, gas production increased from 2,000 to 10,000 Mscf/d over the same period.

3.4.1 Roma Water Production

Quantity Schedules

Associated water production from Roma is expected to peak (for the maximum scenario) at around 20Ml/d in 2014 during the early dewatering phase of the GLNG project, and remain at above 10Ml/d for a period of 5 years (see Figure 3-1). The upper bound estimate for the total volume produced over the lifetime of the field is 91,336 ML (approximately 91 Gigalitres or GL). These water production estimates were provided by Santos on 29 May 2008. They have also been used to describe water production profiles from the Fairview and Arcadia Valley CSG fields in Sections 3.4.2 and 3.4.3.

Figure 3-1 Water Quantity Schedule for the Roma Field



Quality Characteristics

The data presented in Table 3-1 has been limited to key water quality parameters that are likely to have implications for management, or those that are typically associated with the CSG industry. A total of 12 monitoring wells were reviewed during this assessment (samples were taken in October 2008).

Table 3-1 Summary of Roma Water Quality Data

Parameter	Average Concentration	Maximum Concentration	Minimum Concentration
pH	8.54	8.8	8.4
Total Suspended Solids (mg/L)	325	1200	100
Total Dissolved Solids (mg/L)	1,992	2,400	1,300
Sodium (mg/L)	838	990	620
Bicarbonate Alkalinity (mg/L)	785	1,100	540
Chloride (mg/L)	670	1,100	460
Sodium Adsorption Ratio	102	116	81
Ammonia (mg/L)	0.63	0.72	0.47
Orthophosphorus (mg/L)	0.019	0.027	0.007
Fluoride (mg/L)	2.59	3.1	2.0
Boron (mg/L)	0.40	0.46	0.32
Mercury (µg/L)	<0.1	<0.1	<0.1
Lead (mg/L)	0.037	0.31	0.001
Iron (mg/L)	20.27	190	0.029
Zinc (mg/L)	0.279	2.6	0.007

pH

The pH of associated water from Roma ranges from 8.4 to 8.8, with an average of 8.54. Therefore, pH is typically more alkaline than surface waters but well within the range of natural variability. Associated water pH is generally suitable for aquatic ecosystems, stock, irrigation, recreation and raw drinking water supply.

Total Dissolved Solids (TDS)

Data in Table 3-1 indicates that the highest concentration of TDS recorded is 2,400 mg/L, with an average concentration of 1,992 mg/L across all wells, representing moderate salinity. This concentration precludes it from most beneficial reuse options, without treatment by Reverse Osmosis or other similar technology. Livestock can tolerate TDS concentrations up to 4000 mg/L, therefore this could be a potential use without significant treatment (although Fluoride levels may exceed guidelines, see below). Potable water for humans is required to be below 500 mg/L, and even direct use for dust suppression requires the TDS to be below 2000 mg/L.

Calcium and magnesium are generally present in low concentrations only, with average concentrations across all wells being 4.7 mg/L and 1.5 mg/L, respectively, which is significantly below the guidelines for livestock consumption. These values also suggest that the characteristic “hardness” of the water is low, and scaling potential is low.

Total Suspended Solids (TSS)

The Roma field associated water generally has low concentrations of suspended solids, averaging 325mg/L. Although this concentration is relatively low, it is recommended that some treatment (i.e. filtration) be used to remove suspended solids from the water for most re-use options.

Sodium Adsorption Ratio

The Roma field associated water has an elevated Sodium Adsorption Ratio (SAR is the ratio of sodium to calcium and magnesium), with an average of 102. For most irrigation schemes a SAR of between 10 and 20 is required to avoid the sodicity of the water degrading the physical structure of the soils. Some level of dosing would likely be required to reduce the SAR to an acceptable value for long term irrigation schemes.

Fluoride

Fluoride, which is found in natural waters, is present in the Roma field associated water, with an average concentration of around 2.6 mg/L and a maximum concentration of 3.1 mg/L. These concentrations are above typical surface water concentrations (<0.1 – 0.5 mg/L) and marginally above guideline values for many reuse options, including drinking water (threshold is 1.5 mg/L above which dental fluorosis can occur) and stock watering (threshold is 2 mg/L). Some degree of fluoride removal may be a requirement of any potential treatment process, depending upon the management option selected.

Metals

According to data provided to URS by Santos, all mercury concentrations in the Roma field associated water samples were below the limit of detection (<0.1 µg/L).

A further review of mercury concentrations in associated water from overseas based CSG operations did not indicate the presence of mercury at concentrations sufficient to create any issues with respect to specific treatment or disposal requirements. CSG associated water quality data from the Powder River Basin, Wyoming (the largest CSG producing basin in the U.S.) was reviewed, which included water quality data from 47 wells. All wells with the exception on one reported mercury concentrations below the limit of detection (< 0.1 µg/L and <0.005 µg/L). The other sample reported a concentration of 0.25 µg/L, which, for comparison, is still below Australian Drinking Water Guidelines.

Minor concentrations of lead and zinc were detected at all of the wells.

Nutrients

The concentration of oxidised nitrogen (nitrate and nitrite) in the water is low with an average concentration of 0.002 mg/L (compared to trigger values of 400 mg/L for nitrate and 30 mg/L for nitrite for stock watering re-use). Ammonia and orthophosphorous are also present in low concentrations, posing no significant constraint on re-use options.

Boron

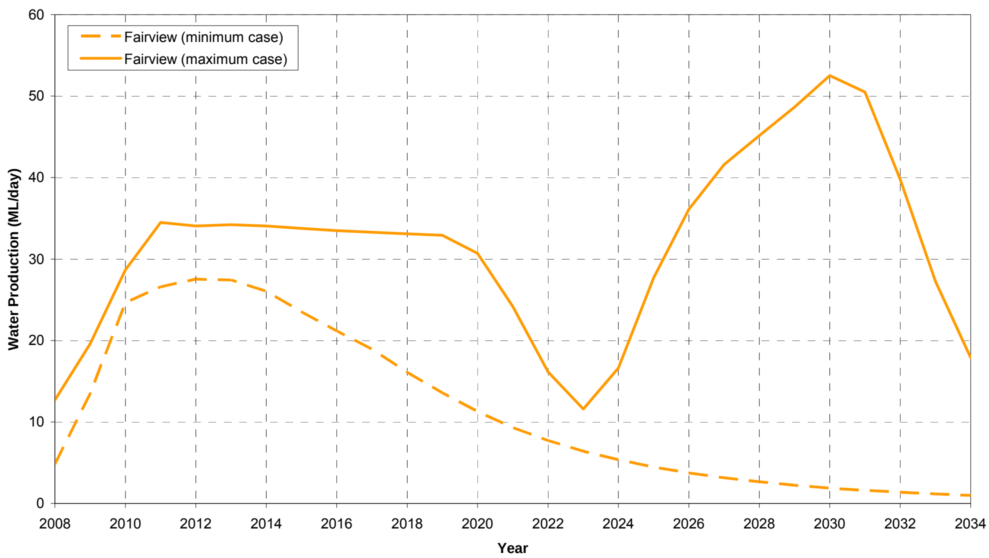
Boron concentrations are marginally above the trigger value for the protection of aquatic ecosystems (trigger level of 0.37 mg/L) although this would not preclude discharge to surface waters. The water is suitable for stock watering (trigger level 5 mg/L), potable drinking water supply (trigger level 4 mg/L), irrigation (trigger value 0.5 mg/L) and recreation (1 mg/L).

3.4.2 Fairview Water Production

Quantity Schedules

Associated water production for the maximum scenario from the Fairview field is expected to increase from around 12 Ml/d to around 35 Ml/d by 2011. This rate of water production is likely to continue for around 10 years, after which it is expected to decrease. A second peak in water production is then predicted to occur in 2030 at 52Ml/d, in line with the most substantial phase of well development (see Figure 3-2 and Section 3.3). The upper bound estimate for the total volume of associated water produced over the lifetime of the field is approximately 236,000 ML (236 GL).

Figure 3-2 Water Quantity Schedule for the Fairview Field



Quality Characteristics

The data presented in Table 3-2 has been limited to key water quality parameters that are likely to have implications for management, or those that are typically associated with the CSG industry. A total of 57 monitoring wells were reviewed during an assessment undertaken by URS in 2008, as part of the Fairview Environmental Management Plan (2008).

Table 3-2 Summary of Fairview Water Quality Data

Parameter	Average Concentration	Maximum Concentration	Minimum Concentration
pH	8.8	9.56	7.9
Total Suspended Solids (mg/L)	62	2,988	<5
Total Dissolved Solids (mg/L)	1,489	5,568	403
Sodium (mg/L)	482	1,484	193
Bicarbonate Alkalinity (mg/L)	808	1,852	391
Chloride (mg/L)	134	1,370	8
Sodium Adsorption Ratio	98	126	85
Ammonia (mg/L)	0.66	2.63	0.15
Orthophosphorus (mg/L)	0.07	0.28	0.008
Fluoride (mg/L)	2.25	8.75	0.55
Boron (mg/L)	0.75	1.7	0.2
Mercury (µg/L)	<0.1	<0.1	<0.1
Lead (mg/L)	0.01	0.152	<0.005
Iron (mg/L)	0.55	4.125	0.038
Zinc (mg/L)	0.01	0.375	<0.005

pH

The pH of associated water from Fairview ranges from 7.9 to 9.56, with an average of 8.8. Therefore, pH is typically more alkaline than surface waters but well within the range of natural variability. Associated water pH is generally suitable for aquatic ecosystems, stock, irrigation, recreation and raw drinking water supply.

Total Dissolved Solids (TDS)

Data in Table 3-2 indicates that highest concentration of TDS recorded is 5,568 mg/L, with an average concentration of 1,279 mg/L across all wells. This concentration precludes it from many potential reuse options, particularly irrigation of sensitive croplands. However, some species of plants and trees (e.g. Bermuda grass and Chinchilla White Gum Trees) can tolerate TDS concentrations up to 5,000 mg/L.

Some of the wells in the north-west field area produce relatively low salinity water (<1,000 mg/L), creating the potential for water from this area to be managed separately (possibly without treatment) from wells producing water with higher TDS concentrations.

Calcium and magnesium are generally present in low concentrations only, with average concentrations across all wells being 1.5 mg/L and 0.2 mg/L respectively. Therefore, characteristic “hardness” of the water is low, and scaling potential is low.

Total Suspended Solids (TSS)

The Fairview associated water generally has low concentrations of suspended solids. A maximum concentration of 2,988 mg/L was recorded from one well, although this is nearly 50 times higher than the next highest concentration. The reasons for this anomalous result are not known. Excluding this anomalous result, the average suspended solids concentration across all wells is 66 mg/L.

Although this concentration is relatively low, it is recommended that some treatment (i.e. filtration) be used to remove suspended solids from the water should direct injection be considered as an alternative for disposal of associated water.

Sodium Adsorption Ratio

The Fairview associated water has an elevated SAR, with an average of 149. For most irrigation schemes a SAR of between 10 and 20 is required to avoid the sodicity of the water degrading the physical structure of the soils. Some level of dosing would likely be required to reduce the SAR to an acceptable value for long term irrigation schemes.

Fluoride

Fluoride, which is found in natural waters, is present in the associated water, with an average concentration of 2.2 mg/L, and a maximum concentration of 8.75 mg/L. These concentrations are above typical surface water concentrations (<0.1 – 0.5 mg/L) and above guideline values for many reuse options, including stock watering. Some degree of fluoride removal may be a requirement of a potential treatment process, depending upon the management option selected.

Metals

All mercury concentrations in the CSG associated water samples were below the limit of detection (<0.1 µg/L).

Lead and zinc were detected at several of the wells, although the maximum concentrations listed in Table 3-2 appear to be anomalous, with many wells showing concentrations below limits of detection. Iron is also present in high concentrations, which has implications for scaling.

Other metals including beryllium, cadmium, chromium, cobalt, manganese, nickel, selenium, arsenic and vanadium were detected in either very low concentrations or at concentrations below the limits of detection.

Nutrients

The concentration of oxidised nitrogen (nitrate and nitrite) in the associated water is low. However, ammonia and orthophosphorus are present in significant concentrations. The average concentration of ammonia is 0.7 mg/L, with a maximum concentration of 2.6 mg/L. For comparison, the Australian Water Quality Guideline toxicity trigger level for the protection of aquatic ecosystems (slightly-moderately disturbed systems) is 0.9 mg/L. However, the concentration of ammonia is generally not an issue while the pH of the water is $\leq$9.5, due to the low concentration of the free ammonia ion (NH_3).

Orthophosphorus is present in the water with an average concentration of 0.07 mg/L and a maximum concentration of 0.28 mg/L. The Queensland Water Quality Guidelines (2006) for total phosphorus in upland and lowland streams is 0.03 to 0.05 mg/L.

While the presence of nutrients in the water may encourage biological growth within treatment systems (particularly filters), this can be controlled through simple chemical (i.e. chlorine) addition.

Boron

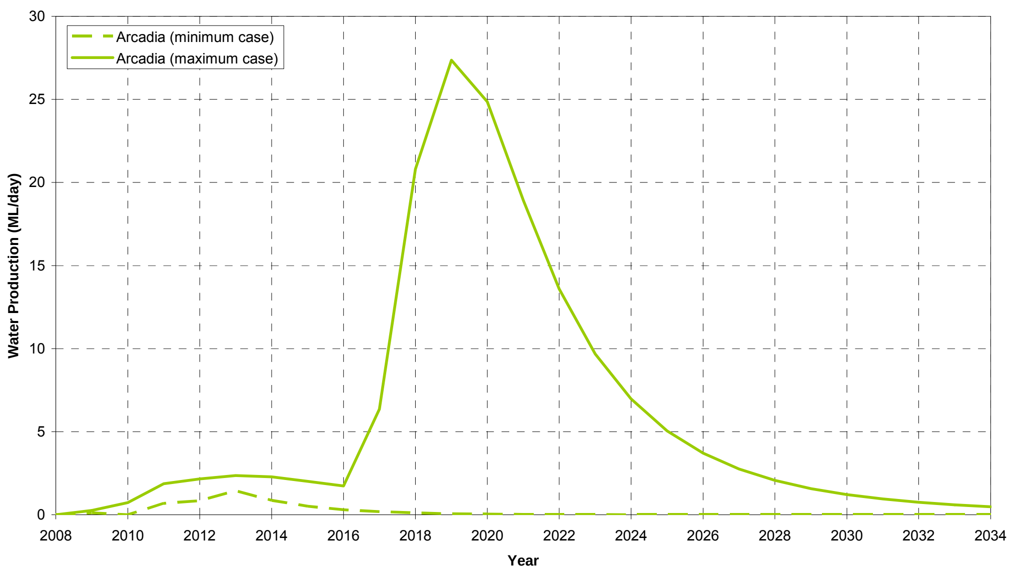
Boron concentrations are often well above the trigger value for the protection of aquatic ecosystems (trigger level of 0.37 mg/L) but almost always below 2 mg/L. As such, water is generally not suitable for discharge to surface waters (although there are wells which produce lower Boron concentrations that are below the trigger level). The water is suitable for stock watering (trigger level 5 mg/L), and raw water for drinking water supply (trigger level 4 mg/L). But concentrations regularly exceed that suitable for irrigation (trigger value 0.5 mg/L) and recreation (1 mg/L).

3.4.3 Arcadia Valley Water Production

Quantity Schedules

Associated water production for the maximum scenario from the Arcadia Valley field is expected to peak at around 27 Ml/d in 2020 and remain above 10 Ml/d for at least 5 years (see Figure 3-3) The upper bound estimate for the total volume of water produced over the lifetime of the field is 58,815 ML (approximately 59 GL). Peak water production at the Arcadia Valley field is likely to be 5 years later than peak production from Roma and Fairview, reflecting the later phasing of the field development. To date, there has been no sampling or testing of associated water quality within the Arcadia Valley field (currently no appraisal wells have been installed). However, from discussions with Santos water team personnel, water quality is expected to be similar or marginally worse compared with the Fairview field (i.e. TDS ranging between around 500 to 6,000mg/L, with an average concentration of around 1,600mg/L). The broad range of issues relating to water quality and potential management options discussed for Fairview (see Section 3.4.2) are therefore likely to be similar for Arcadia Valley.

Figure 3-3 Water Quantity Schedule for the Arcadia Valley Field

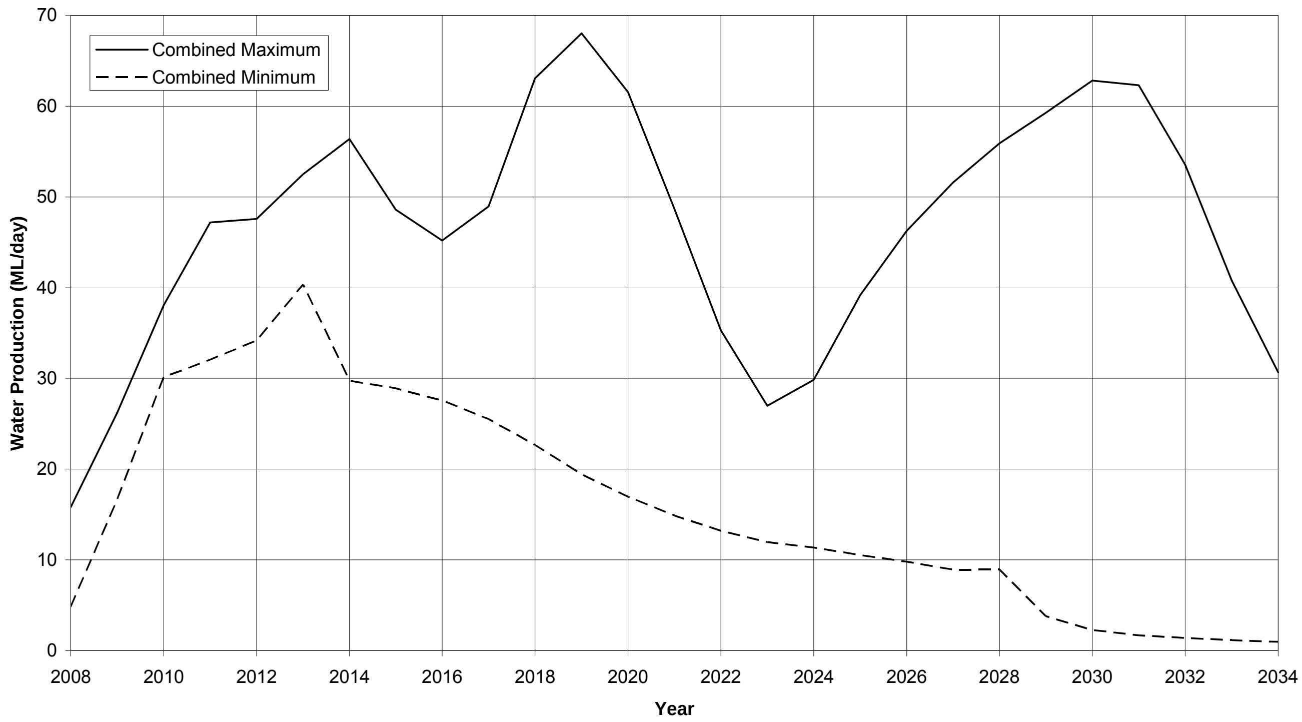


3.5 Summary

Across the entire CSG field study area there are expected to be up to 2,600 wells installed over the next 10-15 years, producing a vast quantity of associated water. The total volume of associated water is expected to range from 157 to 461 GL; with total peak production rates from 40 to 70 Ml/d. 70% of the total volume of water is expected to originate from the Fairview field, with Roma and Arcadia Valley contributing around 20% and 10%, respectively. In terms of water quality, the limited available monitoring data suggests that the key contaminants of concern for the likely re-use options are TDS, Fluoride and SAR (i.e. relative concentrations of sodium, calcium and magnesium). Concentrations of these contaminants are generally above trigger values for most beneficial re-use options. As such, it is likely that some form of treatment will be required for the majority of associated water, in the form of desalination (such as Reverse Osmosis) and dosing to reduce SAR.

It is clear that given the uncertainty over the expected water quantities and the limited knowledge of water quality from each field area, the water management strategy needs to be adaptive relative to actual production rates and qualities. A full description of the available management options is provided in Section 4.

Table 3-3 Minimum and Maximum Water Production Estimates for all Fields



Section 4 Water Management Options Review

4.1 Overview

This section provides an overview of current short term water management operations within the three CSG fields (Section 4.2), and introduces the key long term water management options available to Santos, with a review of their technical, environmental, social, economic and regulatory constraints and opportunities (see Sections 4.3 & 4.4).

4.2 Current Water Management Operations

4.2.1 Roma Field

During the appraisal stage, several water management dams with capacities of between 120 ML and 200 ML have been proposed to store associated water from pilot wells. Two of these have already been constructed at Coxon Creek and Hermitage, to the north east of Roma Township, and are currently being used to store associated water produced from the pilot wells. These are likely to form part of the overall infrastructure for the long term water management strategy described in Sections 5.3 to 5.5. A full description of the approach to the design, construction, operation and maintenance and rehabilitation of water management dams is provided in Appendix C.

4.2.2 Fairview Field

More than 110 wells have been drilled in the Fairview area. Of these, 70 wells are connected to the gas pipelines with the remainder undergoing dewatering operations and/or awaiting completion and connection. Approximately 50 of the 70 wells are producing associated water. At this point, around 4.5 ML/day of associated water is produced and either discharged to Hutton Creek, approximately 6km upstream from its confluence with the Dawson River or to the water gathering system for injection into the Timbury Hills formation via Fairview 77 and 82.

Since May 2007, Fairview Operations for Water Management has operated under an 'Interim Associated Water Management Policy'. This temporary policy has been put in place to allow the development of a long term strategy and for the time being involves discharge of untreated water to grade with careful monitoring of the impact on stream health. The longer term strategy is likely to consist of an extensive irrigation system, including elements of water treatment and injection of brine into underlying aquifers.

The current Fairview Environmental Management Plan (EMP), dated May 2008, relates to the existing CSG development and operations in Fairview. The EMP provides environmental management strategies and conditions for current and predicted activities in 2008. An amendment is currently being prepared to the 2008 EMP by URS for the 2009 operational year. All subsequent development will then be managed through the GLNG EIS project.

The Fairview EMP proposes a mixture of Category 1 and 2 waste water management solutions (see Section 1.5.2) reviewed within an adaptive management framework to account for government initiatives in regional water development and management, changing economics of gas and water markets and improvements in the science and understanding of the extraction and use of associated water.

The EMP details the following operational strategy within which the EPA objectives will be addressed:

Category 1 Options (Preferred):

- Construction of the Pony Hills Water Treatment Plant (WTP) which will discharge permeate (treated water) into the Dawson River (via Hutton Creek) (during 2009).
- A possible increase in the number of injection wells to receive brine reject from the Pony Hills WTP by 2009 (subject to engineering constraints and the findings from more detailed hydrogeological studies).
- Construction of an additional desalinisation plant and brine reject injection wells in 2009.
- Continued direct use of associated water for operational purposes such as dust suppression, hydro-testing, road and plant construction, stock watering and workforce accommodation water supply.
- Commencement of irrigation pilots pending the outcome of the Resource Utilisation Plan (RUP) application for beneficial use which is currently before the EPA (2009).
- Continued evaluation of beneficial reuse strategies.

Category 2 Options (Non-Preferred):

- An increase in the number of temporary water management dams to support pilot and appraisal wells (2008/9).
- Although discharge to grade will continue for a limited time no increases in volumes are predicted.

4.2.3 Arcadia Valley Field

The appraisal stage for the Arcadia Valley has not yet started and therefore at present there are no water management activities being undertaken. It is possible that desalination units (Reverse Osmosis) could be used and located to treat several clusters of wells. The treated water would then be preferentially used for local community benefit (e.g. stock watering, small scale irrigation and local farm uses). It may be necessary to construct temporary water management dams (<250ML capacity) to support pilot and appraisal wells (in accordance with the specification provided in Appendix C). Additional short term water management strategies will be investigated and researched, as the field develops.

4.3 Long Term Water Management Options Appraisal

A variety of options exist for the long term management of associated water throughout the CSG fields. These have been categorised as follows (broadly in order of preference as per the EPA's Operational Policy waste hierarchy):

- Municipal Use – including potable water supply, community uses (e.g. irrigation of sports fields/open spaces);
- Agricultural Use – including small to large scale irrigation schemes, stock watering, local farm uses;
- Industrial Use – coal mine/s, feedlots, cooling tower water;
- Injection – of associated water or brine stream (following treatment) into underground aquifers being either the aquifer from which the water was extracted or another formation with appropriate characteristics to receive the water;
- Water management dams – store and release, constructed wetlands, recreation; and
- Surface Discharge - to surface water systems either via direct discharge or via overland flow paths.

Section 4 Water Management Options Review

Different solutions (and levels of water treatment, principally to reduce TDS) will be appropriate for different areas depending on the quantity and quality of associated water, and the intended use. It is therefore likely that water management options will be site-specific and constrained by some or all of the following factors:

- Location of production area and proximity to communities, industries and agricultural lands;
- Confidence in the water production rates that can be guaranteed for beneficial use;
- Water quality;
- Environmental sensitivity of surroundings/receiving environment;
- Quantification of risks associated with various uses;
- Responsibility for costs for beneficial use schemes; and
- Regulatory guidance, in particular from the Queensland Environmental Protection Agency (EPA).

Sections 4.3.1 to 4.3.6 provide a detailed description of the available water management options, including a review of their general constraints and opportunities, and potential relevance to the Roma, Fairview and Arcadia CSG fields. Further reference can be made to Appendix B, which includes a full review of technical, environmental, social, economic and regulatory constraints and opportunities.

4.3.1 Municipal Use

This option involves use of associated water for potable and non-potable municipal uses such as:

- Potable water for drinking water supply;
- Non-potable water for irrigation and maintenance of community facilities (e.g. road works, sports facilities, recreational areas, parks and gardens).

In accordance with the *EPA Operational Policy*, these options are considered under the following categories:

- Category 1 (Preferred) – Treated Use; and
- Category 1 (Preferred) – Direct Use.

Key Constraints

- Distance to the nearest towns (demand areas) is a key factor. Distances beyond 50km are likely to render the option of municipal use uneconomic due to significant costs associated with constructing, operating and maintaining pumps and pipelines.
- Seasonal variability. Potable (and town) water demands and demand for irrigation water for the upkeep of community facilities is likely to vary significantly between wet and dry seasons, whilst water production rates will be constant. As such, the option of municipal use alone will not be sufficient to manage associated water.
- Water will only be available for the duration of the project, beyond which traditional (or other alternate) supplies will have to be made available. The relatively limited time period may preclude certain options on the basis of economics.

- The cost of treatment (desalination) by Reverse Osmosis or similar technology, to produce potable water, is significant. Added to this is the cost of managing the brine stream by injection or HDPE lined water management dams (evaporation ponds).
- The end-user cost of existing municipal water supplies (from freshwater aquifers) is therefore likely to be significantly less than associated water, which includes the additional cost of treatment and management of the resultant brine stream. As such, it is likely that Santos would have to heavily discount prices to remain competitive.
- If associated water is to be used directly for non-potable municipal uses then the water quality will be a key constraining factor. Water for such uses will generally be required to have a TDS of less than 1,000mg/L (see Table 1-1). On the basis of the existing knowledge of water quality, it is considered unlikely that there will be water of sufficient quality to undertake direct use (i.e. without treatment). If water is used directly with TDS above this then contamination of surface water, shallow groundwater and soil profiles could potentially occur.

Key Opportunities/Benefits

- Availability of associated water for potable and general municipal uses will reduce reliance on surface and ground water sources leading to better environmental outcomes (e.g. groundwater recharge and improved environmental flows).
- In water constrained areas such as south east Queensland, the availability of treated associated water will provide improved security of supply for the duration of the project and potentially beyond.
- Availability of additional water for general municipal uses could lead to improvements in recreational amenity (e.g. irrigation of sports fields) and biodiversity (e.g. creation of riparian 'green' corridors).

Relevance to CSG Fields

The most significant constraint listed above relates to the proximity of the CSG fields (or water production area) to communities of sufficient size to make such an option economically viable. The Roma CSG field has a number of local towns nearby, including Roma, Wallumbilla and Yuleba. Whilst these are relatively small, they do constitute a viable end user and therefore the option of providing water for municipal uses is most relevant in these locations (see Section 4.4.1 for more detail).

The Fairview CSG field is located at least 60km from the nearest communities of Injune, Roma and Taroom. As such, options for providing water for municipal uses are more difficult. Likewise, the Arcadia Valley is very sparsely populated and is located at least 60km from Rolleston to the north, and more than 150km from Blackwater and Emerald. As such, large scale municipal uses will not be viable, although small scale municipal uses could be provided as part of a broader water management scheme (see Section 4.4.3).

4.3.2 Agricultural Use

This option involves the use of associated water for agricultural uses such as:

- Irrigation of crops and tree plantations;
- Stock watering;
- Intensive arable production (e.g. to supply feedlots)

Section 4 Water Management Options Review

In accordance with the *EPA Operational Policy*, these options are considered under the following categories:

- Category 1 (Preferred) – Treated Use; and
- Category 1 (Preferred) – Direct Use.

Key Constraints

- Availability of suitable land for irrigation within reasonable proximity to the CSG field areas to make the schemes economically viable. For crop irrigation to be successful, suitable soils and topography (< 6 degree slope) are required.
- Willingness of local land holders to use treated or untreated associated water and ability of the Operator to guarantee water supplies during the course of the project.
- Sensitivity of receiving environment (surface water, shallow groundwater and soil profiles) to the application of untreated water for irrigation, which can lead to soil sodicity and adverse impacts on aquatic and terrestrial ecosystems (necessitating dosing of water). A key water quality constraint on untreated irrigation is the Sodium Adsorption Ratio (SAR) which is measure of the relative concentrations of sodium, calcium and magnesium.
- Ability to manage the significant seasonal variation in water demands via under-irrigation (and therefore maintenance of soil storage capacity) for trees, or temporary water management dams for crops.
- The limited duration of the CSG field development program and likely period of water production may render some irrigation options uneconomic.
- Commercial demand for crop or tree products will need to be sufficient to demonstrate cost effectiveness of the new irrigation schemes.
- Whilst cattle are tolerant of high TDS water (up to 4000mg/L), Fluoride levels significantly above 2mg/L may prevent the direct use of water for this purpose.
- Regulatory approval will be required from the EPA under the EP Act 1994. Also under the Water Act 2000, new irrigators will require a water licence (approved by the DNRW).

Key Opportunities/Benefits

- Improve supply of water to existing irrigation schemes and reduce the need for extractions from local surface water and ground water resources, thereby reducing drawdown on aquifers and improving the natural flow regimes of the creeks;
- Provide opportunities for local landholders to develop new or increase their crop production areas and yields, or grow other types of crops for a limited period.
- Add value to the local and regional economy via the marketing of sawn (millable) timber, wood products and wood waste for biofuel.
- Improve supplies of local food and fodder crops and reduce dependency on outside sources.

Relevance to CSG Fields

For the Fairview CSG field, Santos already owns freehold land of around 18,000ha within the Fairview and Springwater properties, of which approximately 3,437 ha is suitable for plantation establishment on plateau areas (at least 90m above the water table), and 1,555 ha is potentially suitable in the valley areas (land less than 4 degree slope and suitable soils). As such, large scale agricultural uses (i.e. irrigation) of associated water produced from the Fairview CSG field are considered viable.

Within the other two fields, Santos do not own any land for irrigation[2], and therefore it would be necessary to either purchase or lease suitable areas. A review of freehold and leasehold properties surrounding the CSG fields indicates that within the Arcadia Valley and on the outskirts of Roma there are many sizeable plots (in excess of 1,500 – 2,000 ha) which are currently being irrigated (crops and plantations). As such, large scale irrigation schemes are also considered potentially viable for these two areas.

The level of treatment required will vary depending on the location of the irrigation scheme and the sensitivity of the receiving environment.

During several community engagement workshops, agricultural use (particularly irrigation of crops, tree plantations and agroforestry systems) was highlighted as a priority and received general support from all stakeholders (see Section 4.4).

4.3.3 Industrial Use

This option involves use of associated water for other industries such as:

- Coal mine use (dust suppression & wash plant);
- Animal feeding operations (feedlots); and
- Cooling tower water (power stations and other industrial applications).

In accordance with the *EPA Operational Policy*, industrial uses of associated water are considered under the following categories:

- Category 1 (Preferred) – Direct Use; and
- Category 1 (Preferred) – Treated Use.

Key Constraints

- Proximity of CSG fields to suitable industrial end users with significant water needs. Large distances, requiring significant lengths of pipeline and expensive pump operations, could render the supply of associated water to many industrial users uneconomic, especially given the limited lifetime of the CSG field development.
- Given the inherent uncertainty over water production rates, there may be a problem with being able to guarantee water supplies. This guarantee would be necessary for all industrial end users.

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[2] Santos has purchased two properties in Roma but these are not for irrigation purposes.

- It is likely that water would need to be treated for most industrial uses. As such, there would be a need for expensive treatment facilities and a means of safely managing the brine stream via injection or lined water management dams (evaporation ponds).
- The cost of existing industrial water supplies is likely to be significantly less than associated water. As such, it is likely that Santos would have to discount prices to remain competitive.

Key Opportunities/Benefits

- Potential to provide additional water for dust suppression at industrial sites, thereby improving air quality, as well as water for materials handling, construction purposes and road maintenance.
- Potential to improve the water quality of industrial effluents through dilution with treated associated water.
- The availability of associated water as a water supply sources could reduce the reliance on existing surface and ground water supply sources, allowing recharge of aquifers and enhancing environmental flows in nearby watercourses.
- The availability of associated water could create opportunities for new industries, such as aquaculture.

Relevance to CSG Fields

Within and around Roma township there are a number of potential industrial users. As such, industrial uses of water from the Roma CSG field could be viable, subject to the constraints listed above (see Section 4.4.1). The Arcadia Valley CSG field is remote and the nearest potential industrial end users are located in Rolleston, around 60km north of the Arcadia Valley. As such, there are unlikely to be any viable industrial end uses. The same applies to the Fairview CSG Field which is located a significant distance away from potential industrial end users (e.g. Injune).

4.3.4 Injection

This option involves the injection of associated water into underground formations being either the aquifer from which the water was extracted or another formation with appropriate characteristics to receive the water. The ability to do this is dependent upon several variables, including the quality of water in the receiving formation, the quality of water being injected, the hydraulic conductivity of the target aquifer, the ultimate storage capacity of the receiving formation(s) and existing regulatory constraints.

Three options have been considered for injection and are as follows:

- Injection either directly back into the coal seam from which the gas has been extracted, or a hydraulically discontinuous non-producing seam above or below;
- Injection into a non-coal seam aquifer most commonly into formations or reservoirs below coal deposits (into basement); and
- Injection into a non-coal seam aquifer into aquifers overlying the coal seam

In accordance with the *EPA Operational Policy*, injection of associated water is considered under the following categories:

- Category 1 (Preferred) - Injection of associated water into an underground reservoir, or an aquifer of equal or lesser water quality, without intermediate surface storage; and

- Category 2 (Non-Preferred) - Injection after surface water storage (>24hrs) or injection of lesser water quality than the receiving aquifer.

A summary of the key constraints and opportunities relating to injection is provided below.

Key Constraints/Benefits

- Presence of suitable target formations within the CSG field areas - the intrinsic properties of the formation will determine the viability of injection including:
  1) formation hydraulic conductivity, which dictates the rate of fluid movement within the formation;
  2) storage capacity of the receiving formation; and
  3) the existing static pressure, which must be low enough to allow sufficient injection of the water to be economic.
- The water quality of the receiving formation will determine the level of treatment required prior to injection (currently, it is mandated by the EPA that injection must be into an aquifer of equal or lesser water quality for Category 1 use) and therefore the economic viability of the scheme.
- Injection is very expensive as a result of the need for pre-treatment, temporary surface storage in water management dams, as well as the process of injection itself (which is technically challenging) and is therefore likely to be uneconomic compared to other alternatives.
- Potential for communication with other formations (including potential contamination of water supply aquifers) is likely to be a risk and significant constraint to large scale injection schemes into overlying aquifers.
- Approval from the EPA under the EP Act 1994 and DNRW will require extensive hydrogeological/investigation as well as comprehensive ongoing monitoring and reporting.

Key Opportunities/Benefits

- Opportunity to eliminate the potentially detrimental impacts relating to surface treatment, disposal or reuse alternatives, although if pre-treatment (desalination) is required there will be a requirement to manage the resultant brine stream.
- Potential to recharge freshwater aquifers if treated to a high standard prior to injection, and improve the reliability of existing groundwater supplies to communities.

Relevance to CSG Fields

A technical report has been developed (see Appendix P2 of this EIS) which specifically investigates and reports on the potential for localised and regional drawdown as a result of GLNG project CSG field development activities, as well as the constraints and opportunities for injection across the Roma and Fairview CSG fields (there is insufficient information for the Arcadia Valley region at present). A summary of the key findings in relation to injection potential is provided below.

Injection into overlying aquifers

With respect to the Fairview field, the opportunity to inject associated water (treated) into overlying aquifers (Precipice sandstone) has not yet been assessed and will require additional investigation and studies (see Section 5.6).

The Mooga and Gubberamunda Sandstone Aquifers overlie the Roma field. These aquifers are used extensively for stock, domestic and feedlot purposes. They also provide significant urban water supplies for surrounding towns including Roma, Wallumbilla and Yuleba. To mitigate the background of high historical depletion within the Gubberamunda Sandstone, treated associated water from the Roma field could be injected into the aquifer. Further investigation will be required though to determine the viability of this option.

Injection into CSG aquifers

In theory, injection of associated water back into coal seams within the CSG field study area could mitigate many of the adverse impacts relating to its management at the surface. However, the associated water would need to be stored above-ground in water management dams for a significant period of time to allow complete CSG extraction. This would be uneconomic and against current regulatory guidance (the option of long term storage/evaporation of associated water is a Category 2 option).

Injection into underlying aquifers

Within the Fairview field, there are currently two active injection wells known as Fairview 77 and 82. These have a combined capacity of approximately 2.4Ml/d and inject into the Timbury Hills formation (an underlying aquifer). Whilst there may be some additional opportunities for injection into Timbury Hills formation, at present there is insufficient hydrogeological information (from monitoring or modelling) to determine this. Irrespective, it is unlikely that injection will be sustainable for the disposal of all of the associated water both from a technical and economic perspective.

These deeper fractured rock formations are likely to have lower transmissivities than the coal seams and the transmissivity will decrease with depth as the fractures become tighter. It is also unlikely that the fractures in these deeper formations will have sufficient storage volume to be able to accept the large volumes required. Using injection wells to manage the smaller volumes of brine stream following RO treatment, however, may be viable, although dilution of the brine stream may be required to meet the water quality characteristics of the receiving formation.

As a result of depressurisation of the Walloon Coal Measures at Roma, there is a potential for inter-aquifer transfer from the Hutton Sandstone to the overlying Walloon Coal Measures. The rate of such transfer will only be able to be ascertained after several years of appropriate ground water monitoring, including water pressure and quality parameters. Injection of associated water or brine stream may be a viable option depending on the results from these monitoring programmes as well as more detailed desk top reviews and hydrogeological modelling.

At present, there is insufficient hydrogeological information to determine the viability of injection (above, below or within the coal seam) within the Arcadia Valley CSG field.

4.3.5 Storage

This option involves construction of water management dams (by excavation or dam structures) as a method of disposal or for beneficial reuse of associated water. Four options have been considered for the surface storage of associated water:

- Water management dams for management of associated water or containment of the brine stream (following treatment);
- Permeate water management dams (store and release for agricultural reuse, injection or discharge to grade);
- Constructed wetlands (to provide environmental enhancement and a water quality treatment train); and
- Recreational lakes for community use (boating, camping, fishing etc.).

In accordance with the *EPA Operational Policy*, the construction of surface storages is considered under the following categories:

- Category 1 (Preferred) – Direct Use (for augmentation of water management dams);
- Category 1 (Preferred) – Treated Use (including storage of water in dams prior to treatment and the disposal of brine (treatment by-product) via evaporation ponds); and
- Category 2 (Non-Preferred) – Disposal via evaporation ponds.

A summary of the key constraints and opportunities relating to storage is provided below.

Key Constraints

- The environmental values of the surrounding area will typically pose the main constraint to the construction of water management dams. These include:
  1) soils and geology;
  2) groundwater and surface water resources;
  3) flora and fauna; and
  4) human habitation and property.
- Areas of suitable land are required which are ideally situated above the 1 in 100 year ARI flood level of nearby watercourses, to avoid the potential for erosion to the base of the dam structure (threatening overall dam stability).
- Depth to groundwater and underlying soil permeability will determine the potential for contamination of soil profiles and shallow groundwater resources as a result of long term seepage through the base of the dam. Clay and HDPE liners will restrict seepage to very low levels, control seepage but not eliminate it[3].

[3] Santos have committed to lining all water management dams with compacted clay liners and HDPE in line with best practice and latest policy.

- Depending on the interest of landholders in retaining the dams, decommissioning of water management dams may be required at the end of the CSG field life. This would involve significant earthworks and revegetation measures to restore the land to a 'natural' state.
- Large scale water management dams could potentially lead to property devaluation and potentially limit future use of the land, following decommissioning (Santos proposes that dams will be limited to 250ML or less).
- Nearby communities are likely to oppose the construction of large scale water management dams, and in particular large scale evaporation ponds given the potential for environmental harm (which includes air pollution).
- Regulatory approval will be required from the EPA to construct the water management dams. These dams may be considered 'Regulated Dams' depending on the height of the dam wall, likely contaminant concentrations and potential for harm or loss of environmental values in the event of an uncontrolled discharge or catastrophic failure of the dam embankment.

Key Opportunities/Benefits

- Improve recreational amenity (such as fishing, swimming, boating and camping).
- Improve environmental flows in the case of store and release schemes.
- Enhance the environment and provide wetland habitat for water birds.
- Supplement existing and expand stock watering capabilities.
- Expand grazing and pasture lands through irrigation.

Relevance to CSG Fields

Water management dams (for temporary surface storage) will likely be required in all three CSG fields to support the overall long term water management strategy, and whilst the constraints listed above will limit the number and area of suitable sites, there is likely to be sufficient space available. Water management dams (up to 1,000 Ml in capacity for example) will be required as part of any scheme involving significant volumes of treatment, irrigation or evaporation (of brine stream). A detailed description of Santos' approach to the construction, operation and maintenance, and decommissioning of water management dams is provided in Appendix C.

Associated water will not be managed (disposed of) by evaporation ponds. However, it could be viable (and necessary) to manage the brine stream (following treatment) within brine containment ponds, especially given the likely constraints to injection within all three CSG fields. Depending on the outcome of more detailed studies, the brine contained within the ponds may be i) injected into suitable formations, ii) crystallised and either encapsulated or transferred to a suitable landfill site and/or iii) naturally evaporated. This option would still be classified as a Category 1 option by the EPA, and would be subject to a full assessment and appropriate design requiring regulatory approval. In addition, the disposal of brine in lined evaporation ponds is considered an acceptable solution under the recent DIP water policy (see Section 1.5.4).

4.3.6 Surface Discharge

Overview

This option involves discharge of associated water to surface water systems via either of the following methods:

1) Direct discharge of treated or untreated associated water to grade by overland or subsurface flow; and

2) Discharge of treated or untreated associated water to surface water via a pipeline or open drain.

In accordance with the *EPA Operational Policy*, discharge of untreated associated water to surface water systems is a Category 2 (non-preferred) option – disposal via discharge to surface waters.

A summary of the key constraints and opportunities relating to surface discharge is provided below.

Key Constraints

- The range of water quality parameters that exceed recommended trigger levels for the protection of aquatic ecosystems and the potential for dilution of this water quality in-stream are key factors governing the viability of this option. In general, the ability to discharge untreated associated water to streams while protecting aquatic ecosystems is significantly constrained unless significant dilution occurs.
- Discharge to ephemeral streams, in particular, will be significantly constrained by regulatory agencies as a result of the potential for significantly altering the flow, salinity and temperature regimes of the receiving watercourses.
- The quantity of water that can be managed by surface discharge will depend on the existing character of the surface water system (ephemeral, intermittent or perennial) and sensitivity of the receiving environment and biota.
- Significant lengths of pipeline (and associated pumps) may be required to enable discharge to appropriate locations (where there are more consistent flows). This can result in this option being very expensive.
- Treatment is likely to be required to match background water quality, and water storage (store and release) dams may be required to help mimic natural flows and reduce the high (up to 40^0C) temperature of associated water to ambient levels (typically between 22^0C to 28^0C, in the Fairview field region).
- There is likely to be community opposition to large scale discharge, as this would likely be considered a 'loss' of valuable resource that could be used for local community benefit.
- Regulatory approval will only be provided once it has been proven there are no negative impacts and all other associated water management options have been exhaustively examined (since this is a Category 2 option, and therefore should only be a temporary measure).

Key Opportunities/Benefits

- Opportunity to increase environmental flows and support aquatic and riparian ecosystems;
- Improve supply of water (reliability and volume) to downstream users – municipal, industrial and agricultural uses.
- Opportunity to use surface watercourses to transport water to beneficial uses downstream (e.g. transport of water to the Wandoan coal project via the Dawson River).

Relevance to CSG Fields

The discharge of associated water to surface streams is considered in detail in the technical report entitled, '*GLNG Gas Field Development -Associated Water Discharge Study*', which is included in the GLNG EIS (refer Appendix Q of the EIS). The focus of the report is on discharge to grade and the potential for adaptive water management to minimise any risks associated with this management option. Potential hazards identified include water quality, changes in habitat availability or biological triggers related to increased water flows, erosion, weed growth and aquifer contamination.

Since many of the streams in the CSG field study area are ephemeral, discharge (especially during the dry season) is likely to be limited by the EPA to areas where the discharge does not significantly alter the in-stream environment.

Recent data on the quality of associated water from the Fairview and Roma fields shows that associated water from most wells will not meet trigger levels for the protection of aquatic ecosystems without significant dilution in stream. While discharge to grade may be an option for some wells, it is clear that the majority of associated water will require treatment before discharge to ephemeral stream systems. This is also likely to be the case for the Arcadia Valley field.

In the Fairview field, the Dawson River downstream of Dawson's Bend is an exception as it has been found that this section of river is perennial, as it is maintained by significant spring flows arising from the river bed and adjacent to the stream. However, the assimilative capacity of the Dawson River is also limited in the dry season. In order to maintain the Dawson River within the trigger value for TDS, any future development of the Fairview field will require associated water to be treated to appropriate standards.

Even if treated, associated water discharges to ephemeral streams will be controversial from an environmental and social perspective. It is therefore recognised that there are likely to be more readily acceptable local alternatives for the water use, although a risk based approach to discharge to surface waters may be required as a backup or short term contingency option for all CSG fields.

4.4 Community Engagement - Beneficial End Users

Following the review of various water management constraints and opportunities, and their relevance to the three CSG fields (in Section 4.3), local communities were engaged to identify local water needs and establish priorities. The underlying aim of the long term associated water management strategy is to maximise opportunities for local community use of associated water and, where ever possible, add value to the local environment and economy (see Section 1.4). As such, this first step, and the ongoing process of community engagement throughout the duration of the CSG field development program is considered fundamental to achieving the objective.

4.4.1 Roma and Wallumbilla Communities

Roma Town Water Opportunity Workshops

Santos recently engaged key stakeholders, during 2 workshops held in Roma on 2 &16 September 2008, to identify and evaluate a range of potential water uses within Roma Township and the surrounding area. These workshops involved representatives from Roma Regional Council, Queensland Murray-Darling Commission, AgForce Queensland, Commerce Roma, Uniting Church, as well as selected individual local landowners. The main objectives of the workshops were to:

- listen to and work with a representative cross-section of the community to understand their expectations and potential water needs,
- explore and identify opportunities and mechanisms for providing water to the community (in line with best practice and current legislative guidance); and
- provide the community with a central contact for all issues relating to associated water.

The broad agendas and main outcomes of the workshops were as follows:

Workshop 1 – The main objective was to identify beneficial water use opportunities and consider how they could be implemented and potential barriers to implementation as well as identify key environmental, social, economic and technical issues, and discuss how they could be addressed. A total of 29 options were identified and discussed, including a brief review of their pros and cons. Following the workshop, URS water engineers reviewed the options and undertook a high level risk assessment to determine their feasibility.

Workshop 2 – The main objective was to undertake a screening exercise on the options identified in the first workshop (on the basis of the feasibility assessment) to rationalise the list and determine the preferred options in order of priority. The following beneficial end uses (considered high priority) were identified as potentially viable from a technical, social, economic and environmental perspective. These are considered in more detail in Section 5.3.

1) Provide potable water to Roma Township.
2) Provide treated water for local municipal and industrial uses (feedlots, saleyards, truck washdowns and Council road works).
3) Augment water levels within Lake Campbell (using treated water) to allow recreation and fishing, with opportunistic release to Bungil Creek during the wet season (and eventual supply to Surat Weir).
4) Provide water for the irrigation of existing crops.
5) Provide water to establish new Agroforestry projects.

Wallumbilla Town Water Opportunity Workshop

A water opportunity workshop was also held in Wallumbilla with local community representatives on the 18 October 2008 to identify possible water demands in Wallumbilla and Yuleba townships, which are located off the Warrego Highway approximately 40-60km east of Roma township. The following options were identified and are considered in more detail in Section 5.3:

1) Provide potable water for Wallumbilla Township.
2) Provide water for irrigating local food crops (melons, grapes, vegetables).
3) Supply water to local industry (fertilizer plant and sand washing facility) and a newly proposed feedlot.
4) Discharge to Wallumbilla and Yuleba Creeks.

4.4.2 Fairview Community

There is good potential that all water produced from the Fairview field could be managed within the land already owned by Santos, or land immediately adjacent. This would likely be achieved by irrigation of crops and tree plantations (see Section 5.4). The process of engaging the local community has been ongoing since Santos purchased the Fairview CSG field and there are already established uses of associated water for stock watering. Whilst this only constitutes a small proportion of the expected volume, Santos will endeavour to continue the supply for local small scale farm uses, subject to regulatory approval.

4.4.3 Arcadia Valley Community

Santos recently engaged local landholders, via a survey, to identify a range of potential water uses within the Arcadia Valley and surrounding area. The following options were identified:

1) Irrigate existing and new Chinchilla White Gum plantations.
2) Irrigate existing and new Leucaena and Cereal crops.
3) Discharge to surface waters and augmentation of Lake Nuga Nuga for environmental and recreational uses.
4) Provide water for stock watering.
5) Develop new aquaculture schemes.
6) Supply water for road works.

Of these, the first 3 are considered potentially feasible, and have been adopted as preferred options for long term water management (see Section 5.5). Whilst opportunities such as providing water for road works, stock watering and new aquaculture schemes could be pursued, they are unlikely to have a combined demand of more than 1Ml/d and would therefore only be a small component of the overall long term associated water management. The distance and limited size of the nearest communities (Rolleston to the north and Injune to the south west) preclude opportunities for large scale municipal and industrial re-use options, as for Roma. These options are considered in more detail in Section 5.4.

4.5 Summary

Table 4-1 summarises the constraints to the water management options in each CSG field on the basis of the information provided in Section 4.3. The constraints relate to the following:

- Location of production area and proximity to communities, industries and agricultural lands;
- Confidence in the water extraction rates that can be guaranteed for the intended use;
- Water quality;
- Environmental sensitivity of surroundings/receiving environment;
- Quantification of risks associated with various uses;
- Responsibility for capital costs for beneficial use schemes; and,
- Regulatory guidance, in particular from the Queensland Environmental Protection Agency (EPA).

It is clear that the least constrained area is the Roma field as a result of its proximity to sizeable communities with a demonstrated need for additional water to support existing potable, municipal, industrial and agricultural supplies, and interest in exploring added value uses of water, thereby contributing to the local economy.

The Fairview field is constrained largely by the absence of any nearby end users which renders all municipal and industrial uses uneconomic. However, on the plus side is the significant area of freehold land owned by Santos, which is potentially suitable for large scale irrigation schemes, and the potential to use the Dawson River to transport water to downstream users. Coupled with this is the availability of existing injection well infrastructure, which can be used to manage the resultant brine stream.

It is likely that treatment would be required for the majority of associated water from the Arcadia Valley and Fairview CSG fields, given the sensitivity of the receiving environment and options for beneficial re-use. Given the likely constraints to injection it is highly likely that evaporation ponds would be required to store and dispose of the resultant brine stream.

The most constrained area, from a water management perspective, is the Arcadia Valley field. This is due to the lack of any significant municipal or industrial water demand, as well as the general lack of knowledge regarding the quality of associated water and hydrogeology (as yet no appraisal wells have been developed).

Section 4 Water Management Options Review

Table 4-1 Water Management Options Constraints Summary

Water Management Option	CSG Field		
	Roma	Fairview	Arcadia
Potable Use	Green	Red	Red
Other Municipal Uses	Green	Red	Red
Agricultural Use	Green	Green	Green
Industrial Use	Green	Red	Red
Injection into overlying aquifers – Brine Stream	Red	Red	Red
Injection into overlying aquifers – Associated Water	Red	Amber	Red
Injection into CSG aquifers	Red	Red	Red
Injection into underlying aquifers – Brine Stream	Red	Green	Red
Injection into underlying aquifers - Associated Water	Red	Red	Red
Storage Dams - Large Scale (>250ML)	Red	Red	Red
Storage Dams - Small Scale (<250ML)	Green	Green	Green
Large Scale Evaporation Ponds for Associated Water	Red	Red	Red
Evaporation Ponds for Managing Brine Stream	Amber	Amber	Amber
Treated Discharge to Surface Water	Amber	Amber	Amber
Untreated Discharge to Surface Water	Red	Red	Red

Key to Constraint Levels: (**Green** – Low, **Amber** – Medium, **Red** – High)

Water Management Strategy — Section 5

5.1 Overview

At present, the field development plans and predictions of water quantity and water quality schedules are being updated on a regular basis, as information from the appraisal stage is fed into the overall GLNG planning process. As such, the water management strategy presented here is at the Concept Evaluation Stage (Stage 1). This has involved a high level review of all potential water management options and an assessment of their constraints and opportunities across the CSG field study area, as outlined in Section 4. The remainder of this section describes the development and application of a risk assessment tool to support the Concept Evaluation process (Section 5.2) and an overview for each CSG field of the preferred water management strategy, including a review of the potential impacts and mitigation measures, and environmental benefits.

Following this initial stage, there will be a number of subsequent phases, ultimately leading to strategy implementation. The stages are summarised below:

- Stage 1 - Concept Evaluation
- Stage 2 - Concept Selection
- Stage 3 - Detailed Appraisal and Outline Design
- Stage 4 - Detailed Design & Approvals
- Stage 5 - Implementation

The process above is iterative and will be rolled out progressively in accordance with the development of each CSG field. At this stage, therefore, it is not possible to assign specific timeframes. However, once the concept water management strategies have been selected (Stage 2), a programme will be developed and linked to the field development plan.

A key underlying theme of the strategy selection and implementation process is the need for continual review and improvement. Recommendations for this are provided in Section 5.7.

5.2 Risk Assessment Tool

5.2.1 Background

Management of associated water in the gas field area will be complex and the potential water management options vary substantially, depending on location, water volume availability, water volume constraints, regulator preferences, community perceptions, economic costs and timing.

Santos has indicated that it wants to progressively evaluate and select associated water management methods that are most appropriate and reasonably consider the above variables. A risk-based screening method for selecting future preferred scenarios for the management of associated water has been developed for this purpose. The methodology developed can be constantly updated and adapted as new information becomes available. Using this tool, Santos has a process for rationally comparing and identifying management methods on the basis of risk to the wider environment (including social, environmental, economic, technical and regulatory considerations).

A brief overview of the risk assessment tool is provided below (refer to Appendix D for a full report on the risk assessment process and findings).

5.2.2 Risk Identification and Quantification

A workshop was held on Wednesday 23rd July and attended by a range of subject matter specialists to identify key risk issues and their likelihoods and consequences, for a range of water management methods (as listed in Section 4.3). This information was used to develop 'risk profiles' for each management method in each CSG field.

5.2.3 Baseline Risk Summary

The risk profiles for Roma, Fairview and Arcadia Valley (Figures 5-1 to 5-3) show the risk in relation to the effect of the water management methods on public health and safety, economics, social, environmental and property/ infrastructure.

The risk profiles in Figures 5-1 to 5-3 show the risk quotient for each management method, which is indicated by the height of the vertical bars on the graph. The risk quotient is a simple multiplication of likelihood and consequence. The colours within the bars represent the proportion of risk contribution from each of the five consequence categories (Property and Infrastructure, Environment, Social, Economic and Public Health and Safety). The 'Risk Target' (red line) represents a notional threshold of acceptability at a risk quotient of 10. This target is consistent with the risk target used in the overall GLNG project hazard and risk assessment. The risk target level of 10 was used because any event with a risk quotient greater than 10 was considered to be high risk. Refer to Appendix D for a full description of the risk scoring system.

Using the baseline risk profiles, Santos can identify the lowest risk scenario in relation to effects on public health and safety, economics, social, environment and infrastructure and property. The risk profiles show the risk after the implementation of generic risk mitigation measures identified by Santos. Mitigation measures include the following:

- Instrumentation and monitoring of associated water; surface water and groundwater;
- Identification and purchase of suitable (location, physical, etc) land;
- Development of a local employment plan, public awareness program and effective regulator engagement;
- Comprehensive investigation into injection and modelling of reservoirs; and
- Engineering design to minimise the likelihood and consequence of discharge to the receiving surface water and groundwater environments.

It is assumed that these mitigation measures will be incorporated into the GLNG project to reduce the level of risk to as low as reasonably practicable. Specific potential impacts and mitigation measures are described in Sections 5.3 to 5.5 for the preferred water management strategies.

The Roma, Fairview and Arcadia Valley baseline risk profiles (Figure 5-1, 5-2 and 5-3) indicate that, by and large, the lower risk management options are in accordance with the EPA hierarchy of preferred options. Across all of the management methods it can be seen that the majority of the risk is posed to environmental assets (green) and social assets (yellow). Economic and public health and safety assets face a minor amount of risk and only one management method poses a risk to property and infrastructure assets.

All of the risks for the three CSG fields are either below or within an order of magnitude above the risk target. Considering the order of magnitude "accuracy" of the assessment results, the levels of risk posed by the management methods are not significantly above the risk target and therefore it is reasonable to assume that none of the management options pose an inherently unacceptable level of risk.

Figure 5-1 Roma - Baseline Risk Profile

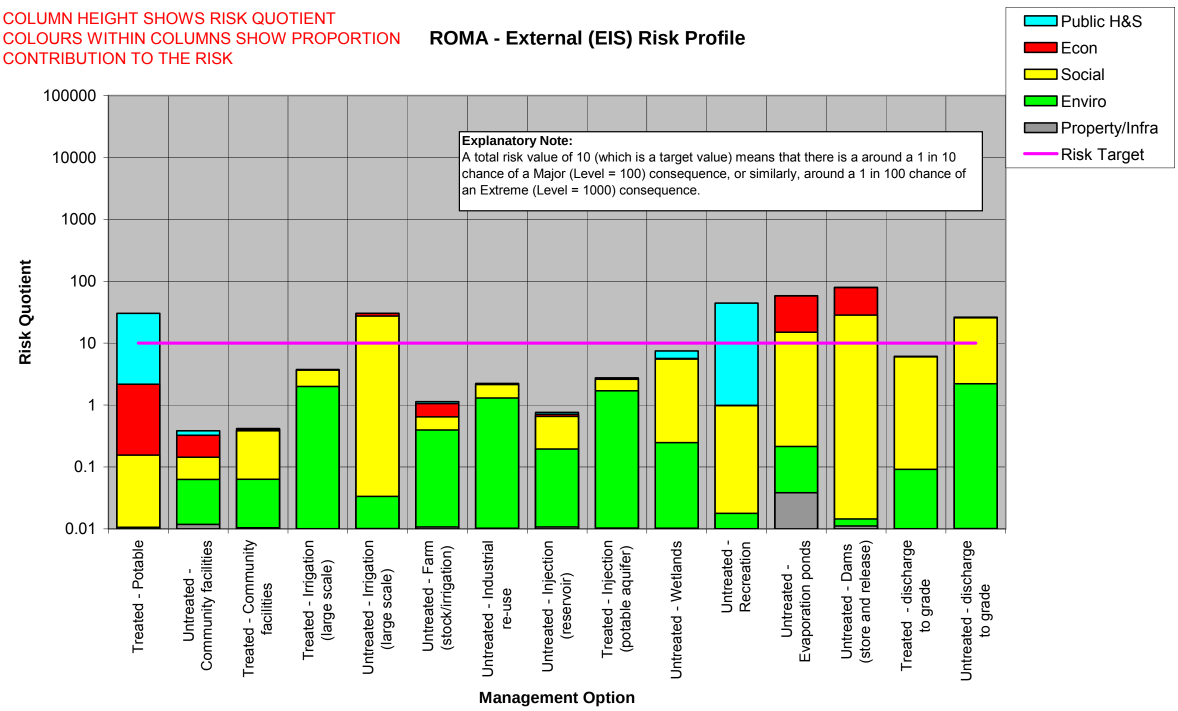


Figure 5-2 Fairview - Baseline Risk Profile

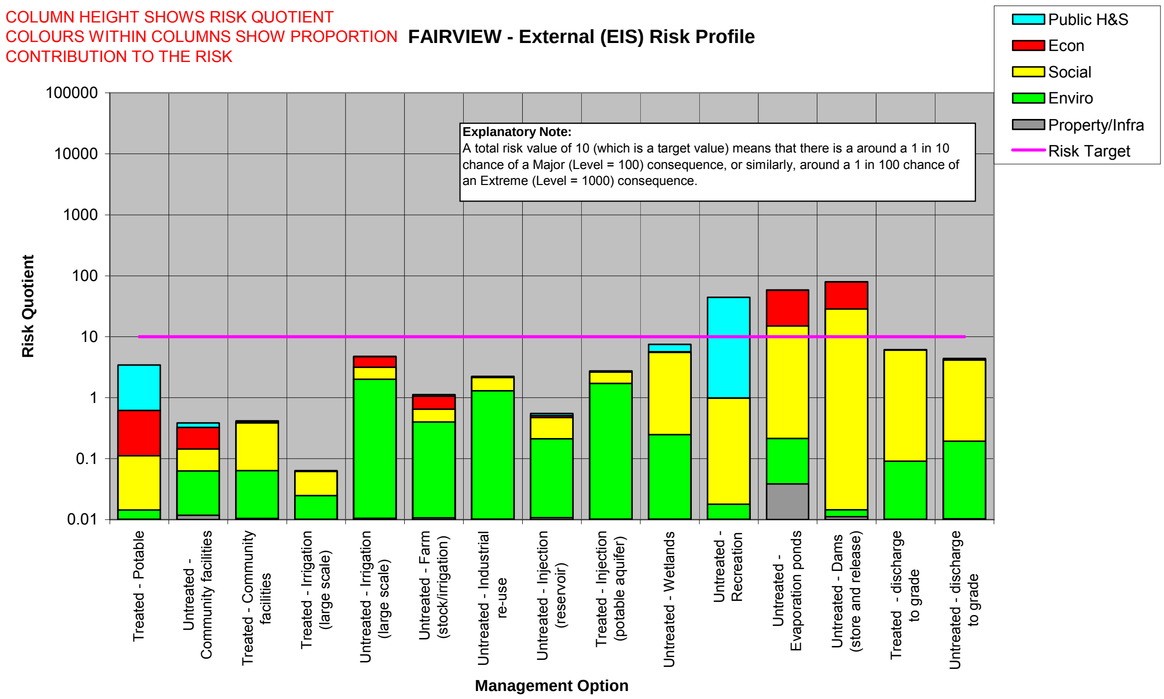
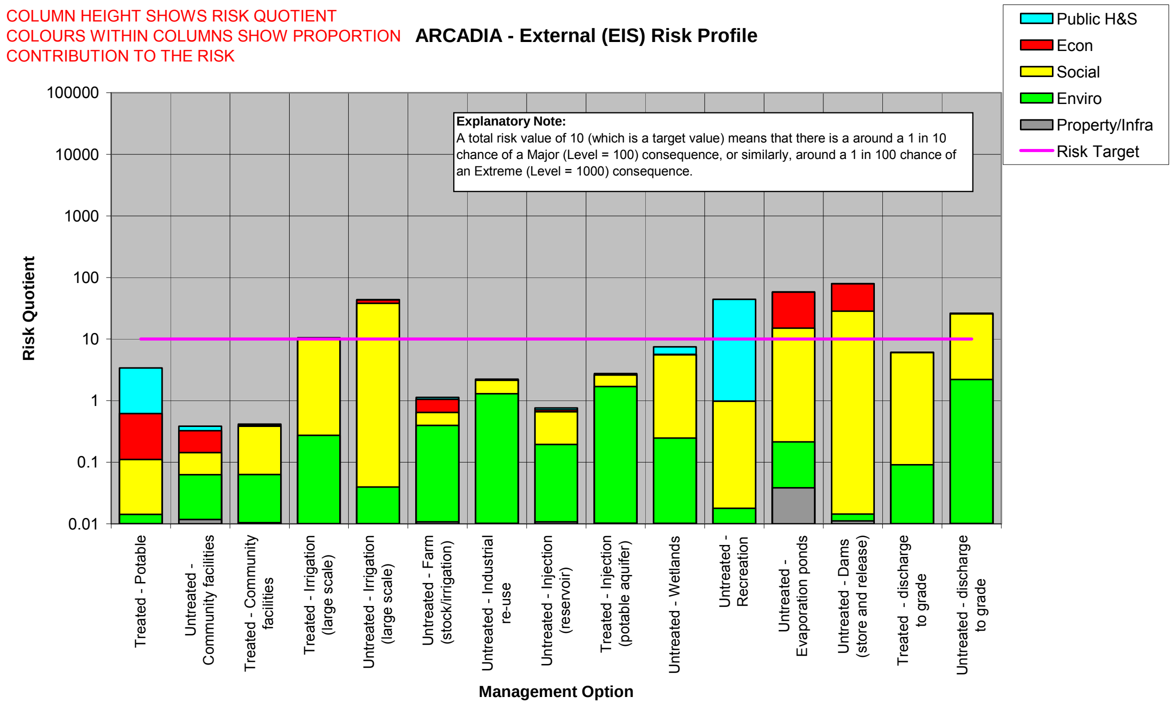


Figure 5-3 Arcadia Valley - Baseline Risk Profile



5.2.4 Preferred Scenario Selection

A spreadsheet options selection model (WATERMAN) has been specifically developed by URS to help Santos use a risk-based approach to compare and select preferred associated water management scenarios for each CSG field. For any combination of associated water management methods, WATERMAN applies the baseline risk profiles, adjusts for planned volume of water usage (which is constrained by the available demand) and shows the relevant risk profile.

Santos has used WATERMAN to select a preferred scenario for each of the CSG fields and in addition, has selected either one or two possible alternatives. These are described in Sections 5.3, 5.4 and 5.5, along with an overview of the specific strategies. The selection of preferred scenarios is considered appropriate for the current understanding of the project; however the most suitable scenario may differ depending on changes to the CSG field design and as knowledge of the CSG field footprint becomes more refined.

The WATERMAN model that was used to select the preferred scenarios incorporates other constraining factors in the management of associated water, including risk to the wider environment, practicality, cost effectiveness and site specific constraints such as the water disposal capacity (i.e. demand) of a particular management option, as summarised in Section 4.5.

A description of each preferred scenario (i.e. initial associated water management strategy) is presented in Sections 5.3 to 5.5, along with potential impacts and proposed mitigation measures.

5.3 Roma Water Strategy

The Roma CSG field initial associated water management strategy consists of several components (identified from the community engagement process – refer to Section 4.4.1):

- Roma, Wallumbilla and Yuleba Township Beneficial Uses;
- Lake Campbell and Opportunistic Release to Bungil Creek;
- Irrigation of Existing or New Crops; and
- Irrigation of New Agroforestry Initiatives.

5.3.1 Strategy Description

Roma Town Beneficial Uses

The current population of Roma Township is approximately 6,800. This is unlikely to change significantly over the next 20 years, according to the Queensland Government Department of Infrastructure and Planning. The town's drinking and municipal water supply is currently provided by a network of 12 groundwater bores. Of the 12 bores used, 7 pump directly into the distribution network without treatment. The bore pumps run continuously during peak demand (summer) and there is very little spare capacity in the system. Approximately 3 Ml/d of wastewater is produced by the town which is all treated and used to irrigate the golf course and local Lucerne crops.

The water demand in Roma varies significantly depending on the season. Peak demand during summer is in the order of 14Ml/d. This reduces to just 2Ml/d during the winter. Such significant variance presents a challenge in terms of providing water for potable use. The Council currently distributes 40% of its water to residential/commercial users and 60% to public spaces in the summer (this is seasonal and reverses in winter).

Additional uses for the water include other council uses (such as road works), existing and planned feedlots (10,000 Standard Cattle Units are planned for a new feedlot in Roma), an existing truck washdown facility, an existing saleyard, and existing and a new industrial subdivision. A summary of water demands is provided in Table 5-1, along with the key water quality criteria. All uses will require some degree of desalination to reduce the TDS to acceptable levels.

Table 5-1 Summary of Roma Town Municipal and Industrial Water Demands

Beneficial Use Option	Summer Demand (Ml/d)	Winter Demand (Ml/d)	Average Demand (Ml/d)	Water Quality Criteria
Potable Water Supply	14	2	8	TDS<500mg/L, Fl<1.5mg/L
Council Uses	0.5	0.5	0.5	TDS<1,000mg/L
Truck Washdown Facility	0.1	0.1	0.1	TDS<1,000mg/L
Saleyard	0.2	0.2	0.2	TDS<1,000mg/L
Feedlots	1	1	1	TDS<4,000mg/L, Fl<2mg/L
Industrial Areas	0.2	0.2	0.2	TDS<1,000mg/L
TOTAL	16	4	10	

The basis for this option would involve the construction of a water gathering network (assuming a total of 100km in length for costing purposes) and main water pipeline and pumps (20km in length) to transport water from the CSG field to the eastern outskirts of Roma.

Reverse Osmosis (RO) plants with a peak treatment capacity of up to 20Ml/d would be constructed at locations convenient to the water supply and overall field layout. It is likely that the RO plants would be located close to a compressor station (or power station) to reduce pumping costs, limit the environmental impacts of brine reject on the receiving environment, reduce noise, offer opportunities for waste heat recycling and provide opportunities for other users who are located out of town.

It is proposed that all raw water is treated to potable water standard for a range of high value uses (TDS = 500mg/L), which could also include irrigation and discharge to grade (see Sections 3 to 6). The existing groundwater bores which feed the network would likely be put on standby duty until such a time that CSG water supply is no longer sustainable or potentially adapted to inject water of suitable quality into receiving formations.

The base case for brine management is to construct compacted clay and HDPE lined water management ponds to contain the brine, which will be located next to each RO plant. Depending on the outcome of more detailed studies, the brine may be i) injected into suitable formations (Precipice and Showground formations), ii) crystallised and either encapsulated or transferred to a suitable landfill and/or iii) naturally evaporated.

In summary, the option of providing potable quality water to the town of Roma for a variety of municipal and industrial uses, could use between 20% and 80% of the peak associated water volume, depending on the season. The significant seasonal variation means that additional water management options are likely to be required, particularly for the winter months during which there would be an excess of water.

Wallumbilla and Yuleba Township Uses

Wallumbilla and Yuleba townships have populations of around 300 and 200, respectively. These have declined over recent years and it is unlikely that they will increase over the duration of the CSG field development program. There are several possible beneficial end users within the regions surrounding the towns, including local industry and small scale agriculture. A summary of potential demands is provided in Table 5-2.

Table 5-2 Summary of Roma Town Municipal and Industrial Water Demands

Beneficial Use Option	Average Demand (Ml/d)
Potable Water Supply	0.25
Proposed New Feedlot	1
Food Crop Irrigation	0.5
Supply to Local Industry	0.25
TOTAL	2

The maximum demand from this area is in the order of 2Ml/d. It is likely that all stated uses would require treated water with a TDS of less than 500mg/L, to avoid contamination of the environment and meet water quality standards for the stated uses. To service this need, water could be treated at a local RO plant and piped to the town for appropriate re-use. The reject brine stream would be stored in an HDPE brine containment pond, located nearby the RO plant and possibly injected into a suitable formation, depending on the outcome of more detailed studies which are currently on-going).

One of the options identified at the water opportunity workshop was to discharge associated water to the Wallumbilla and Yuleba Creeks. Hydrological modelling of various treated and untreated discharge to stream scenarios shows that even minor discharges of untreated water would result in a significant increase in in-stream salinity. The streams are ephemeral and are characterised by high water quality with background average TDS concentrations in the order of 220mg/L (and a maximum TDS concentration of approximately 270mg/L). Assuming that around 2Ml/d is discharged to the Wallumbilla or Yuleba Creeks, the TDS would likely increase to an average of 2100mg/L. This is primarily due to the high TDS of untreated water compounded by the low base flows and ephemeral flow regimes (with significant periods of no flow). Whilst treated discharge to grade would negate the impact on the salinity regime, there would be a significant alteration to flow and temperature regimes. If a small volume of discharge to grade were considered necessary then these impacts could be mitigated by adopting the use of “store and release” dams to mimic the natural flow regime of the creeks and increase retention time, thereby allowing the water to cool prior to discharge.

In general, it is considered that given the other alternative uses within Wallumbilla and Yuleba, and the potential adverse impacts, discharge to grade should not be considered for these areas. Of all local watercourses, Bungil Creek offers the best opportunity for discharge to grade, whilst minimising risk to the environment.

Lake Campbell and Opportunistic Release to Bungil Creek

Lake Campbell is located approximately 5km to the east of Roma on the north side of the Warrego Highway. It is situated around 500m to the west of the existing Roma town water supply storage tanks.

The lake is man-made and has a 4m high, 500m long earth bund (most likely constructed using material excavated from the centre of the lake) and provides approximately 300ML of storage. From a visual inspection, the embankment is well vegetated and shows little or no sign of erosion, differential settlement or instability. To the west of the dam is a lower spillway section, approximately 50m in length.

A committee is responsible for maintaining the lake and it is occasionally used for water skiing and jet skiing, when water levels permit. Adjacent to the lake, and overlooking it, is Campbell Park (community events are held here in the summer), which includes a rest area containing toilets and cold water shower facilities.

The lake has a very limited catchment area and receives minimal overland flow. Water to fill the lake is sourced via an existing pump and pipeline connecting the lake to Bungil Creek, located around 2.5km to the west of the lake. Under the existing operational rules, water can only be pumped from Bungil Creek when flows are above a certain threshold in the creek. Bungil Creek is predominantly ephemeral and therefore opportunities to fill the Lake are restricted to periods within the wet season (November to February). As a result of this the Lake is either empty or has very low levels for the majority of the year (especially in the winter).

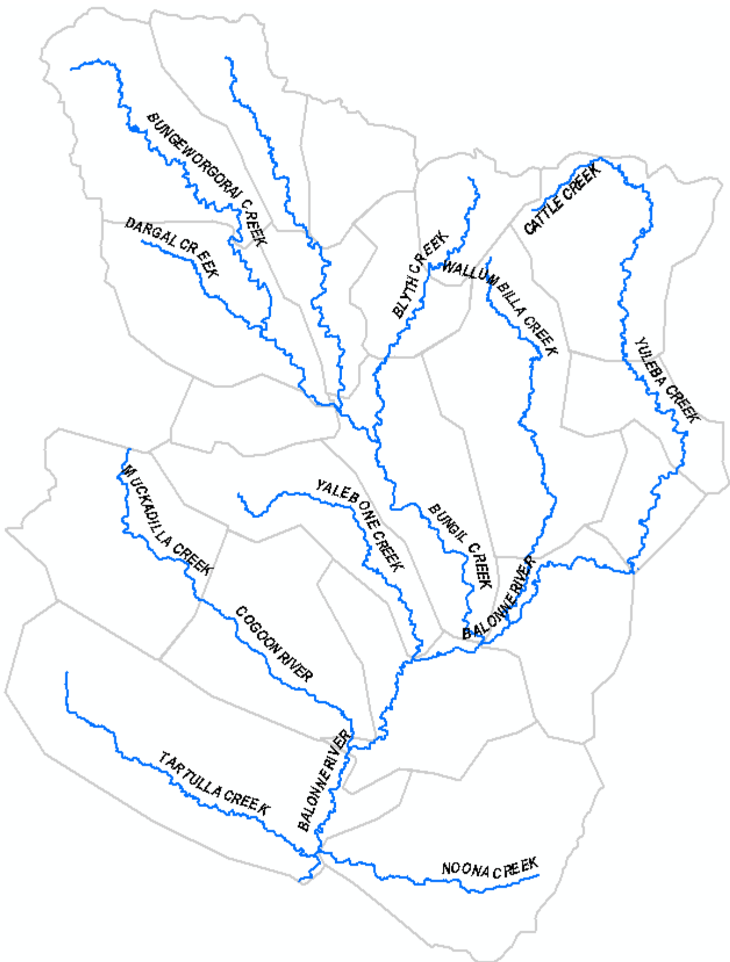
There is a significant opportunity to improve the amenity, recreational and environmental value of this area. The basis of this option is as follows:

- Raise the embankment (and spillway section) up to 2m to provide an increase in the operational storage capacity;
- Supply water from the nearest RO plant to fill the lake during the dry winter months (around 7 months of the year); and,
- During the wet season (or around 5 months of the year) investigate opportunities to discharge treated water from the lake to Bungil Creek as and when flows within the creek permit this activity, ensuring a minimum operational water storage of 200ML is maintained for recreation. For recreational purposes and in order to undertake opportunistic release the water would need to be treated to a TDS concentration of around 400mg/L.

The demand for water would be in the order of 2Ml/d in the winter and up to 5Ml/d in the summer. This is based on the assumption that at the beginning of the dry winter season, the operational water level is 200ML. This provides sufficient capacity to store up to 210 days of inflow at 2Ml/d, assuming no losses, whilst maintaining an 80ML freeboard. Another key assumption is that during the wet season (the initial lake level at the beginning of the wet season would be 600ML) treated water can be discharged to Bungil Creek at up to 5Ml/d, without significantly altering the flow regime. If there were 120 days during which discharge would be possible and around 40 days in which discharge was not possible, the maximum net discharge volume would be 400ML/yr, resulting in an end of wet season storage level of 200ML. The operational details of this plan would require refinement and the scheme would have to be adaptable relative to the number of days during the year (or wet season) on which discharge would be possible. This is likely to be a key regulatory constraint. In summary, this scheme could be used to manage an annual average of 3Ml/d, equivalent to around 15% of the permeate.

A key element of the scheme is the ability to discharge treated water to Bungil Creek. Bungil Creek is a tributary to the Balonne River which flows to the Surat Weir some 60km downstream (see Figure 5-4). As part of the Surface Water Hydrological Study for the Balonne-Condamine catchment, an E2 catchment model capable of predicting daily runoff, creek flow and electrical conductivity was developed for Bungil Creek (refer to the EIS technical report, *GLNG Gas Field Development -Associated Water Discharge Study* in Appendix Q of the EIS report). This was calibrated reasonably successfully, and used to test a number of discharge-to-grade scenarios, including treated and untreated discharge to Bungil Creek of some and all of the peak Roma discharge (ranging from 1.3Ml/d to 20Ml/d).

Figure 5-4 Major Streams within Balonne-Condamine Study Area



The model results suggest that Bungil Creek has an average baseline TDS concentration of 380mg/L and a maximum of 750mg/L (i.e. moderate salinity), and importantly, flows regularly during the wet season. This is based on the DNRW spot measurement data from 1975 to 2006. Both the relatively high background TDS concentrations and regular flow regime of the creek make the option of discharging treated water potentially viable. As a result of the high dilution factors from natural runoff and high background TDS; there would be negligible impact on the average or maximum in-stream TDS concentrations for the treated scenario, irrespective of discharge volumes. It should be noted that under the untreated discharge scenario, the average in-stream TDS concentration is predicted to increase three-fold (to around 1,100mg/L) and therefore approval by the EPA would be unlikely.

From the available model results, it appears that limited treated discharge to grade could be undertaken (at rates of up to 5Ml/d) with minimal impact on the receiving watercourse salinity regime (although a more detailed site specific study would be required to confirm this). However, it should be noted that this is a Category 2 non-preferred option (as defined by the EPA) so justification would need to be provided on why this option is required and what additional benefits it may bring to the surrounding area.

Irrigation of Crops

Approximately 3km to the south of the proposed desalination plant and Lake Campbell are four freehold properties (all greater than 500ha), with a total area of around 4,000ha. This land is currently used to grow wheat and other cereal crops. Irrigation water is currently sourced from the neighbouring Bungil and Blythe Creeks.

This option would involve providing treated water to landowners to irrigate their crops, replacing existing or providing new irrigation supplies. Water would be gravity fed (pumping may also be required in certain locations to achieve the desired rates) from Lake Campbell, which would contain water with TDS concentrations of around 500mg/L, to the intended irrigation area. Although treated to a high quality, the projected residual SAR of 35 will require calcium and magnesium ameliorants to amend irrigant SAR in the range 6 to 10, to avoid development of excessively sodic soils and associated degradation of soil structure. Other pre-treatment may be required depending on the needs of the specific crop. The water would then be distributed via the existing irrigation infrastructure.

The water demand from cereal crops is in the order of 1.5Ml/d/100Ha, and therefore to manage the peak water production from the Roma area (16Ml/d of permeate), around 1,100Ha of land would be required (around a quarter of the available land area). It is expected that the demand would vary according to season.

Irrigation has a number of benefits compared with other alternatives, including simple implementation, scalability, a more straight forward regulatory approval process, manageable technical risk as well as being environmentally attractive. Given the significant uncertainty of the likely quantities of associated water over the lifetime of the project, the ability to scale the water management option is seen as a considerable advantage.

This option could be readily integrated with the other suggested water management options (i.e. Lake Campbell and Roma Town supply), and would provide the overall system with more overall capacity and flexibility (since the Roma Township and discharge to Bungil Creek water demands are constrained by population/existing industrial activity, and the sensitivity of the creek to altered flow regimes, respectively).

Irrigation of New Agroforestry Initiatives

Agroforestry is an agricultural approach of using the interactive benefits from combining trees and shrubs with crops and/or livestock. It combines agriculture and forestry technologies to create more integrated, diverse, productive, profitable, healthy and sustainable land-use systems. Knowledge, careful selection of species and effective management of trees and crops are needed to maximise the production and positive effects of trees and to minimise negative competitive effects on crops.

The World Agroforestry Centre defines agroforestry as *"A collective name for land use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land management unit. The integration can be either in a spatial mixture or in a temporal sequence. There are normally both ecological and economic interactions between woody and non-woody components in agroforestry".*

The proposed scheme would use the same principles as set-out in the irrigation of crops option. High value treated water from the desalination plant would be provided to the landowner and piped to the relevant irrigation area. Additional treatment may then be required to reduce the SAR to an acceptable level, depending on the specific needs of selected crops and trees.

The success of the proposed agroforestry initiative would be largely dependent on the willingness of landowners to change existing land uses from crops to mixed uses (education would also be required). The most effective form of information, knowledge and skill development that leads to practice change will be to provide landowners with regular exposure to regional / national models of agroforestry / multiple land use options and to practitioners who already manage such systems. There are significant properties (each >500Ha) located to the south of the desalination plant, bordering the riparian zones of Bungil Creek and Blyth Creek. Cypress Pine and Sandalwood are grown locally and these could be planted around these as part of the scheme. The average water demands for these are in the order of 2.4Ml/ha/yr, and therefore around 2,500Ha of land would be required to manage the peak water production rates of 16Ml/d.

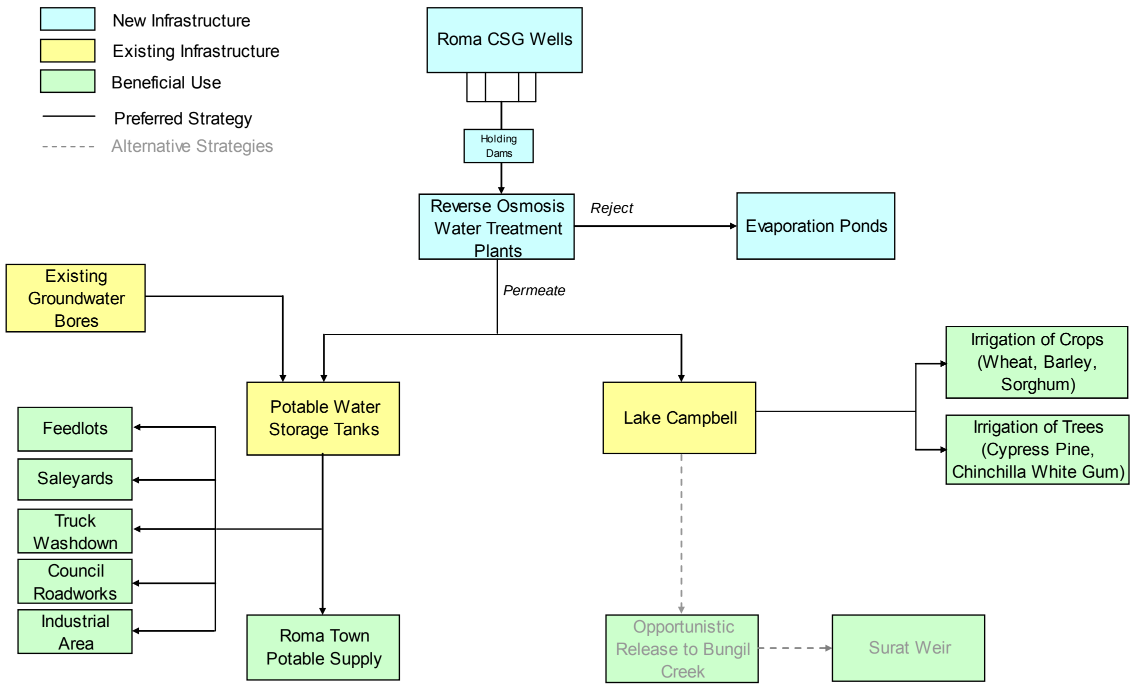
Preferred Option Combinations

The WATERMAN model has been used to assess a number of option combinations based on the available beneficial end-uses as detailed above. Following risk optimisation and careful consideration of the constraints identified in Section 4, and summarised in Section 4.5, the following preferred option and two alternative options have been identified for progression to the Concept Selection stage (see Table 5-3 and Figure 5-5). These options are (on balance) cost-effective, pose acceptable risk to the wider environment and least possible risk to Santos. A detailed review of the risk profiles associated with each option is provided in Appendix D.

Table 5-3 Roma Associated Water Management Options (% distribution)

Option	Town Supply	Industrial Supply	Irrigation (Crops or Agroforestry)	Treated Discharge to Bungil Creek
Preferred	22%	12%	66%	0%
Alternative 1	22%	12%	51%	15%
Alternative 2	0%	0%	100%	0%

Figure 5-5 Roma Water Management Conceptual Model



It should be noted that these options are preliminary and will require further examination and optimisation. Furthermore, they are based on assumed water production schedules which are likely to change as the field development plans are developed and refined, and additional monitoring data becomes available.

The preferred and alternative strategies are broadly in line with the recently published Queensland Government EPA Operational Policy entitled *'Management of water produced in association with petroleum activities (associated water)'* (refer to Section 1.5.2) and the Queensland Government DIP Policy, Queensland Coal Seam Gas Water Management Policy (refer to Section 1.5.4). They are all Category 1 options (i.e. preferred uses), with the exception of the option to store and release water to Bungil Creek (Alternative 1) which is classified as Category 2 (i.e. non-preferred) by the EPA. Several benefits have been identified in relation to the option for discharge to stream which are discussed in Section 5.3.3. These may outweigh the potential risks associated with this option and make it sustainable, at least as a temporary measure.

5.3.2 Potential Impacts and Mitigation Measures

The majority of potential detrimental impacts to the environment would be mitigated by the process of treating all of the raw associated water up to a high standard (TDS < 500mg/L). As such, the risk of contamination to receiving surface or ground water resources (in the event of planned or unplanned discharges), harm or loss to important ecosystems, and/or local economic loss is considered negligible.

The key components (or activities) of this option which could result in significant environmental, social or economic impacts are described below, along with the proposed mitigation measures to manage such potential impacts.

Construction of Water Gathering Networks

The water gathering network transporting associated water from the development wells to the RO plants and then the pipeline to transport the permeate to the end user will likely involve several watercourse crossings depending on the layout of the field and location of water management infrastructure. Construction activities at watercourse crossings could cause erosion, mobilise sediment and alter flow and in-stream water quality characteristics. The potential impacts from such activities can be significant if not managed properly, however this will be confined to the construction phase of the CSG field development.

These potential impacts will be mitigated by the following measures:

- Minimise the number of watercourse crossings by careful planning;
- Use trenching techniques to cross watercourses to minimise impacts on the flow regime;
- Design and implement an erosion and sediment control plan;
- Install stormwater management infrastructure prior to commencing construction nearby watercourses; and
- Minimise disturbance by heavy earthmoving equipment, especially in riparian areas to limit the mobilisation of sediments in to the watercourses.

Storage of Associated Water in Water Management Dams

The main potential impacts relating to the use of dams to temporarily store associated water (prior to RO treatment or distribution to beneficial end uses) are;

- Contamination (elevated salinity) of soil and shallow groundwater due to seepage;

- Contamination (elevated salinity) of surface waters due to regular uncontrolled releases;
- Potential for harm to infrastructure, stock and people living downstream of the dam due to catastrophic failure or longer term contamination of potable/stock water supplies; and
- Loss of valuable land due to inadequate rehabilitation at the end of the project.

All of above potential impacts will be effectively mitigated by best practice design, construction, operation and maintenance, and eventual decommissioning/rehabilitation, including implementing monitoring procedures to detect and address potential problems before they cause environmental harm. As requested in the Terms of Reference for this project, a full description of Santos' approach to managing the risk posed by water management dams is provided in Appendix C. The key features of this are as follows:

- Appropriately site the dam above the 1 in 100 year flood level and away from environmentally sensitive areas (e.g. endangered regional ecosystems, sensitive surface/shallow ground water receiving environments and other areas of high environmental value);
- Use HDPE lining in combination with a clay liner to limit seepage and potential contamination of soil profiles and shallow groundwater; and
- Establish a robust monitoring system to provide feedback on the overall performance of the constructed dam and the effectiveness of environmental management controls.
- Explore opportunities to provide the associated water management dams to local landholders for future use and/or convert to surface water harvesting dams.

Water Management Dams (Evaporation Ponds) to Manage Brine

Ponds to store and contain brine have the potential to cause the same impacts as associated water management dams with the addition of the following:

- Air pollution (salts) caused when water levels in the evaporation pond decrease;
- More significant contamination of soil and shallow groundwater due to seepage of highly saline water; and
- Potential property devaluation, loss of farming land and limitations to the future use of the land, following decommissioning.

The additional potential impacts posed by brine storage will be mitigated by best practice design, construction, operation and maintenance, and eventual decommissioning/rehabilitation, including implementing monitoring procedures to detect and address potential problems before they cause environmental harm (see Appendix C). This may include the following measures:

- Use of a heat exchange system recover waste heat from compressors and maximise evaporation rates and limit the footprint of the water management dam; and
- As part of the decommissioning process, remediate impacted areas (as specified in Appendix C) and/or clay cap, mound and divert surface water away from the water management dam footprint area. Also, there is potential to provide the dams to landholders following the project.

Discharge to Bungil Creek via Campbell Lake

The potential impacts of discharging to Bungil Creek are limited as the water would be treated to a high standard prior to entering the watercourse. However, there are some additional impacts which require mitigation. These include:

- Alteration of the flow regime by introducing additional flows, potentially changing long term stream morphology and sediment and erosion patterns;
- Alteration of riparian vegetation and aquatic species through increased/altered environmental flows and differences in water quality (i.e. marginally elevated salinity and possible presence of other contaminants);
- Localised erosion and scour at the point of discharge, if suitable controls are not put in place.

To limit the potential for altering the flow, temperature and water quality regime, it is recommended that discharge to grade is limited to flow periods only or at downstream locations where sufficient baseflow exists. This will limit the alteration to the existing flow regime and offer further dilution to the treated water. Furthermore, where discharge to grade is undertaken, a water quality and river health monitoring programme should be established to detect environmental change outside of agreed limits (physical, chemical and biological change). This should include monthly inspection and water quality sampling at the location of discharge and up to two kilometres downstream. For all discharge scenarios it will be necessary to provide erosion controls (preferably using low impact bioengineering methods) at the point of discharge.

A full and detailed review of potential impacts of surface water discharge within the Condamine-Balonne catchment area is provided in the technical report entitled, '*GLNG Gas Field Development - Associated Water Discharge Study*' (refer Appendix Q of the EIS report).

5.3.3 Environmental Opportunities

The environmental benefits of *treating and providing water for potable supply and other municipal/industrial uses* are as follows:

- Availability of associated water as a water supply source will reduce the existing reliance on surface and ground water sources and improve the security of supply over the next 20 years;
- By replacing the existing groundwater supply, local aquifers will have an opportunity to recharge;
- Treated associated water could be used to rejuvenate and develop green riparian corridors, improving local recreational amenity and biodiversity; and
- Providing local industries with a 20 year water supply will stimulate the economy and create local employment opportunities.

The environmental benefits of *using treated water to maintain a year round operational water level within Lake Campbell, as well as undertake opportunistic release to Bungil Creek* are as follows:

- Help increase environmental flows (and thereby support aquatic and riparian ecosystems) which may have been impacted by over extractions;
- Improve supply of water (reliability and volume) to downstream users – industrial and agricultural. Support existing downstream water allocations and increase flows towards the Surat Weir for beneficial re-use;

- Improve amenity and recreational use of Lake Campbell and the surrounding Campbell Park area (e.g. fishing, swimming, boating and camping); and
- Provide environmental enhancements and increase flora/fauna biodiversity around the lake.

The environmental benefits of using *treated water to irrigate local crops* are:

- Improve supply of water to existing irrigation schemes;
- Reduce the need for extractions from local watercourses and other sources, thereby improving the natural flow regimes of the creeks and improving flora/fauna diversity; and
- Provide opportunities for local landholders to increase their crop production areas and yields, or grow other types of high water usage crops for a limited period. This would add to the local economy of Roma and provide opportunity for local employment.

The environmental benefits of using treated water to *establish new Agroforestry schemes* are:

- Improve biodiversity relative to conventional agricultural systems, by creating habitats that can support a wider variety of birds, insects and other fauna;
- Enhance and protect aquatic and riparian resources;
- Help reduce the impacts of climate change since trees take up and store carbon at a faster rate than crop plants (carbon sequestration);
- Assist in the reduction of odour, dust and noise;
- Provide more green space and improve visual aesthetics;
- Waste water or manure management – opportunity to utilise urban waste water on intensive, short rotation forests for wood fibre production; and
- Opportunity for landowners to generate additional income from timber and non-timber forest products.

5.4 Fairview Water Strategy

The Fairview associated water management strategy consists of the following two components:

- Fairview irrigation scheme; and
- Discharge to Upper Dawson River.

5.4.1 Strategy Description

Fairview Irrigation Scheme

Santos Toga Pty Ltd owns freehold land of around 18,000ha within the Fairview and Springwater properties, of which approximately 3,437 ha is suitable for plantation establishment on the plateau areas of Springwater and Fairview, and 1,555 ha is potentially suitable in the valley areas (land less than 4 degree slope and suitable soils).

Santos has recently submitted a Resource Utilisation Plan (RUP) for beneficial use of approximately 65 GL of associated water produced from coal seam gas to irrigate approximately 2,000 ha of plantation eucalypt forest and 234 ha of Leucaena-pasture grass-fodder crop over the next 10 years. The current projected maximum peak water production during this period would be in the order of 32Ml/d. The water would be treated for irrigation of *Eucalyptus argophloia* (Chinchilla white gum) plantations and desalinated and treated for irrigation of Leucaena dominant forage crops used for grazing and forage harvesting.

It is proposed that the Fairview Irrigation Scheme is extended for the entire duration of the CSG field development, during which maximum peak water production rates may reach around 52Ml/d. The area of land proposed for the Leucaena dominant forage system is constrained by the available RO capacity at Pony Hills, which is 4.5ML/d. Leucaena system total water demand is 7ML/ha/year, therefore a maximum area of approximately 234 ha can be irrigated. Modelling shows potential forest water demand is about 6mm/day or 2,000mm/yr. Average rainfall of 600mm/yr and mean irrigation of 2.4Ml/ha or 240 mm applied/ha/yr represents 38% of potential demand. Application of a maximum planned irrigation rate of 4 Ml/ha would represent 45% of potential water demand. The 2,000 ha forest plantation is planned to take 4,800 ML/yr. Modelling shows the forest system can safely accept 8,000 Ml/yr at planned peak irrigation rates.

A brief description of each component of the scheme is provided below.

Chinchilla White Gum is native to the Chinchilla region and was selected due to its relatively high tolerance to drought, frost, salinity, insect pests and diseases, as well as its economic value as a commercial hardwood timber species.

Under normal, rainfall induced leaching conditions, long-term irrigation with untreated associated water is not predicted to substantially change subsoil salinities, but would substantially increase soil sodicity, leading to soil structural decline. To mitigate this risk, the associated water will be treated with calcium and magnesium sulphates (2:1 cation ratio) to reduce SAR from 100 to around 25. Associated water will also be treated with sulphuric acid to reduce irrigant pH to 6 and carbonates by 50% to about 400 to 500 mg/l to minimise precipitation of calcium carbonates in soils. Combined with a mean TDS concentration of around 2,000mg/L, this will ensure that the integrity of the soil structure and plant health is maintained.

Partly to avoid the need for construction of winter storage, and partly to minimise total salt loads, the operation will be based on “under irrigation’ aimed at capturing ‘salts’ in soils and in strata below the root zone in a controlled manner. This allows continuous daily irrigation.

Modelling highlights the robustness of the forest plantation system. Irrigating of treated associated water using median 2-3 dS/m electrical conductivity irrigant at 4Ml/ha with no leaching (an unrealistic assumption), would require approximately 5 years of continuous irrigation before mean soil salinity levels rise from 2 to 5dS/m, thereby initiating a low level of salinity induced yield loss.

The under-irrigation strategy of an average 2.4 Ml/ha/yr or 40% of long-term rainfall will ensure that forest plantation soils maintain high soil capacity to absorb water at a constant daily rate, including maximum planned daily rates of up to 4.5Ml/ha/yr. The selected irrigation rate strategy has additional benefits of:

a) minimising salt load per unit land area;

b) reduced land impact;

c) slow rate of change in soil properties;

d) greater irrigation volume flexibility; and

e) minimising surface run-off and release to local watercourses.

A 1.4m wide area surrounding each tree row is wet by drip irrigation. SALF (salt and leaching fraction) modelling based on an irrigation rate of 400 mm/yr (compared with the long-term average of 240mm/yr) and a TDS concentration of 2,000mg/L predicts no change in the average root zone salinity for Springwater deep and shallow soils and only a slight increase in root zone salinity for Fairview plateau soils. No salinity impact on inter-row native and improved grasses is expected - these ground covers comprise 65% of the total system area.

Leucaena will be irrigated with desalinated water produced through reverse osmosis at Pony Hills. The maximum capacity of the desalination plant is 6Ml/d, producing 4.5Ml/d of permeate with a TDS < 500mg/L. This process removes most chemical elements from the associated water, but may leave a small residual quantity of sodium (up to 140 mg/l). Because of the very low calcium in this water, SAR is relatively high (approx. 38). Treatment of the desalinated water will be required by addition of calcium and magnesium to reduce the SAR to between 2 and 6. As the sodium concentration of the desalinated water is very low, the total load over time is low, and no significant impacts on soil structural integrity are anticipated.

The reject from the desalination process (brine stream) would be injected into the Timbury Hills formation (basement) using existing borehole infrastructure located at Fairview 77 and Fairview 82. Each injection well has a capacity of around 1.2 Ml/d (only 1.5Ml/d would be injected from Pony Hills), although there is uncertainty over whether these capacities could be maintained in the long term. As a result, in the long term it may also be necessary to consider compacted clay and HDPE lined water management ponds to contain the brine, prior to the establishment of additional viable injection wells, natural evaporation and/or crystallisation.

To provide a feed buffer and allow for variation of water application in line with plant water-use demand (which varies between wet and dry seasons), desalinated water will be stored in a 220 Ml water management dam prior to irrigation. The dam requires no licence or permit given the quality of the water, size of the dam and height of the embankment. Irrigation will be applied by centre pivot irrigation. In years of unseasonal high rainfall (90th percentile rainfall 866mm), the key management option would be to divert excess feed water via drip irrigation to eucalypt forests. This may be achieved given the under-irrigation strategy applied to this crop, and maintenance of a large soil water storage capacity.

In summary, the available area of suitable plantation and crop land within the Fairview and Springwater properties is sufficient to manage the maximum water production rates and volumes from the Fairview CSG field. Irrigation has a significant number of benefits compared to other alternatives, including: simple implementation, scalability, a more straight forward regulatory approval process, manageable technical risk as well as being environmentally attractive and able to generate significant local / regional community economic benefits. Given the significant uncertainty of the likely quantities of associated water over the lifetime of the project, the ability to scale the water management option is seen as a considerable advantage.

Discharge to Upper Dawson River

To support the long term water management strategy under the GLNG Project, an extensive catchment hydrological modelling study has been undertaken to assess potential changes in hydrology, salinity and temperature that may arise in-stream under a range of discharge to grade scenarios (refer to the EIS technical report, *GLNG Gas Field Development - Associated Water Discharge Study* in Appendix Q of the EIS). This has included establishing the baseline conditions of streams in proximity to the Fairview CSG field, which are briefly summarised below:

- The upper Dawson River has been observed to be ephemeral at certain times of the year (mainly winter), and furthermore, the base flow within the stream is often very low, in the order of a few megalitres per day.

Section 5 Water Management Strategy

- Salinity monitoring at the Utopia Downs gauging station over the last 10 years indicates that the upper Dawson River has a relatively low average TDS concentration of 200mg/L.
- The ambient stream temperature ranges between 17 °C to 22 °C in the winter and 22 °C to 27 °C in the winter.

The hydrological model indicates that even moderate discharges of untreated associated water would increase the average in-stream TDS concentrations by 50-400% (300mg/L to 800mg/L), which would be unacceptable to the EPA. As such, it is highly likely that treatment would be required to a background level similar to the receiving watercourses, to avoid detrimental environmental impacts.

The basis of this option is to discharge treated (i.e. desalinated) associated water to the Hutton Creek, Baffle Creek and Dawson River (see Figure 5-6). It is proposed that associated water would be captured via a water gathering network, piped to a water management dam prior to desalination and then discharged to stream locations with spring flows to minimise alterations to flow, temperature and salinity regimes. Discharge would be undertaken on a constant basis rather than opportunistically via store and release schemes, since the significant volumes of water involved would render this option uneconomic and damaging to the environment (several store and release dams with a total capacity of 10 GL would be required to manage the maximum peak discharge). Furthermore, by discharging to springs, the temperature of the water would be normalised within the first 2km from the associated water being introduced to the stream (compared to more than 10km for non-spring flow locations).

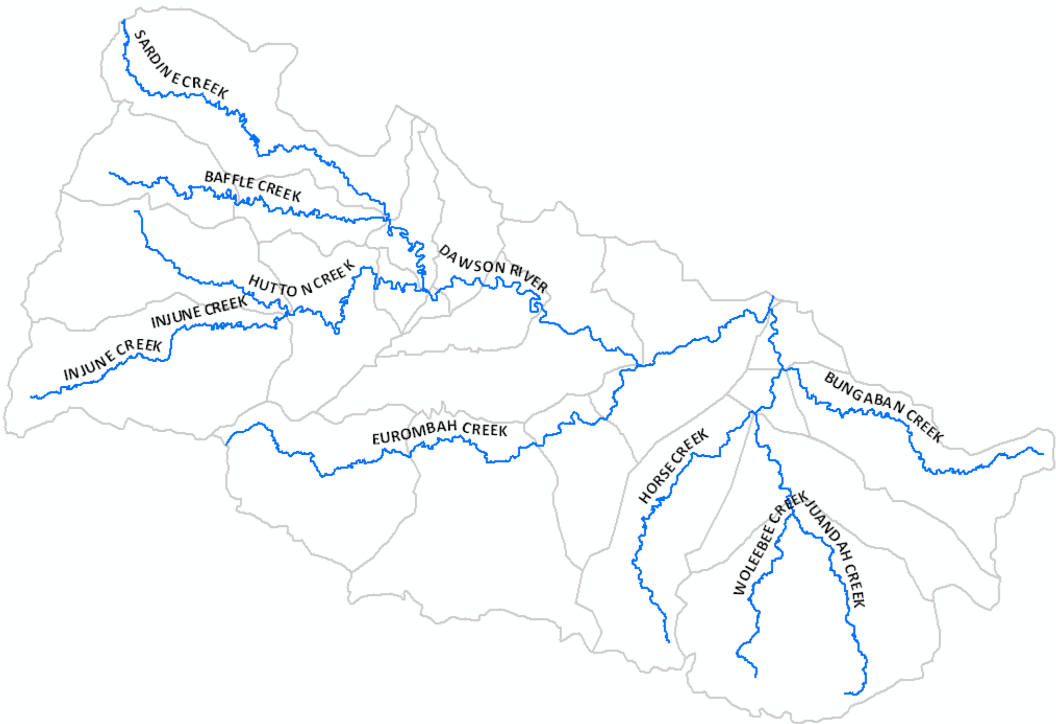
To reduce salinity concentrations, the associated water would be treated at the Pony Hills desalination plant (adjacent to the Hutton Creek), which has a maximum raw water treatment capacity of 6Ml/d, and a maximum output of 4.5Ml/d (i.e. 75% efficiency). Water would be treated to a high standard with a TDS concentration similar to background stream levels. The Pony Hills desalination plant has a capacity to treat around 10% of the maximum peak production, and therefore it is likely that an additional centralised desalination plant would be required, should discharge above 6Ml/d be required.

The reject brine stream (waste stream) would be injected into the Timbury Hills formation using existing borehole infrastructure located at Fairview 77 and 82. If additional associated water were to be treated, then it would be necessary to establish additional injection wells within the Fairview field or consider the use of compacted clay and HDPE lined brine containment ponds.

It is possible that dilution of the brine stream (i.e. mixing with raw associated water) would be required pre-injection depending on the water quality characteristics of the receiving reservoirs. Filtration may also be required to ensure reservoir permeability is not damaged by the injection fluid and biocide/anti-scaling agent/oxygen scavenger may be required to protect both the reservoir and tubing/downhole infrastructure. For this purpose it would be necessary to construct a small water management dam adjacent to the injection wells.

In summary, the option to discharge treated water to grade is considered to add flexibility to the overall long term associated water management strategy for Fairview. It could provide a useful alternative to the Fairview irrigation scheme should actual volumes of associated water be significantly higher than expected. This is especially important since there are no other significant alternative beneficial use options within the area (i.e. no community or industrial demand). The extent of its implementation will be largely constrained by sensitivity of the ecosystem to changes in the flow, temperature and salinity regime of the receiving watercourse. Whilst consideration has been given to using this option to manage 100% of the Fairview associated water, it is more likely that up to 20% of the peak maximum water production would be a reasonable upper limit (maximum discharge of around 10Ml/d).

Figure 5-6 Major Streams in the Dawson River Catchment



Preferred Option Combinations

The WATERMAN model has been used to assess a number of option combinations based on the available beneficial end-uses as detailed above. Following risk optimisation and careful consideration of the constraints identified in Section 4, and summarised in Section 4.5, the following preferred option and one alternative option have been identified for progression to the Concept Selection stage (see Table 5-4 and Figure 5-7). These options are on balance cost effective, pose acceptable risk to the wider environment and least possible risk to Santos. A detailed review of the risk profiles associated with each option is provided in Appendix D.

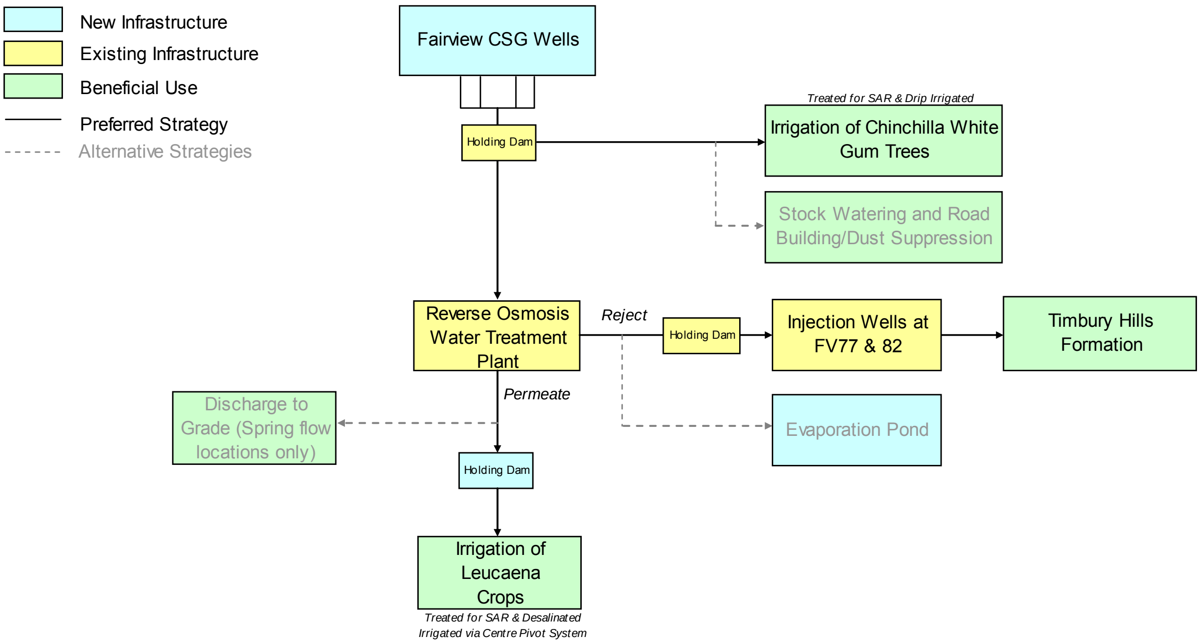
Table 5-4 Fairview Associated Water Management Options (% distribution)

Option	Treated and Desalinated Irrigation (Leucaena)	Treated (for SAR) Irrigation (Chinchilla White Gum)	Treated Discharge to Grade	Untreated Discharge to Grade	Other Local Uses[1]
Preferred	12%	88%	0%	0%	0%
Alternative	12%	68%	10%	0%	10%

[1] Other local uses relate to stock watering, road construction and dust suppression. The total demand has been calculated on the basis of existing water uses from the Fairview CSG field (i.e. at around 5Ml/d).

It should be noted that these options are preliminary and will require further examination and optimisation. Furthermore, they are based on assumed water production schedules which are likely to change as the field development plans are developed and refined, and additional monitoring data becomes available.

Figure 5-7 Fairview Water Management Conceptual Model



The main options put forward for the Fairview CSG field include; irrigation, discharge to grade, and other local agricultural and municipal uses (such as stock watering, road building and dust suppression), with treatment. Notably, the area provides no opportunity for local community or industrial use (as compared to Roma), and therefore, in line with the EPA's waste-hierarchy it is considered that the most attractive long term water management solution is to implement the Fairview irrigation scheme as outlined above. This scheme has the capacity to manage all of the associated water and can be scaled according to actual schedules of water production. It is classified as a Category 1 option (i.e. preferred) by the EPA. As a back-up option, however, the option of treated discharge to grade should be kept, although given the likely impact on the flow and temperature regime of this activity, it is likely that only a small proportion of associated water could be managed in this way, and for a relatively short time period only.

5.4.2 Potential Impacts and Mitigation Measures

The key components (or activities) of the Fairview associated water management strategy which could result in significant environmental, social or economic impacts are described below, along with the proposed mitigation measures to manage the impacts.

Construction of Water Gathering Networks

The potential impacts and mitigation measures are the same as outlined in Section 5.3.2.

Storage of Associated Water in Water Management Dams

The potential impacts and mitigation measures are the same as outlined in Section 5.3.2.

Storage of Brine in Brine Containment Ponds

The potential impacts and mitigation measures are the same as outlined in Section 5.3.2.

Injection of Brine Stream

The main impact arising from the injection of the brine stream into the underlying aquifers is;

- Contamination of ground water in interconnected formations resulting in harm to users of the resource (livestock, humans and other flora/fauna ecosystems).

To mitigate the above impact, it is recommended that the brine stream is diluted (mixed with higher quality water) and/or treated prior to injection to a quality no worse than the target formation. Furthermore, a comprehensive monitoring and reporting programme should be established (on a monthly basis) to monitor the response of the receiving reservoir and nearby aquifers, which may be impacted.

A more detailed review of the range of impacts relating to injection is provided in the Appendix P2; the technical appendix to the GLNG EIS entitled, *Groundwater (deep aquifer modelling)*, Matrix Plus 2008.

Irrigation of Chinchilla White Gum (treated for SAR but not desalinated)

A conceptual hydrogeological model was developed to support the Resource Utilisation Plan (RUP) (recently submitted to the EPA) and long term water management strategy. The model indicates that excess water leaving the root zone, beyond the capacity of the underlying strata to transmit the water to the water table by vertical percolation, could cause the following impacts to occur:

- Localised development of perched water tables and (if close to the surface) water logging and build up of salinity;
- Transport of excess water, potentially at an elevated salinity (relative to the local water quality, which has a background TDS concentration of 200-300mg/L) to springs at the cliff faces surrounding the irrigation areas; and
- Localised tree or plant death as a result of water logging or excess salinity.

To mitigate the above impacts, Santos is currently developing an Adaptive Irrigation and Groundwater Management Plan, supported by rigorous risk-based groundwater and surface water monitoring. The plan will be used to guide the ongoing modification, and where necessary re-direction of the irrigation scheme so that impacts are acceptable and appropriately reported and managed. Long term sustainable management and beneficial use of associated water will rely on detailed monitoring, particularly for changes in soil moisture content and salinity to avoid excessive accumulation of salt in the root zone. Monitoring will also be used to track the movement and deposition of salts which leave the root zone and are deposited deeper in the solum and to allow continuing, evidence-based adaptive management of irrigation practices. Detailed site monitoring, particularly for changes in soil moisture content and salinity, together with periodic measurement of changes in sodicity and chloride, will provide a surrogate measure of evapotranspiration, tree health and estimates of quantities and depths of deep drainage.

The proposed monitoring network will capture the full hydrological cycle from climate, through soil moisture under irrigation, to off-site ephemeral and perennial stream and groundwater monitoring. In addition, regular monitoring of changes in soil chemistry and structure, together with annual tree growth and forage production and live weight gain of centre pivot irrigated forage fed cattle at the end will be undertaken. Monitoring system results will be reported at quarterly, six-monthly and annual frequencies.

Irrigation of Leucaena (treated for SAR and desalinated)

The majority of potential detrimental impacts to the environment posed by irrigation would be mitigated by the process of treating all of the associated water up to a high standard (TDS < 500mg/L). As such, the risk of contamination to receiving surface or ground water resources (from excess water leaving the root zone), and resultant harm or loss to ecosystems is considered negligible.

Treated Discharge to Dawson River

The potential impacts of discharging to the Hutton Creek and Dawson River are:

- Altering the flow regime by introducing additional flows, potentially changing long term stream morphology and sediment and erosion patterns;
- Alteration of riparian vegetation and aquatic species through increased/altered environmental flows and differences in water quality;
- Changes to the temperature regime of up to 10°C at the point of discharge, extending several kilometres downstream; and
- Localised erosion and scour at the point of discharge, if suitable controls are not put in place.

To limit the potential for altering the flow, temperature and water quality regime, it is recommended that discharge to grade is limited to locations where there are consistent wet and dry season spring flows. The maximum discharge of treated water to the spring flow should not exceed 50% of the existing flow. Furthermore, discharges at source should not be made during cease to flow (no flow) periods in any location.

Where discharge to grade is undertaken, a water quality and river health monitoring programme should be established to detect environmental change outside of agreed limits (physical, chemical and biological change). This should include regular inspection and water quality sampling at the location of discharge and up to two kilometres downstream. For all discharge scenarios it will be necessary to provide erosion controls (preferably using low impact bioengineering methods) at the point of discharge.

If the volumes of planned discharges are less than 5Ml/d then it could be possible to discharge at non-spring flow locations (either at source or to the stream) by using water management (store and release) dams. This would limit the impact on the flow regime and increase the detention time, thus allowing the water to cool before being discharged. A total storage capacity of 1GL would be required for this purpose, assuming that opportunistic discharge could be undertaken for 5 months each year.

A full and detailed review of potential impacts of surface water discharge within the Dawson River catchment area is provided in the technical report entitled '*GLNG Gas Field Development -Associated Water Discharge Study*' in Appendix Q of the GLNG EIS.

5.4.3 Environmental Opportunities

The environmental benefits of the proposed *irrigation scheme* are as follows:

- Increase in soil organic matter, soil moisture holding capacity and soil cation exchange capacity through mulching processes at establishment and enhanced soil / litter layer microenvironments increasing carbon cycling;
- Increase in total plant available nutrient pools;

- Increase in sequestration of atmospheric carbon in managed plantations, timber products and the Leucaena dominant forage system;
- Increase in total and available soil nitrogen from legume fixation of atmospheric nitrogen;
- Based on independent consultant research supporting the irrigation program development, a drip-irrigated forest estate, by final harvest, will add major value to the local and regional economy via the marketing of sawn timber, wood products and wood waste for biofuel; and
- The Leucaena dominant forage system is expected to contribute an additional 350,000 to 400,000 kg of live weight gain per annum to the local cattle industry (via grazing and via fodder conservation processes).

The environmental benefits of *discharging treated water to the Dawson River* are as follows:

- Help increase environmental flows (and thereby support aquatic and riparian ecosystems) which may have been impacted by over extractions; and
- Improve supply of water (reliability and volume) to downstream users – industrial and agricultural.

5.5 Arcadia Valley Water Strategy

The Arcadia Valley associated water management strategy consists of the following two components:

- Irrigation of crops and trees; and
- Discharge to Arcadia Creek and Lake Nuga Nuga.

5.5.1 Strategy Description

Irrigation of Crops and Trees

Unlike the Fairview and Springwater plateau areas, the Arcadia Valley is characterised by a dense surface water drainage network. The baseline water quality within Arcadia Creek, which flows northwards through the valley towards Lake Nuga Nuga, is high, with an average TDS concentration of 146mg/L (and maximum of 270mg/L). As such, to avoid contamination of surface water and groundwater resources, as well as soil profiles, any sustainable long term water management option for the area will require treatment (i.e. desalination and SAR reduction) to a high standard (TDS < 200mg/L).

Within the Arcadia Valley, both existing and new irrigation schemes could be supplied with treated and desalinated associated water. There are at least 20 properties (a mixture of freehold and leasehold) greater than 1,500ha. Key landholders have indicated that they would be keen to use the water to irrigate existing crop and tree plantation areas, as well as expand operations to include other high value food crops. Current productivity within the Arcadia Valley is limited by the lack of water. CSG field development in this area may allow this constraint to be removed for a period of 10-15 years, during which significant volumes of water will be produced in this region.

It is proposed that a combination of the following tree plantations and crops could be irrigated with treated water (note: there would be nominally 21.5Ml/d of permeate available for the irrigation scheme assuming an RO efficiency of 80%):

- Irrigation of *Eucalyptus argophloia* (Chinchilla white gum) plantations. Chinchilla White Gum is currently grown within the valley (in small areas) and has a high tolerance to drought, frost, salinity, insect pests and diseases. Other types of trees may also be appropriate. It is proposed that up to 2,000ha could be irrigated. The water demand from this, assuming that drip-fed under-irrigation is applied to avoid the use of water management dams, is an average of 2.4Ml/ha/yr. As such, a total of 13Ml/d of permeate could be used by the irrigation scheme.

- Irrigation of Leucaena dominant forage crops used for grazing and forage harvesting. There are existing areas of Leucaena cropping (at least 800 ha) which could be supplied with treated water. It is proposed that in total up to 1,000ha could be irrigated. The Leucaena water demand is 4ML/ha/year, which equates to 11Ml/d of permeate for 1000ha.
- Irrigation of cereal crops and non-cereal crops (such as chick peas and lucerne). It is proposed that up to 1,000ha could be irrigated. The water demand of most cereal crops is around 4ML/ha/year, which equates to 11Ml/d of permeate for 1,000ha.

The proposed basis of this option will be to irrigate 1,500 ha of Chinchilla White Gum and 1,000 ha of crops (either Leucaena or crops). This will be sufficient to manage the maximum peak permeate production of 21.5ML/d.

For the irrigation of Leucaena and cereal crops, desalinated water would be stored in water management dams to allow for seasonal variation of water application in line with plant water-use demand. The total capacity of the holding dams would be around 400ML. In years of unseasonal high rainfall (beyond the capacity of the holding dams), excess feed water may be diverted onto drip irrigation of Chinchilla White Gum or, as a backup, discharged to grade. Diversion to the drip irrigation system may be achieved given the under-irrigation strategy, and maintenance of a large soil water storage.

It is proposed that a water gathering network would be developed (100km total length has been assumed for the purpose of costing) and linked to a temporary holding dam (100ML capacity) prior to being fed to several RO plants (locations dependent on the layout of the development wells) with a capacity to treat up to 27Ml/d of raw water. This would produce around 21.5Ml/d of permeate, assuming 80% RO efficiency. Additional pipelines (up to 40km in length) would then be required to transfer the water to the irrigation areas.

This treatment process removes most chemical elements from the associated water, but may leave a small residual quantity of sodium. Because of the likely low calcium in this water, SAR would be expected to be relatively high (around 40, similar to the Fairview field). Further treatment of the desalinated water would therefore be required by addition of calcium and magnesium to reduce the SAR to below 10. Given comprehensive soil surveying and the selection of soil types suitable for irrigation, long term irrigation would not change subsoil salinities or impact the integrity of the soil structure.

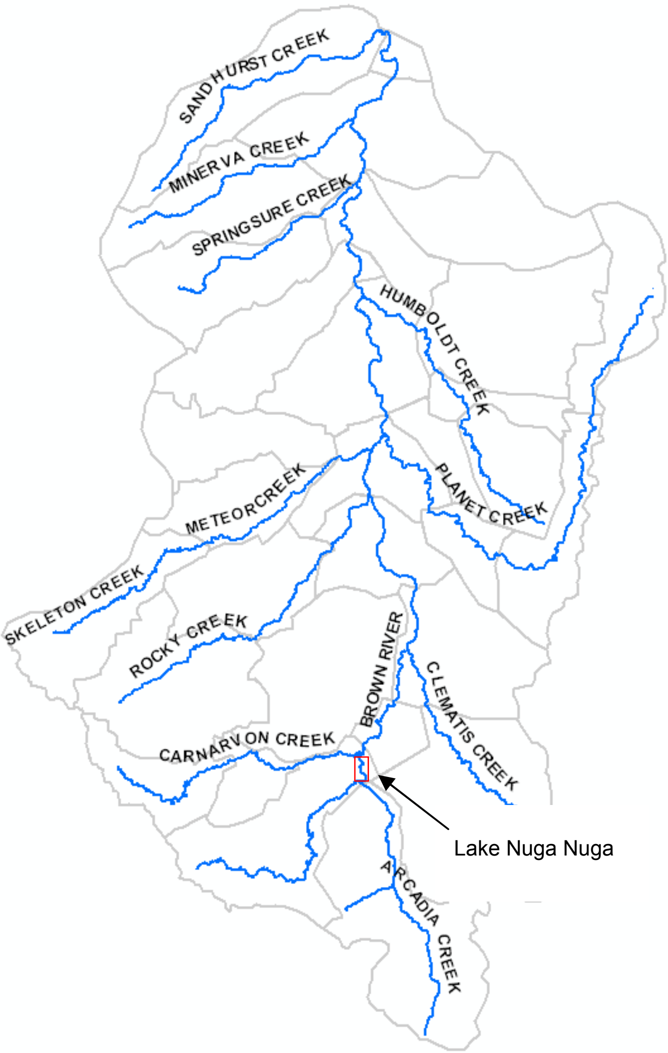
The base case for brine management is to construct compacted clay and HDPE lined water management ponds to contain the brine, which will be located next to each RO plant. Depending on the outcome of more detailed studies currently being undertaken by Santos, the brine may be i) injected into suitable formations, ii) crystallised and either encapsulated or transferred to a suitable landfill and/or iii) naturally evaporated.

In summary, the available area of suitable plantation and crop land within the Arcadia Valley is sufficient to manage the maximum water production rates and volumes from the Arcadia Valley CSG field. The main challenge will be the safe disposal of the brine stream from the desalination process, and the ability to manage the likely seasonal variation in irrigation water demand for the suggested crops. Given the significant uncertainty of the likely quantities of associated water over the lifetime of the project however, the ability to scale the water management option is seen as a considerable advantage.

Discharge to Arcadia Creek & Lake Nuga Nuga

The basis of this option is to discharge treated associated water to Arcadia Creek, which flows northwards through the middle of the Arcadia Valley into Lake Nuga Nuga before joining the Comet River (see Figure 5-8). The Comet River and headwater catchments form part of the Fitzroy Basin, which flows into the Great Barrier Reef Lagoon at Rockhampton.

Figure 5-8 Major Streams in the Comet River Catchment



To inform the viability of this option, an extensive catchment hydrological modelling study has been undertaken to assess potential changes in hydrology and salinity that may arise in-stream under a range of discharge to grade scenarios (refer to Appendix Q in the EIS report, *GLNG Gas Field Development - Associated Water Discharge Study*). This included establishing the baseline conditions of streams in proximity to the Arcadia Valley CSG field, which are briefly summarised below:

- The Arcadia Creek is ephemeral and only flows for around 3-4 months of the year (in the wet season); and
- Salinity modelling indicates that water quality in the Arcadia region is high, with an average TDS concentration of 146mg/L and maximum TDS concentration of 270mg/L.

Section 5 Water Management Strategy

A further review of Lake Nuga Nuga has been undertaken since this water body is listed in the Directory of Important Wetlands in Australia and is classified as a Wetland of 'National Importance'. The key features of Lake Nuga Nuga are as follows:

- Located in the broad valley between the Expedition and Carnarvon ranges, with Mount Warrinilla located at its northern end. It is located on Arcadia Creek and is constructed with levees at its northern most extent. It is managed by Bauhinia Shire Council;
- It has a maximum surface area of 2,070ha, with a depth ranging between 2m and 9m. The available storage in the lake is in excess of 103 GL. The volume of water in Lake Nuga Nuga varies considerably from year to year, depending on rainfall totals. Lake Nuga Nuga is classified as semi-permanent;
- Current water uses include extraction for irrigation, stock watering and limited recreation (camping, boating, fishing);
- The lake provides important refuge for dependent flora and fauna. Significant use of the lake is made by waterbirds such as pelicans and cormorants. Aquatic bed communities are dominated by Nymphaea sp. Flora species such as Acacia harpophylla and Casuarina cunninghamiana occur on the margins of the lake;
- The lake is known to suffer from algal blooms as a result of drought, water extraction for irrigation, stock consumption, runoff and erosion from fertilized agricultural areas (resulting in phosphorous loading) and regulation of rivers upstream of the lake and by the levee itself; and
- Continued and intensified grazing is considered a threat to the lake ecosystem.

The hydrological model of Arcadia Creek indicates that with constant discharge (i.e. including during no flow conditions) even moderate discharges of untreated associated water would increase the average in-stream TDS concentration by 1,200% (to around 1,800mg/L). This would result in additional 'salt loading' within Lake Nuga Nuga and as such would be unacceptable to the EPA. It is highly likely, therefore, that treatment would be required to a background level similar to the receiving watercourses, to avoid detrimental environmental impacts. The hydrological model shows that if the associated water is treated to a TDS concentration of less than 200mg/L, the average and maximum TDS concentrations would be marginally increased above the baseline condition (176mg/L and 267mg/L, respectively).

It is proposed that associated water would be captured via a water gathering network, piped to a water management dam, prior to RO treatment (TDS <200mg/L). Treated discharge to Arcadia Creek would be undertaken on a constant basis or, if required, via store and release schemes.

In summary, the option to discharge treated water to grade is considered to add flexibility to the long term associated water management strategy for the Arcadia Valley CSG field, which is likely to be focused upon irrigation of crops and trees. It could provide a useful alternative to the proposed irrigation scheme should actual volumes of associated water be significantly higher than expected or high annual rainfalls exceed the capacity of the irrigation demand. The extent of its implementation will be largely constrained by the sensitivity of the ecosystem to changes in the water balance, flow and temperature regimes of Arcadia Creek and Lake Nuga Nuga. Whilst consideration has been given to using this option to manage 100% of the Arcadia CSG field associated water, it is more likely that up to 20% of the peak maximum water production would be a reasonable upper limit (equating to a maximum discharge to grade of around 5.5Ml/d).

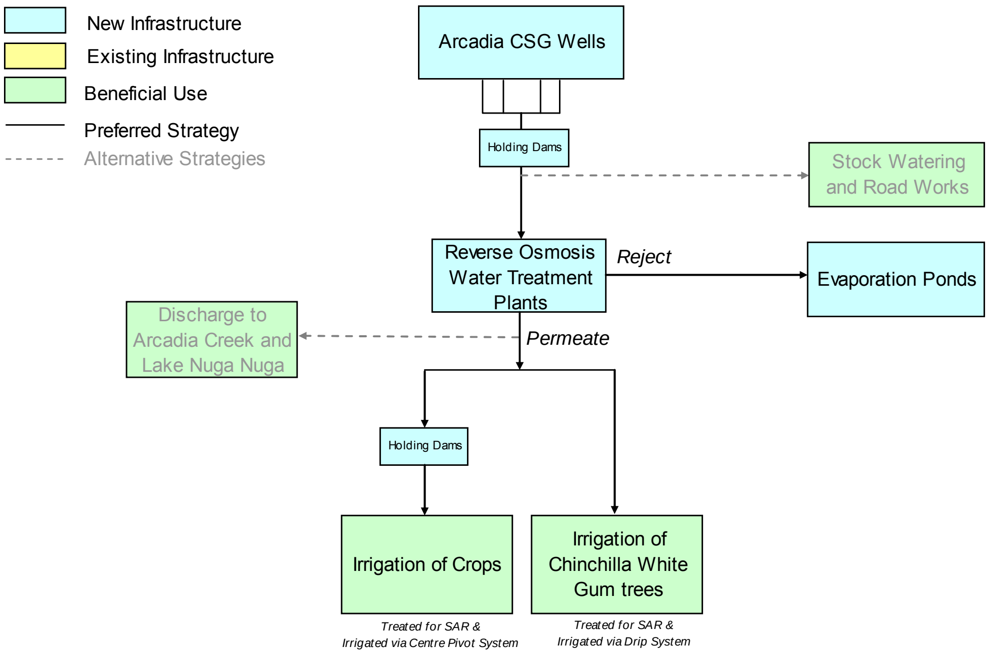
Preferred Option Combinations

The WATERMAN model has been used to assess a number of option combinations based on the available beneficial end-uses as detailed above. Following risk optimisation and careful consideration of the constraints identified in Section 4, and summarised in Section 4.5, the following preferred option and one alternative option have been identified for progression to the Concept Selection stage (see Table 5-5 and Figure 5-9). These options are (on balance) cost effective; pose acceptable risk to the wider environment and least possible risk to Santos. A detailed review of the risk profiles associated with each option is provided in Appendix D.

Table 5-5 Arcadia Valley Associated Water Management Options (% distribution)

Option	Treated and Desalinated Irrigation	Treated Discharge to Grade	Untreated Discharge to Grade	Other Local Uses (road works, stock watering)
Preferred	100%	0%	0%	0%
Alternative	80%	20%	0%	0%

Figure 5-9 Arcadia Valley Water Management Conceptual Model



It should be noted that the options identified are preliminary and will require further examination and optimisation. Furthermore, they are based on assumed water production schedules which are likely to change as the field development plans are developed and refined, and additional monitoring data becomes available.

The main options put forward for the Arcadia CSG field include irrigation, discharge to grade and minor local agricultural and municipal uses (such as stock-watering and road building). All of these options require treatment, as a result of the sensitivity of the receiving environment to changes in salinity inputs. Notably, the area provides very limited opportunity for local community or industrial use (as compared to Roma), and therefore (in line with the EPA's waste-hierarchy) it is considered that the most attractive long term water management solution is to implement the irrigation scheme as outlined above. This has the capacity to manage all of the associated water, can be scaled according to actual schedules of water production and is in line with EPA and DIP policies on associated water (i.e. a Category 1 preferred option). As a back-up option, however, the option of treated discharge to grade could be kept, although given the likely impact on the flow and temperature regime of this activity, it is likely that only a small proportion of associated water could be managed in this way, and for a relatively short time period only.

5.5.2 Potential Impacts and Mitigation Measures

Construction of Water Gathering Networks

The potential impacts and mitigation measures are the same as outlined in Section 5.3.2.

Storage of Associated Water in Water Management Dams

The potential impacts and mitigation measures are the same as outlined in Section 5.3.2.

Storage of Brine in Brine Containment Ponds

The potential impacts and mitigation measures are the same as outlined in Section 5.3.2.

Irrigation of Crops and Trees

The majority of potential detrimental impacts to the environment posed by irrigation of crops and trees would be mitigated by the process of treating all of the associated water to a high standard (TDS concentration < 500mg/L) prior to application. As such, the risk of contamination to receiving surface or ground water resources (from excess water leaving the root zone), and resultant environmental harm is considered negligible.

Treated Discharge to Arcadia Creek and Lake Nuga Nuga.

The potential impacts of discharging treated associated water to Arcadia Creek and Lake Nuga Nuga include:

- Altering the flow regime by introducing additional flows, potentially changing long term stream morphology and sediment and erosion patterns;
- Alteration of riparian vegetation and aquatic species diversity through increased/altered environmental flows and changes in water quality;
- Changes to the temperature regime of up to 10°C at the point of discharge, extending several kilometres downstream; and
- Localised erosion and scour at the point of discharge, if suitable controls are not put in place.

To limit the potential for altering the flow, temperature and water quality regime, it is recommended that discharge to grade is only undertaken during periods of flow. Given the highly ephemeral nature of the Arcadia Creek, this would likely require the potential use of water management (store and release) dams, especially if reasonably significant quantities of water are managed in this way. Alternatively, treated water could be piped directly to Lake Nuga Nuga from a water management dam (temporary storage would be required prior to piping to Lake Nuga Nuga to reduce the temperature of the water to match the ambient temperature). This would remove the potential impacts associated with altering the flow/temperature regime and potentially allow for year-round constant discharge. Additional baseline studies on the environmental values of Lake Nuga Nuga and more detailed impact modelling would be required to support this option (see Section 5.6).

If treated discharge to Arcadia Creek was undertaken, a water quality and river health monitoring programme should be established to detect environmental change outside of agreed limits (physical, chemical and biological change). This should include regular inspection and water quality sampling at the location of discharge and up to two kilometres downstream. For all discharge scenarios it will be necessary to provide erosion controls (preferably using low impact bioengineering methods) at the point of discharge.

A full and detailed review of potential impacts of surface water discharge within the Dawson River catchment area is provided in Appendix Q of the EIS report, the technical report entitled, '*GLNG Gas Field Development - Associated Water Discharge Study*'.

5.5.3 Environmental Opportunities

The environmental benefits of using *treated water to irrigate local crops and trees (or agroforestry schemes)* include:

- Improve supply of water to existing irrigation schemes;
- Reduce the need for extractions from local watercourses and other sources, thereby improving the natural flow regimes of the creeks and improving flora/fauna diversity;
- Provide opportunities for local landholders to increase their crop production areas and yields, or grow other types of high water usage crops for a limited period. This would add to the local economy of the Arcadia Valley and provide opportunity for local employment;
- Improve biodiversity relative to conventional agricultural systems, by creating habitats that can support a wider variety of birds, insects and other fauna;
- Enhance and protect aquatic and riparian resources;
- Assist in the reduction of odour, dust and noise; and
- Provide more green space and improve visual aesthetics

The environmental benefits of *discharging treated water to Arcadia Creek and Lake Nuga Nuga* are as follows:

- Help increase environmental flows (and thereby support aquatic and riparian ecosystems) which may have been impacted by over extractions; and
- Improve supply of water (reliability and volume) to industrial and agricultural downstream users.

5.6 Recommended On-going Studies

A number of feasibility studies and additional investigations are required to support the initial water management strategies put forward in this document, in order to progress to Stage 2, Concept Selection. These include the following:

- Undertake detailed investigations into the proposed irrigation schemes for Roma and Arcadia Valley CSG fields to assess feasibility from a technical, economic, social, environmental and regulatory perspective.

Further investigation should be undertaken into the potential for implementing polyculture rather than monoculture systems.

- Establish a peer group drawn from the commercial Leucaena/grazing and farm forestry sectors to guide the technical development of the proposed irrigation schemes and engage regional communities.
- Undertake a more detailed baseline and impact assessment study on Lake Nuga Nuga to determine whether the option of treated discharge to the lake via Arcadia Creek or direct piping to the lake can be undertaken without detriment to the environment.
- Develop a stakeholder engagement plan specific to the preferred associated water management strategies. The process of stakeholder engagement should be continued within all CSG field areas to ensure that the beneficial uses put forward in this initial strategy are supported by the community.
- Develop a public awareness program for local communities who will be affected by associated water either directly or indirectly. This is important in order to manage the perceived risks relating to the use of treated associated water (potable, feedlots/stock watering, irrigation, and recreational uses etc.).
- Undertake further investigation into best practice approaches for the construction, operation and maintenance and decommissioning of water management dams (evaporation ponds) to ensure that the disturbance footprint and potential for environmental harm are limited as far as possible.
- Undertake a comprehensive study into the feasibility of injecting brine into underlying aquifers within the Roma and Arcadia Valley CSG fields.

5.7 Review and Updating of the Strategy

The initial strategies put forward in this document are based on the existing knowledge of the CSG fields and likely schedules of water production and expected water quality. These are expected to change on a regular basis during the appraisal phase of the CSG field development program, and as such the strategy will require regular monitoring and review, initially on a quarterly basis. The review period will change as the field development plans are further developed and it is expected that an annual review of the water management strategy should be sufficient to ensure that the findings from ongoing studies are taken into account, as well as continual improvement in best practice water management for CSG operations and consultation/negotiation with potential end users.

This process of periodic review and continual improvement also extends to the WATERMAN model. Any changes to the baseline risk profiles, as a result of the outcomes from on-going and recommended studies, will directly affect the selection of the preferred scenario. Santos has indicated that WATERMAN will be continually updated to ensure it reflects the current risk posed by the project. Therefore it is most appropriate to review the selected scenario when changes have been made to the baseline risk profiles.

Summary Section 6

The primary objective of this study has been to develop an Associated Water Management Strategy that considers a range of water management options that can be adapted relative to variability in quality and quantity of associated water produced from wells in different areas, and continual improvement in best practice water management for coal seam gas operations. A key foundation of the strategy has been the development of a knowledge base of constraints, opportunities and risks of various water management options and a risk assessment framework to select appropriate water management options at various stages of the CSG field development program.

At this preliminary stage of the GLNG Project, the Associated Water Management Strategy presented in this report is at the *Concept Evaluation* stage. By March 2009, a number of on-going feasibility studies (recommended in this report) will have been completed which will inform the strategy and allow Santos to progress to the *Concept Selection* stage.

Preferred Water Management Scenarios

In summary, during Concept Evaluation, separate associated water management strategies have been developed for the Roma, Fairview and Arcadia Valley CSG fields. At this preliminary stage of the project, the preferred scenarios that have been selected include:

- Potable, industrial re-use and treated irrigation for Roma CSG field;
- Treated irrigation and untreated irrigation for Fairview CSG field; and
- Treated irrigation for Arcadia Valley CSG field.

The selection of the preferred scenarios has considered the risk to the wider environment, practicality, cost effectiveness and site specific constraints.

The selected strategies are considered to:

1) Provide a viable long term strategy that provides the best net environmental, social and economic outcomes for the region.
2) Promote and adopt EPA category 1 preferred uses of associated water and only use non-preferred uses as a temporary/back-up measure.
3) Maximise opportunities for local community use of associated water and, where ever possible, add value to the local environment and economy.

It is recommended that the strategy is reviewed, monitored and continually improved on a regular basis. Initially, this should comprise quarterly reviews, extending to annual reviews once the field development plans have been further developed. It is envisaged that the strategy will be developed to allow informed decisions to be made throughout the lifetime of the CSG field development program and help meet the needs for regulatory approvals, negotiations, and compliance with EPA requirements.

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A.1 Overview

There are many technologies available for the treatment of associated water. The adoption of one particular technology or combination of technologies is dependent on various factors such as the initial quality of the associated water, the desired end use of the water and hence the level of treatment required and capital and operational and maintenance (O&M) costs. Consumables such as filtration membranes and high energy demand significantly add to the lifecycle costs of associated water treatment. It is unlikely that one single technology can be adopted in isolation as some sort of pre-treatment is usually required to maintain the integrity of the primary system and it should be noted that all of the technologies reviewed here produce significant concentrated waste brine streams requiring treatment and disposal.

A.2 Reverse Osmosis

Reverse Osmosis (RO) is often considered as the preferred desalination technology for associated water due to the advanced nature of its commercial development and widespread use in the desalination industry, the availability of a number of local vendors and its ability to produce high quality water suitable for a wide range of reuse applications. Since the early 1970's the desalinisation of seawater using RO has become an increasingly common option for coastal areas with little or no surface or groundwater, where its high energy requirements are lower than other technologies such as distillation. For the treatment of brackish waters, the use of RO can become increasingly less competitive compared to other solutions.

A.2.1 Technology Summary

RO employs a high pressure differential across a membrane to selectively remove contaminants in the associated water. As the water is forced across the membrane all molecules larger than water are excluded leaving behind a concentrated waste stream. RO is in widespread use for applications such as desalinisation of seawater, treatment of municipal water supplies, purification of industrial cooling water and treatment of water for the food, beverage and pharmaceutical industries.

A.2.2 Applicability

RO already has a history of use in the treatment of associated water in Australia with Origin Energy installing 9Ml/d capacity system at Spring Gully, Queensland and the Queensland Gas Company set to supply up to 1.5Ml/d of potable water to the town of Miles, Queensland in early 2008. Santos is also in the process of installing a small RO plant at Pony Hills capable of treating up to 4.5Ml/d of associated water. This proven technology has the advantages of a low footprint, low operator intervention, modular design allowing easy expansion and maintenance and a number of local suppliers are available. The product water also has the widest range of applications due to its high quality. However it is subject to a relatively high capital and running cost. The high running costs are generated primarily from the high energy demand of maintaining the cross-membrane pressure differential as well as the physical cost of replacing the membranes which have a typical service life of 3-4 years.

However the presence of specific CSG contaminants such as precipitates of iron, manganese and calcium as well as dissolved and free oils can lead to reduced performance due to membrane fouling which reduces permeability. The incidence of soluble organics can also initiate biological growth on the membranes further reducing performance.

URS (2007) recommended the use of several pre-treatment technologies to ameliorate the quality of the associated water to be essential in preserving operational efficiencies and membrane longevity. Specifically, aeration to remove precipitates of iron as well as multi-media/micro filtration to remove suspended and colloidal solids. Consideration of the raw water management also needs to be made in respect to prevention of algal growth during distribution and storage. This might entail disinfection of the feed water.

The waste stream produced is also larger than for comparable technologies being in the order of 20-30% of the feed stream. This water would also require disposal either through evaporation ponds or reinjection.

A.3 Ion Exchange

Ion exchange technology has an established history of use in household water softening and purification, domestic water supply and various industrial treatment, purification and materials recovery processes. Its use in the treatment of associated water has been limited to date but several proprietary units are available and have been used in the full scale treatment of CSG associated water, primarily in the United States.

A.3.1 Technology Summary

Generic ion exchange processes involve the exchange of positively charged (cations) and negatively charged (anions) particles (ions) between those in solution and those attached to an immobile solid particle. The process is generally facilitated through the use of an 'ion exchanger' such as synthetic organic ion exchange resins or naturally occurring inorganic zeolites.

Ion exchange resins are often the preferred exchange medium as they can be tailored to specific applications. They are spherical polymer beads approximately 1mm in diameter that have a microscopically porous structure saturated with loosely held ions able to be exchanged with the ions in solution that need to be removed. Typically a process used in water treatment and purification it is used in water filters to reduce water hardness caused by $Mg2+$ and $Ca2+$ ions which are usually exchanged with $Na+$ and $H+$ ions.

As the influent water is passed through beds of the resin beads the ions in the water have a greater affinity to the beads than those already in place and an exchange occurs. Once the replacement ions are exhausted the resin is recharged by a concentrated solution of the replacement ions. This regeneration of the resin beads usually involves regenerating them in either a concentrated acid solution for the cation resin or a caustic solution for the anion resin. For further water polishing which targets both cations and anions different resins must be used and this can be achieved through the use of twin or mixed resin beds.

A.3.2 Applicability

Ion exchange systems are already in use for the treatment of production water with several propriety systems in use in the United States, however indications are that the process has only been used to treat water to a quality suitable for environmental and agricultural use and that while low in sodium would require further treatment technologies to make it suitable for high quality reuse.

One disadvantage of ion exchange systems is that ion removal is discrete and the process must be specifically targeted to remove the desired contaminants unlike electrostatic processes which tend to target all charged particles. Ion exchange processes also require the use of significant amounts of the chemicals used to regenerate the resin beads and the amount required increases in proportion to increases in the TDS of the feedwater. Neutralisation and disposal of a highly acidic or caustic waste stream would also need to be considered. However the process has a very low energy and maintenance demand and is capable of producing very low mineral content water when used in combination with other treatment technologies such as RO.

A.4 Electro Deionisation

This technology also uses an ion exchange resin however the difference lies in how the resin is regenerated. Instead of using a chemical concentration an electric current is used to remove the contaminant ions and create the replacement ions. This can substantially reduce the costs associated with the use, storage and disposal of conventional regenerative chemicals.

A.5 Capacitive Deionisation

The potential of this relatively recent development has yet to be fully explored for large scale desalinisation projects however it is ideally suited to the treatment of brackish waters where its energy demand compares very favourably with RO.

A.5.1 Technology Summary

Capacitive deionisation is an electrostatic process taking advantage the fact that most salts dissolved in water are ionic i.e. they are either positively (cation) or negatively (anion) charged. The feed water is passed through a high surface area carbon aero gel electrode assembly. When a direct current is applied across the electrode assembly the salt solution ions (as well as heavy metal ions and some organics) are attracted to the oppositely charged electrode and removed from the water. The deionised (treated) water then passes through the unit. The process is unable to operate continuously as the surface of the carbon aero gel electrodes becomes progressively saturated with ions. Regeneration of the electrode surface is simply achieved by reversal of the direct current. Ions are then repelled from the surface of each electrode back into solution where they are removed by purging the system.

The process is particularly advantageous due to its low energy and maintenance requirements. It operates at a low pressure of 15psi and with a voltage difference of around 1.3V little or no electrolysis reactions occur, precluding breakdown of the capacitor material and the formation of secondary solid phases. This should ensure a long service life.

A.5.2 Applicability

The process has only had limited use in associated water treatment and has not been implemented at full production scales therefore its cost effectiveness and practicality remain undetermined. However trials conducted in New Mexico’s San Juan Basin have indicated that TDS removal rates of 75-90% are achievable from water with an initial loading of 2,000-5,000mgL-1 although it was found to be most effective at treating production water at the lower end of this range. This technology is unsuitable for the treatment of high quality water to levels below 100mgL-1 TDS and the cost of the carbon aero gel electrodes is relatively high. As with RO and ion exchange a concentrated brine waste stream will also require disposal however due to its lower tendency to foul the membranes lower levels of pre-treatment would be required.

A.6 Electrodialysis Reversal

This process has enjoyed a variety of uses including the treatment of industrial wastewaters for reuse, treatment of municipal drinking waters and the treatment of agricultural water. It is characterised by its high product to waste stream ratio significantly reducing costs associated with the management of concentrated brine streams.

A.6.1 Technology Summary

Electrodialysis reversal is also an electrostatic process which takes advantage of the ionic nature of the dissolved salts in the feed water. When a direct current is applied to electrodes immersed in the solution ions are attracted to the electrode with the opposite charge. This process takes place in an electrodialysis cell where the movement of the ions is controlled by selectively permeable membranes that allow the transfer of oppositely charged ions but prevent the transfer of similarly charged ions and water. The cell consists of a feed (and product) channel and a concentrate (brine) channel formed between anion and cation exchange membranes placed between two electrodes.

Effectively, concentrated streams (containing salts) and diluted streams (containing reduced salt levels) are produced in the spaces between the membranes (cells). In almost all commercial applications electrodialysis cells are arranged in layers of several hundred called a membrane stack.

By periodically reversing the polarity of the electrodes so that the brine and diluted stream channels are swapped, film, scale and other deposits built up on the membranes may be flushed from the system before fouling occurs. This process may be carried out several times per hour.

A.6.2 Applicability

Electrodialysis has the advantage that it produces a much smaller (but more highly concentrated) waste stream compared to RO, the membranes typically have a longer service life of 8-10 years and the process typically has a lower energy demand. It is better suited to brackish rather than highly saline waters but is capable of removing any charged ions including heavy metal cations and soluble organics. It is able to produce a product stream with a TDS of less than 200mgL-1 however as the level of salts in the feed stream are reduced, increasingly higher amounts of energy are required to overcome the reduced current density caused by reduction in the ions available to carry the charge. Consequently the generation of low TDS product water becomes increasingly uneconomical. Capital costs for electrodialysis may also be higher than a RO system of similar capacity and some pre-treatment of the water is required to remove hardness, suspended solids and organic compounds to reduce membrane fouling. The process also generates a concentrated brine stream which would require disposal although at around 10% of the influent stream (compared to 20-30% for RO) brine management costs could be expected to be lower than other technologies.

A.7 Emerging Technologies

A variety of commercial zero liquid discharge (ZLD) technologies exist that employ rapid crystallisation or evaporation processes to concentrate an effluent stream to a solid residue. These technologies have the potential to reduce the costs involved in the disposal of concentrated brine streams resulting from treatment technologies such as RO and ion exchange by removing the need for evaporative ponds of reinjection however they are subject to very high energy and capital costs are usually found in industrial applications for the recovery of high value materials such as metals from waste streams.

Carbon nanotube filtration has the potential to offer the same purification levels of RO but at a fraction of the energy cost. While the tubes themselves are so small that only seven water molecules may fit across their diameter flow rates are much higher than equivalent RO membranes and trans-membrane movement can be achieved at much lower pressures such that the energy costs associated with RO desalination could be reduced by up to 75%. This emerging technology currently only has a very limited commercial applicability due to the expense of producing the carbon nanotubes.

Options Appraisal

Appendix B

Option	Alternatives	EPA Classification
Injection	**Alternative 1.** Injection into coal seam aquifer - (i) coal seam re-injection - injection back into the producing coal seam. This option has not been thoroughly studied and may have a significant detrimental impact on gas production. (ii) coal seam injection - this could be into a non producing coal seam that lies above or below a producing coal deposit. This would have little or no impact on gas production as the hydrostatic pressure within the coal seam would not be influenced.	**1.** Category 1 (Preferred) - Injection of associated water into an underground reservoir, or an aquifer of equal or lesser water quality, without intermediate surface storage. **2.** Category 2 (Non-Preferred) - Injection after surface water storage (>24hrs) or injection of lesser water quality than the receiving aquifer.
	Alternative 2. Injection into non-coal seam aquifer - (i) coal sequence injection - into hydrologically separated permeable zones/coal-bearing formations (ii) non-coal sequence injection - the most common alternative which involves injection into formations or reservoirs which are well below coal deposits (into basement). This is usually used where CSG water is of poor water quality or has little or no beneficial use.	
	Alternative 3. Aquifer Storage/Recovery (ASR) - injecting associated water into an aquifer for storage and recovery for beneficial re-use (using the same well).	
Storage	**Alternative 1.** Evaporation Ponds	**1.** Category 1 (Preferred) - Direct Use. Including augmentation of water storage dams. **2.** Category 1 (Preferred) - Treated Use. This option may include storage of water in dams prior to treatment and the disposal of brine (treatment by-product) via evaporation. **3.** Category 2 (Non-Preferred) - Disposal via evaporation ponds.
	Alternative 2. Dams (store and release for irrigation or re-injection)	
	Alternative 3. Constructed wetlands	
	Alternative 4. Recreation	
Surface Discharge	**Alternative 1.** Direct discharge to surface water (may be via pipeline or open drain)	**1.** Category 2 (Non-Preferred) - Disposal via discharge to surface waters.
	Alternative 2. Discharge to grade (overland flow or subsurface flow paths)	
Agricultural Re-use	**Alternative 1.** Irrigation	**1.** Category 1 (Preferred) - Direct Use
	Alternative 2. Stock Watering	
Municipal Re-use	**Alternative 1.** Potable Water	**1.** Category 1 (Preferred) - Direct Use. **2.** Category 1 (Preferred) - Treated Use
	Alternative 2. Irrigation and Maintenance of Community Facilities	
Industrial Re-use	**Alternative 1.** Coal Mine Use	**1.** Category 1 (Preferred) - Direct Use. **2.** Category 1 (Preferred) - Treated Use
	Alternative 2. Animal Feeding Operations (Feedlots)	
	Alternative 3. Cooling Tower Water (Power Stations and other industrial applications)	
	Alternative 4. Enhanced Oil Recovery (Not applicable)	
	Alternative 5. Aquaculture (Not applicable)	
	Alternative 6. Fire Protection (Not applicable)	
	Alternative 7. Other Industrial Uses (Not applicable)	

Overview of Option

This option involves the injection of associated waters into underground aquifers being either the aquifer from which the water was extracted or another formation with appropriate characteristics to receive the water. The ability to do this is dependent upon several variables, including the quality of water in the receiving formation, the quality of water being injected, the ultimate storage capacity of the receiving formation(s) and existing regulatory constraints.

Categories

Alternative 1. Injection into coal seam aquifer - (i) coal seam re-injection - injection back into the producing coal seam. This option has not been thoroughly studied and may have a significant detrimental impact on gas production. (ii) coal seam injection - this could be into a non producing coal seam that lies above or below a producing coal deposit. This would have little or no impact on gas production as the hydrostatic pressure within the coal seam would not be influenced.

Alternative 2. Injection into non-coal seam aquifer - (i) coal sequence injection - into hydrologically separated permeable zones/coal-bearing formations (ii) non-coal sequence injection - the most common alternative which involves injection into formations or reservoirs which are well below coal deposits (into basement). This is usually used where CSG water is of poor water quality or has little or no

Alternative 3. Aquifer Storage/Recovery (ASR) - injecting associated water into an aquifer for storage and recovery for beneficial re-use (using the same well). Also known as water banking.

EPA Classification

1. Category 1 (Preferred) - Injection of associated water into an underground reservoir, or an aquifer of equal or lesser water quality, without intermediate surface storage

2. Category 2 (Non-Preferred) - Injection after surface water storage (>24hrs) or injection of lesser water quality than the receiving aquifer

Spreadsheet Input from:

Philippa Kassianos
Tom Silverman - Underground Injection
Lili Pechey - Economics
Benita Blunden - Regulatory
Jim Barker - General review
David Fuller - Surface Discharge
Gary Smith - Treatment
Paul Wilkinson - General review

			Relevance Across CSG Field (refer colour key below)				
			high	medium	low	not applicable	
Factor	**Constraint/Opportunity Description**	**Threshold Values (if available/applicable)**	**Roma**	**Arcadia**	**Fairview**	**Comments**	**Data Needs/Gaps & Monitoring**
Technical	Constraint: FORMATION PROPERTIES: Transmissivity/permeablity needs to be sufficiently high to allow fluid movement within the receiving reservoir or aquifer.					Formation must be able to accept injected water for this option to work. Intrinsic GW formation property not affected by treated associated water; however treatment is crucial to maintain initial aquifer transmissivity/permeability. Santos has some data for Timbury formation.	Pumping tests to determine hydraulic parameters (hydraulic conductivity and storativity) is required. Groundwater analytical or numerical modelling may also be necessary.
	Constraint: FORMATION PROPERTIES: Sufficient storage capacity should be available within the receiving aquifer or reservoir to consume the planned volume of associated water.					Formation must be able to accept injected water for this option to work. Current data collection by Santos indicates that the Timbury formation should be adequate to assimilate the expected volumes of treated associated water; however this is site-specific and potentially tens of injection wells may be necessary in each CSM field. Treatment of associated water is crucial to maintain WQ properties and allow full use of available aquifer storativity.	Pumping tests to determine hydraulic parameters (hydraulic conductivity and storativity) is required. Groundwater analytical or numerical modelling may also be necessary. Also need to characterise distribution of CSG reservoir.
	Constraint: FORMATION PROPERTIES: The static pressure within the receiving formation may limit the rate at which fluids can be injected and/or limit the total volume of injected fluids.					High static pressure will increase injection costs. Costs will likely increase over duration of injection. Current data collection by Santos indicates that the Timbury formation has variable properties, and static pressure may limit the rate/volume of injection in several areas of the CSM fields - individual injection studies will be necessary. Treatment of associated water is crucial to maintain WQ properties and allow maximum/design injection rate/total injected cumulative volume.	Simple field monitoring coupled with groundwater modelling.
	Opportunity: FORMATION PROPERTIES: Alternative 1: Re-injection into the same coal seam aquifer could maintain/re-establish the hydrostatic pressure of the aquifer.					Re-establishing hydrostatic pressures maintains consistent hydraulic gradients. Don't know status of Santos studies of direct re-injection - likely a major data gap. However, previous studies in NSW suggest injection into production formation may be helpful or necessary to avoid CSG "blowouts". Treatment of associated water won't affect this opportunity except to provide a baseline WQ for injection.	Groundwater modelling likely necessary. Long term gw monitoring likely required.
	Constraint: FORMATION PROPERTIES: Alternative 1: Re-injection into the same coal seam aquifer would increase hydrostatic pressure and reduce gas production.						Formation characteristics. Groundwater modelling likely necessary. Long term gw monitoring likely required.
	Constraint: GEOTECHNICAL PROPERTIES: Alternative 1: Compaction of unit during water and gas extraction may prevent re-injection.						Geotechnical evaluation required.
	Constraint: FORMATION PROPERTIES: Alternative 1 and 2: The receiving formation should be vertically and laterally isolated to avoid migration into zones that are not permitted for injection.					Not applicable to associated water treatment issues. However, data collection is necessary to establish injection well integrity (by monitor well program surrounding injection wells), including continuous recording of injection pressure, treated associated water quality measurement, annual mechanical integrity testing by down hole geophysics methods.	Formation Characteristics. Horizontal and vertical distribution of reservoir characteristics such as porosity, permeability, continuity, geochemistry, pressure, fracturing, structure and thickness. Close monitoring is required to ensure that new fractures and old fractures are not propagated through the confining zone as a result of injection pressures. Periodic gw monitoring required over duration of injection.
	Opportunity: FORMATION PROPERTIES: Alternative 1 and 2: Injection into conventional coal sequence formations (which are not connected to CSG formations) or other non coal units will not affect the CSG production.					Likely a major data gap - how will injection into coal sequence formations affect subsequent CSG production rates?	Formation characteristics (see above). Groundwater modelling likely necessary. Long term gw monitoring likely required.

Relevance Across CSG Field (refer colour key below)			
high	medium	low	not applicable

Factor	Constraint/Opportunity Description	Threshold Values (if available/applicable)	Roma	Arcadia	Fairview	Comments	Data Needs/Gaps & Monitoring
Environmental	Constraint: WATER QUALITY: Receiving aquifer water quality should be of equal of lesser quality than the injectate water quality (measured by TDS).					A possible out here is that this can be argued to apply only where the beneficial uses of the aquifer may be affected. Where beneficial uses are identified as nil opportunities to increase e.g. salinity may be appropriate. Treatment of associated water can be tailored to provide the necessary TDS reduction for injection. Therefore, this should not be a program constraint. However, only the necessary TDS reduction should be practiced, as treatment costs rise rapidly with excessive TDS reduction.	Associated Water & Aquifer Characteristics (an assessment of the compatibility of the injectate and aquifer water. Chemistry and volume of associated water to be injected and the receiving aquifer (especially TDS). Note: the range of water chemistry can vary greatly throughout a network of injection wells and can change over time)
	Constraint: FORMATION PROPERTIES: Potential contamination of interconnected aquifers which may cause environmental or social harm.					As above. If aquifers have beneficial uses then need to consider confined aquifer systems for injection; alternatively treat and inject. Deal killer for treated (or untreated as currently practiced) associated water (injected water).	Associated Water & Aquifer Characteristics.
	Constraint: DECOMMISSIONING: Decommissioning (plugging and abandonment) must be undertaken in an environmentally prudent manner.					This is extremely important, but is already regulated and should not be a major risk factor if rules are followed.	No major data gaps. Standard rules must be followed for P&A activities.
	Opportunity: IMPACT REDUCTION: Re-injection to the same coal seam could eliminate the full range of impacts related to surface treatment, disposal or reuse.					Major opportunity to create an environmental benefit by eliminating surface water discharges of associated water.	
	Opportunity: IMPACT REDUCTION: Treat and inject into shallow water aquifers, on-sell water via water trading - offset GAB aquifer usage.					Currently, DNRW only has an embryonic policy for groundwater trade.	
Social	Constraint: WATER QUALITY: Degraded aquifer water quality (as a result of contamination by injectate) could pose a risk to the public water system and other existing uses (industrial, municipal, environmental).					A possible out here is that this can be argued to apply only where the beneficial uses of the aquifer may be affected. Where beneficial uses are identified as nil opportunities to increase e.g. salinity may be appropriate. If aquifers have beneficial uses then need to consider confined aquifer systems for injection; alternatively treat and inject. Deal killer - a major environmental risk. Must be addressed by appropriate planning of injection program and associated water treatment design. Public water system is from separate aquifers. Other aquifer uses are limited and therefore risks are minimal.	Information about current uses of groundwater
	Opportunity: AQUIFER RECHARGE: Alternative 1: Injection into coal sequence may provide an opportunity for aquifer storage/recovery (ASR) and possible aquifer recharge (for depleted areas) for future beneficial uses of the water.					Injected water would need to be of good quality to be used later (i.e. low TDS). The potential to inject treated associated water of sufficient WQ to be used for drinking or other purposes is a major environmental opportunity, and is in direct proportion to the surrounding user community needs for water supplies.	Information about potential future uses of groundwater resource
	Constraint: WATER QUALITY: Alternative 3: Pre-treatment may be required for either aquifer recharge or Aquifer Storage/Recovery (ASR), depending on water quality of the associated water and receiving aquifer.					Pre-treatment/treatment of associated water is likely to be required for most associated water sources. Treatment regime will depend on disposal option - minimal for injection to maintain aquifer integrity; maximum for treatment to drinking water quality standards.	Water quality testing and monitoring or associated water and aquifer water
	Constraint: COMMUNITY: Community acceptance of re-injecting associated water instead of beneficial reuse.					All Comet Ridge communities are likely to perceive that beneficial reuse has a higher priority than injection because of the drought conditions in the area.	
	Constraint: COMMUNITY: Community worried that if water is injected into a confined aquifer, can it burst?					This was a query from Queensland Murray Darling Committee (QMDC). See formation properties constraints above.	
	Constraint: TREATMENT: Pre-treatment desalination costs (if required) can be significant (capital and O&M costs).	Annualised capital and O&M costs for high quality water are estimated to range from $445,000 - $1.543m , depending on volume treated/day (URS 2007). For medium quality water the same costs range from $311,000 - $1.08m. Estimated costs for injection are $M2 to 4 for 1 ML/d.				TDS of associated is dependent upon the depth of the coal seam, the geology surrounding the coal seam, the amount of time the water reacts with the surrounding geology, and the quality of the water entering the coal seam. Based on a previous assessment undertaken by URS for the Santos GLNG project, reverse osmosis (RO) has been identified as the preferred water treatment technology. Medium priority because Santos recognizes that associated water treatment will be required, however expensive it might be.	
	Constraint: INFRASTRUCTURE: Potential need for expensive buffer storage infrastructure/dams to hold the water prior to injection. The size (and cost) of these will be dependent on the rate at which water can be injected (versus supply) and the potential need to treat (or mix) the water prior to injection.	Depending on the storage purpose (i.e.. Storage & release of associated water, storage of brine stream, storage and evaporation of ass. water and brine stream), dam type and capacity, capital costs range from between $6.6m to $55.2m. (GHD 2007 - estimates based on Fairview conditions)				Depending on the availability of appropriate sites, dams may be constructed either as a conventional embankment style dam in a valley, or as a 'turkey's nest', formed by creating a circular wall on a plateau. Infrastructure constraints introduce other issues into the associated water treatment practice, e.g. approvals for dams. Suggested approach is to consider dams specifically for associated water storage prior to treatment, or for treated water storage prior to injection, be considered part of treatment process.	Regulatory and community issues with construction and use of dams for holding associated water influent or treated effluent.

			Relevance Across CSG Field (refer colour key below)				
			high	medium	low	not applicable	
Factor	**Constraint/Opportunity Description**	**Threshold Values (if available/applicable)**	**Roma**	**Arcadia**	**Fairview**	**Comments**	**Data Needs/Gaps & Monitoring**
Economic	Constraint: INFRASTRUCTURE: Long distance pipelines and water gathering networks would be required adding to the cost of injection.	David Keith/Lili Pechey have developed a spreadsheet tool to estimate both capital costs and operating & maintenance costs based on three key inputs: pipeline length, hydraulic head and required flow rate.				The size of pipes and pumps required for a particular application, and hence cost, is a function of several factors, including length, pipe diameter, hydraulic head and flow rate. As such, it is not easy to develop a generic unit cost (i.e.. $ per kilometre) for pipelines. If associated water must be captured due to water quality issues already, then costs may be defrayed. Medium priority because Santos recognizes that associated water treatment will be required, however expensive it might be.	
	Constraint: CSG PRODUCTION: Alternative 1: Injection in close proximity to (or re-injection within) a productive coal seam may result in a loss of CSG resource with significant economic impact.	Estimated capital costs for injection are $7M for 1 ML/d. O&M are estimated at 2% (i.e. $140,000)				Very important issue to determine the effects of injection on CSG production	Injection into zones that are geographically or stratigraphically close to producing coal seams will need to be monitored for any pressure communication with the producing coals
	Constraint: FORMATION PROPERTIES: Greatest determinant on cost is the depth of the well (increasing depth requires more drilling time and advanced equipment).					Disagree - greatest impact on cost is the life of the well in productive use; can greatly outweigh initial drilling cost. The cost of re-injection is dependent on three major factors: the depth of injection required, the pressure required for injection, and the rate at which water is to be injected. Santos has successfully previously conducted a down-hole water injection trial at the Fairview-77 site, pumping for one month into the Timbury Hills Formation. The Timbury Hills Formation was selected as the objective for water disposal on the basis that it had no economic value likely to make it a drilling target in the future (TOGA, 2005).	Formation Characteristics
	Constraint: CSG PRODUCTION: Alternative 1: Potential to impact other CSG operators within the field could result in litigation.					An issue for Santos and other CSG operators in Queensland. Generally the fields are co-owned and therefore this is not a significant risk.	
	Opportunity: INFRASTRUCTURE: Existing wells could be used for the purpose of injection.					Not likely that existing wells could be used efficiently for injection purposes. Will require purpose-constructed injection wells.	
	Constraint: FORMATION PROPERTIES: Aquifer pressure may require expensive pumps to re-inject the associated water.					Unit cost for injection will likely increase over duration of injection. Injection pressure could be a significant economic issue over the life cycle of injection wells.	Formation Characteristics
	Opportunity: INFRASTRUCTURE: Alternative 3: Santos could undertake the AS component and transfer rights to irrigators for the R and avoid pipeline and pump costs.						
Regulatory	Constraint: TREATMENT: If treatment is required prior to injection, the treatment facility needs to be located on the petroleum authority (although the treated water can then be disposed of or reused either within or off the petroleum authority).	WQ to set guideline determined by the EPA - probably ANZECC guidelines.				Probably a negotiating point with EPA. It is likely that most treatment scenarios will involve treatment facility on the petroleum authority for economic and practical reasons.	Associated water treatment system design and layout alternatives/scenarios must be developed to determine economic and practical solutions.
	Constraint: INFRASTRUCTURE: The EPA preferred option (Category 1) for injection does not allow intermediate surface storage (storage must be less than 24 hrs).					Pond is generally required for intermediate storage. 7Ha is the surface area of the pond that is likely to be required. Yes, but why? Possibly an arguing point with EPA. Strategy should be to include associated water treatment dams (storage of influent or effluent) as components of treatment systems, thus achieving Category 1 option requirements. Several injection wells would be required per field area to negate the need for temporary storage.	Must obtain regulatory agreement of what constitutes a associated water treatment system.
	Constraint: APPROVALS: Injection into productive aquifers would require approval from NRW & EPA.	Timing				Under petroleum and gas act 2004 requires groundwater impact study. Timeframes are detailed in the act. Demonstration of adequate treatment will be key to obtaining regulatory approval for injection. EPA approvals timeframe is >12months (Fairview already has approval for FV77 and therefore this process may be expedited	
	Constraint: APPROVALS: Regulatory Authorities are likely to require extensive hydro geological/groundwater modelling to assess the likely impacts on existing and future users of the resource.	Timing				as above Modelling will require a number of scenarios from untreated associated water injection to highly treated associated water injection.	Modelling will be required to fill significant data gaps relative to GW hydrogeology and geochemistry. MatrixPlus are currently undertaking a broad scale study to determine the potential for injection across the field
	Constraint: APPROVALS: Regulatory Authorities are likely to require ongoing monitoring programs and continual reporting to ensure protection of the aquifer.	Timing				as above. If not true isolation of CSM aquifer then similar requirements are likely to apply (especially in future). Monitoring programs will include key WQ parameters, which will in turn feed back into associated water treatment programs.	Monitoring will be required to fill significant data gaps relative to ongoing injection programs. Monitoring programme will be developed by MatrixPlus

STORAGE

Overview of Option
This option involves construction of storages (by excavation or dam structure) for disposal or beneficial

Categories
Alternative 1. Evaporation Ponds
Alternative 2. Dams (store and release for irrigation or re-injection)
Alternative 3. Constructed wetlands
Alternative 4. Recreation

EPA Classification

1. Category 1 (Preferred) - Direct Use. Including augmentation of water storage dams.
2. Category 1 (Preferred) - Treated Use. This option may include storage of water in dams prior to treatment and the disposal of brine (treatment by-product) via evaporation.
3. Category 2 (Non-Preferred) - Disposal via evaporation ponds

Spreadsheet Input from:
Philippa Kassianos
Tom Silverman - Underground Injection
Todd Armstrong - Dams and Evaporation Ponds
Lili Pechey - Economics
Benita Blunden - Regulatory
Jim Barker - General review
David Fuller - Surface Discharge
Paul Wilkinson - General review
Gary Smith - Treatment

Relevance Across CSG Field (refer colour key below)			
high	medium	low	not applicable

Factor	Constraint/Opportunity Description	Threshold Values (if available/applicable)	Roma	Arcadia	Fairview	Comments	Data Needs/Gaps & Monitoring
Technical	Constraint: ENGINEERING: To limit seepage, water storage structures designs will be required to be lined.					Liner either HDPE geomembrane or compacted clay. EPA may also require leakage monitoring. This is a very sensitive issue (regulators and landowners) as seepage of poor quality water through the base of the storage could impact on shallow groundwater.	Geotechnical properties of soils for design of liners. Shallow groundwater monitoring throughout the field to determine position and flow characteristics (this is on-going as part of the EIS) and should be incorporated when available.
	Constraint: SITE CONDITIONS: Availability of suitable topography for construction of the storage (i.e. to minimise earthworks required for construction of the storage and above flood levels).					Topography generally not a fatal flaw. Varies across the field. Certainly the case in Roma. Fairview some opportunities exist. Santos has on drawing board. Acadia true for Comet plains, but some opportunities for storage in hills. Possibly use existing holes - Coal mines? At the appraisal stage (pilot wells) a 5Ha footprint is required to store 200ML of water. Up to 20Ha and beyond could be required for more significant structures (>200ML).	Local topography information
	Constraint: SITE CONDITIONS: Alternative 1: Construction of evaporation ponds is not suitable in hilly areas or areas where limited land is available, as large surface areas are required.					For Roma, some hilly areas, some flat. Land availability is the issue. Land blocks are small in Roma and this could limit the potential for this option.	Local topography information
	Constraint: SITE CONDITIONS: Areas with high water tables should be avoided.					Unlikely to be a major issue in the Comet Ridge area, except immediately near water courses, where dams should not be constructed.	Local groundwater information. Shallow groundwater monitoring throughout the field to determine position and flow characteristics (this is on-going as part of the EIS) and should be incorporated when available.
	Constraint: SITE CONDITIONS: Permeable foundations should be avoided.						Local soils & geology information
	Constraint: ENGINEERING: Storages for stock watering and/or wildlife use should have gentle slopes to reduce erosion and suspended solids.					This is generally the case anyway. Besides, sediment is contained within the storage dam. That is a requirement for RUP for beneficial reuse. May need to actively exclude wildlife and stock access - depending on water quality.	
	Constraint: ENGINEERING: Surface area requirements for storages for wildlife may need to be large in order to support particular animal populations.						
	Constraint: ENGINEERING: Access needs to be maintained for maintenance and inspection of storages.					Access to well sites nearby will be maintained.	Local topography and existing land use information.
	Constraint: WATER SUPPLY: Alternative 4: Large amount of associated water required to supply recreational water storage (especially with high rates of evaporation).					Recreation use is unlikely	Associated water production rates
	Constraint: SITE CONDITIONS: Alternative 3: long-term effects of Sodium Absorption Rate (SAR) on soil permeability could hinder wetland function.					This is only true for loose topsoils at the surface. Insitu mineral soils will not be significantly affected by SAR. SAR will be nearly infinite if near zero Cl and Mg - refer Santos irrigation investigations at Fairview.	Water chemistry information

			Relevance Across CSG Field (refer colour key below)				
			high	**medium**	**low**	**not applicable**	
Factor	**Constraint/Opportunity Description**	**Threshold Values (if available/applicable)**	**Roma**	**Arcadia**	**Fairview**	**Comments**	**Data Needs/Gaps & Monitoring**
	Opportunity: LOCATION: Locating storage dams in centralised locations to optimise construction efficiencies and reduce impacts.					Locating storage dams in centralized locations creates economy of scale, but may not be possible given the distribution of CSG production wells or area topography.	Local topography information; distribution of CSG wells.
	Constraint: REGULATIONS: TO avoid Referable Dam status (Water Act 2000) dams shall be less than 8 metres high and less than 250ML storage.						
	Opportunity: WATER SUPPLY: Water available for construction and dust suppression.						
	Opportunity: IMPACT REDUCTION: minimise adverse impacts on sensitive terrestrial ecosystems, agricultural lands and useful surface or groundwater resources.					Dams must be designed and constructed by suitably qualified persons. To minimise adverse impacts on sensitive terrestrial ecosystems, agricultural lands, and surface or GW resources will require treatment of associated water to achieve regulatory limits or goals.	
	Constraint: WATER QUALITY: Water storages such as evaporation ponds may have potential for vertical leakage of poor-quality associated water into shallow aquifers with high(er) quality groundwater.					Evaluation to determine groundwater depth and water quality is currently underway for Roma, Arcadia, and Fairview.	Associated water quality, location and characteristics of shallow groundwater. Hydrogeologic evaluation of shallow groundwater aquifers to determine items including depth, gradients, conductivity, estimated recharge, and water quality.
	Constraint: WATER QUALITY: Pure water evaporates, resulting in a higher TDS for the remaining water. Overtime when water supply finishes there may be a problem with salt dust.					Dams are designed to prevent seepage, regardless of the contaminant concentrations. Need rehab plan which might involve removal of salts and movement to centralised capped dumps? Opportunity to utilise the Moonie Ponds located 150km from Roma. Associated water could help suppress ongoing issues with salt dust. The key issues with evaporation ponds include 1) loss of fresh water evaporated rather than beneficially reused (assuming associated water treatment), and 2) cost of injection disposal of saline evaporates.	Associated water quality. Water balance modelling including salts balance to determine TDS concentrations.
	Constraint: SITE CONDITIONS: Storages need to be constructed above local flooding levels, to avoid flood waters coming into contact with associated water (or potentially poor water quality)					Dams are generally designed to prevent flood waters coming in contact with dam. Potential for inundation is negligible.	Local hydrology information and supporting hydraulic calculations/modelling.
	Constraint: WATER QUALITY: Depth and quality of shallow groundwater.					Local shallow GW may be used for stock watering, irrigation, or other beneficial uses if of sufficient quality re: TDS and other WQ parameters. It is critical that associated water treatment be used to avoid contaminating local shallow GW.	Aquifer water quality information. Shallow groundwater monitoring throughout field to determine position and flow characteristics (this is on-going as part of the EIS) and should be incorporated when available.
Environmental	Opportunity: WATER QUALITY: transfer associated water to Moonie Evaporation Ponds to suppress salt dust. Moonie ponds are already authorised as regulated water storages.	Combined, the Moonie Evaporation Ponds are 1.0 km by 1.4 km by 1 m deep = 1.4 e6m3 or 1400 ML. This area is broken into 4 parts roughly equal with 3 parts dry and being tilled by dozers to keep the salt contaminants from blowing away.				Major costs involved with this option. Long term solution to the Moonie evap ponds is closure to avoid contamination of adjacent land by salts.	Santos closure plans for Moonie Evaporation Ponds.
	Opportunity: WATER SUPPLY: To increase wildlife populations and vegetation as a result on increased water availability.					This is only an opportunity if the water is of suitable quality. If the water was of poor water quality, the environment would need to be protected against access. Queensland CSG associated water policy may limit the amount of treated associated water that can be used for Category 1 uses, especially increased water availability for wildlife support; however a primary driver for associated water reuse will be increased fresh water availability due to drought conditions in Queensland. The two objectives must be balanced from a regulatory and social perspective.	Knowledge on wildlife species, habitats, breeding, migration and populations. Proximity of wildlife populations or potential sites for the establishment of wildlife populations.
	Opportunity: EROSION & SEDIMENT CONTROL: To reduce livestock entering natural watercourses for water supply and destabilising banks, increasing sediment loads and contaminating waters (manure).						
	Constraint: LIMITED RESOURCE: Impacts of storages drying up on livestock and wildlife.					Only a concern if livestock numbers increase due to availability of additional water. Not important, argue that short term provision of additional habitat provided, Santos cannot be responsible for longer term.	Associated water production rates and treatment rates

			Relevance Across CSG Field (refer colour key below)				
			high	medium	low	not applicable	
Factor	**Constraint/Opportunity Description**	**Threshold Values (if available/applicable)**	**Roma**	**Arcadia**	**Fairview**	**Comments**	**Data Needs/Gaps & Monitoring**
	Constraint: WATER SUPPLY: Alternative 3: Additional water supply may be required to supplement associated water supply during and definitely post associated water production.					There is no guaranteed supply of water even during the project as water production rates may vary (existing estimates have high inherent uncertainty). As such ecosystems dependent on environmental flows may be vulnerable to changes in actual production versus planned. There are limited opportunities for supplemental water supplies, especially given recent drought conditions.	Associated water production rates
	Constraint: WATER SUPPLY: Supply of water to a previously dry area, may introduce problems into an ecosystem.					The greater effect on the ecosystem will be the stripping of soil and construction of the dam. Unlikely to be a significant issue in storages.	
Social	Constraint: COMMUNITY: Aesthetically damaging to landscape						
	Constraint: LANDOWNER: Placement of water storages to meet landowner requirements					Due to drought conditions, landowners likely to be accepting of treated associated water supplies wherever they are provided.	
	Constraint: LANDOWNER: Who takes on the ongoing maintenance of the water storage	Queensland Associated Water Guidelines for Beneficial Reuse				Requires formal agreement under EPA guidelines. Queensland guidelines specify assignment of responsibilities for beneficial reuse plans.	Further discussions between EPA, Santos and Landowners would be required to determine post project dam ownership.
	Opportunity: LANDOWNER: Construction of a new water storage that can supplement livestock watering and/or open new grazing land previously unavailable.					This would require above formal agreement under EPA guidelines to protect Santos.	Water quality. Water quantity required.
	Opportunity: COMMUNITY: Alternative 4: Fishing, swimming, boating camping facility for recreational use.					Could be a significant opportunity for Roma. Unlikely that treated associated water will be supplied for lower priority uses such as irrigation.	
	Constraint: LIMITED RESOURCE: Alternative 4: Recreational water storage would cease to exist once the supply of associated water declined.						
	Constraint: COMMUNITY: Alternative 4: Community may prefer to see more practical uses for associated water than recreational water storage facility.						
	Constraint: COMMUNITY: Alternative 4: Appropriate location close to a community that will derive benefit from the recreational facility.						
	Constraint: LANDOWNER: Landowners not agreeing to any work being performed on their property, beyond the initial appraisal wells.						
	Constraint: LANDOWNER: Landowners want an assessment of diminution in value of their properties prior to construction of storages. If judgement by land tribunal is required, there are potential time constraints.	Timing - 2 years.					
	Constraint: WATER QUALITY: Negotiations with landowners depend on the water quality of associated water.					Associated water treatment demonstration is critical to landowner acceptance of treated associated water reuse plans.	Associated water quality information.
	Constraint: MARKETABILITY: Storage options will need to be sold to landowners as they are the less preferred option.						
	Constraint: DECOMMISSIONING: Legacy of sites (i.e. contamination & salinity) after dams are decommissioned					This was a query from Queensland Murray Darling Committee (QMDC).	
Economic	Constraint: LANDOWNER: Landowner required to provide financial assurance due to potential environmental harm. Legacy Issue.						
	Constraint: CONSTRUCTION: Expensive construction costs associated with water storages - materials, equipment and travel distance.	Dams around Roma generally cost CA 1.5 to $2M for 140 to 200ML capacity. Depending on the storage purpose (i.e.. Storage & release of associated water, storage of binestream, storage and evaporation of ass. water and brine stream), dam type and capacity, capital costs range from between $6.6m to $55.2m. (GHD 2007 - estimates based on Fairview conditions)				Depending on the availability of appropriate sites, dams may be constructed either as a conventional embankment style dam in a valley, or as a 'turkey's nest', formed by creating a circular wall on a plateau. Alternatives include surface water augmentation by treated associated water, allowing extraction under current national and local withdrawal policies.	
	Constraint: DECOMMISSIONING: Decommissioning of basins - salt removal and/or capping.					Also includes partial removal of dams. Closure costs must be factored into life cycle costs of evaporation ponds.	
	Constraint: CONSTRUCTION: Need to import clay materials for construction.					Dams are generally built from materials available on site.	Local soils information
	Constraint: MAINTENANCE: Ongoing maintenance costs for water storages and associated infrastructure.					These costs will not be significant, but the responsibility is. Maintenance costs are low for lined associated water storage dams, compared to tanks or other means of storage.	Estimation of maintenance costs.

			Relevance Across CSG Field (refer colour key below)				
			high	medium	low	not applicable	
Factor	Constraint/Opportunity Description	Threshold Values (if available/applicable)	Roma	Arcadia	Fairview	Comments	Data Needs/Gaps & Monitoring
	Constraint: LAND : Alternative 4: Large amount of land would be required for construction of a recreational water storage.					This may be a challenge for the Roma field	Land acquisition costs
	Constraint: LAND: Alternative 1: Large surface area is required for an evaporation pond - expensive land and economically viable agricultural land.						Land acquisition costs. Existing land use information.
	Constraint: WATER QUALITY: Alternative 1: Higher TDS associated water will result in more concentrated brines - may increase disposal and reclamation costs at evaporation pond closure.					Concentrated brines are more readily evaporated to dry material for easier handling and waste disposal. Costs of associated water treatment and brine disposal will be proportional to initial TDS concentration.	Associated water quality. Water balance modelling including salts balance to determine TDS concentrations.
	Constraint: TREATMENT: Pre-treatment desalination costs (if required) can be significant (capital and O&M costs).	Annualised capital and O&M costs for high quality water are estimated to range from $445,000 - $1.543m , depending on volume treated/day (URS 2007). For medium quality water the same costs range from $311,000 - $1.08m. Estimated costs for injection are $M2 to 4 for 1 ML/d				This may become important if it is planned to release waters to the environment. TDS of associated is dependent upon the depth of the coal seam, the geology surrounding the coal seam, the amount of time the water reacts with the surrounding geology, and the quality of the water entering the coal seam. Based on a previous assessment undertaken by URS for the Santos GLNG project, reverse osmosis (RO) has been identified as the preferred water treatment technology.	Existing Santos associated water treatment designs and plans; cost estimates.
	Opportunity: WATER SUPPLY: Potential supply of drinking and agricultural water						Cost/Benefit of treatment and distribution vs. water value.
Regulatory	Constraint: APPROVALS: Design of water structures is subject to EPA approvals	Timing - approximately 4 months?				EPA have 28 days to respond to a dam design request. If no response, Santos may build the dam provided it is within the EA. An EA amendment will always be required (i.e. the EA needs to be updated to include the new dam). Currently EA amendments are taking between 6 - 12 months, but should only take 3 - 6 months. Regulatory approval process must be incorporated into Santos project timelines.	
	Constraint: APPROVALS: EPA will be required to approve the construction of a storage to contain associated water in accordance with Water Act 2000	Timing????				The more restrictive EP Act applies to dams storing regulated waste. The Procedural Overview (EPA draft 12-11-07) on Regulated Dams is the guideline adopted for design. The only time NRW are required to give an approval is when Santos are building a dam on property that they own. Regulatory approval process must be incorporated into Santos project timelines.	
	Constraint: OWNERSHIP: Transfer of ownership of storage is required	Timing????				Santos are required to submit a Beneficial Re-use Application to enable the landowner to access the water storage that Santos has built on their property. EPA approve the Beneficial Reuse Application. Only one application of this nature has been submitted to the EPA and it took 18 months to process. Regulatory approval process must be incorporated into Santos project timelines.	
	Constraint: OWNERSHIP: Alternative 4: Management and liability implications of recreational water storage facility on private land.					There is a recreational dam in Roma (currently used for water skiing etc) that Santos are considering supplying water to. Santos would set up an agreement with Roma Regional Council that included the following - Santos to supply water at a set quality and the liability would remain with Roma Regional Council (signage already exists that say swim/use at your own risk).	
	Constraint: APPROVALS: ATP areas need to be converted to PLs (with storage dam facilities included on the Environmental Authorities) or the ATPs need to be amended to include storage facilities.	Timing ???				An evaporation pond or storage pond would rarely be required in an ATP. An EA amendment will always be required (i.e. the EA needs to be updated to include the new dam). Currently EA amendments are taking between 6 - 12 months, but should only take 3 - 6 months. Regulatory approval process must be incorporated into Santos project timelines.	

SURFACE DISCHARGE

Overview of Option
This option involves discharge of associated water to surface water systems either via direct discharge

Categories
Alternative 1. Direct discharge to surface water (may be via pipeline or open drain)
Alternative 2. Discharge to grade (overland flow or subsurface flow paths)

EPA Classification
1. Category 2 (Non-Preferred) - Disposal via discharge to surface waters

Spreadsheet Input from:
Philippa Kassianos
Lili Pechey - Economics
Benita Blunden - Regulatory
Jim Barker - General review
David Fuller - Surface Discharge
Penny Flukes - Surface Discharge
Paul Wilkinson - General review
Gary Smith - Treatment

Relevance Across CSG Field (refer colour key below)			
high	medium	low	not applicable

Factor	Constraint/Opportunity Description	Threshold Values (if available/applicable)	Roma	Arcadia	Fairview	Comments	Data Needs/Gaps & Monitoring
Technical	Constraint: SURFACE WATER CHARACTERISTICS: Alternative 1: quantity of water that can be managed by surface discharge depends on existing character of surface water system and quality of associated water.	limitations, guidelines, quantity, etc				Including existing groundwater discharge. Hydrological modelling is proving very difficult, need to install stream gauges. Timing constraint 2 years. TOR requires investigation into cumulative impacts - need to consider cumulative impacts pf multiple surface discharges in catchment by multiple producers (Origin, Arrow & QGC). This was a query from Queensland Murray Darling Committee (QMDC). Streams in Roma/Arcadia predominantly intermittent, low to no flow during dry season; flow governed by rainfall events. Flow in Dawson River and Hutton Creek in vicinity of Fairview maintained by spring inputs. Associated water treatment is key to future Category 1 direct discharge to surface water. Current Santos plan is to continue existing untreated discharges to surface water as long as permitted to do so.	Hydrology & Hydraulic modelling of surface water system. Associated water quality.
	Opportunity: WATER QUALITY: Dilution of associated water with surface water.					Limited by storage locations for either assoc water or surface water. Potential for spring flows to dilute associated water during low flow conditions at Fairview. Dilution of associated water during rainfall events at all fields. Limited or no dilution will be allowed by the regulatory agency. However, Santos does plan to blend untreated and treated associated water before direct discharge.	Hydrology & Hydraulic modelling of surface water systems under varying discharge scenarios. Establish baseline surface water quality and associated water quality. Santos associated water treatment strategy and plans.
	Constraint: SURFACE WATER CHARACTERISTICS: Alternative 1: physical impact of increasing/changing existing flow regimes in receiving waters.					Will be minimal. Potential to alter flow regimes in Roma/Arcadia surface water bodies from intermittent to continual flow. Potential at Fairview to increase current flow. All streams in the field area are ephemeral. The wells would produce water all year round which would drastically change the flow regime (sustained base flows plus removal of zero flow periods). Treated associated water direct discharge should improve riparian habitat and general in-stream WQ. However, there may be regulatory issues to negotiate.	Nil - size of stream channels is many times that of associated water discharge. Hydrology & Hydraulic modelling of surface water systems under varying discharge scenarios. Establish baseline surface water quality and associated water quality. Santos associated water treatment strategy and plans.
	Constraint: WATER QUALITY: Alternative 1: poor water quality of associated water against the water quality of the receiving environment.	EC Water Quality Objective (QWQG) 340uS/cm				Concentrations of parameters and/or physical characteristics in associated water (e.g. EC, temperature, alkalinity, boron, etc.) may alter concentrations of receiving waters. WQ of treated associated water will exceed in-stream WQ in most cases by design, thereby improving overall in-stream WQ.	Quality of associated water and receiving water. Estimation of the capacity of the surface water system to receive contaminant loads in the associated water. This is being assessed as part of the EIS Surface Water Study

Factor	Constraint/Opportunity Description	Threshold Values (if available/applicable)	Roma	Arcadia	Fairview	Comments	Data Needs/Gaps & Monitoring
			Relevance Across CSG Field (refer colour key below)				
			high	medium	low	not applicable	
	Constraint: EROSION & SEDIMENT: Alternative 1: bank erosion, bed scour and/or increased risks of flooding during high flow events.		low	low	low	Nil - as above. Volume of associated water discharge and associated erosive effects likely to be minor contributor to flow compared with bankfull flood. Contribution of sediment loads due to associated water likely to be significantly less than contribution from high rainfall events.	
	Constraint: EROSION & SEDIMENT: Alternative 2: soil erosion could be a problem, depending on soil type, surface vegetation, land slope and water volume.		medium	medium	medium	Minimal - existing soil erosivity is very high. Will vary depending on stream bed substrate (varies across and within each catchment from sand (erosion likely) to bedrock (erosion unlikely)).	Local soil property information. Associated water discharge volume.
	Constraint: LIMITED RESOURCE: Alternative 1: Impacts of removing the additional flow in surface water systems after the operating life of the project.		high	high	low	Under existing arrangements this is a State resource the minute water hits the river system. Something for the State to worry about. Could be considered an opportunity as well - streams may return to current condition (i.e. intermittent) upon removal of resource. May result in shift in species. After 20 years (approximate project lifetime), aspects of the ecosystem may be dependent on the environmental flows.	
	Opportunity: ENVIRONMENTAL FLOWS: Alternative 1: Increased environmental flows - wildlife support.		medium	medium	medium	Can't argue this. Counter-argument is that discharge will affect the available habitat and natural cycles of wetting and drying.	Characterisation (and calculation) of environmental flows in receiving waters.
	Opportunity: EROSION & SEDIMENT: Alternative 1: Use of pipelines to avoid erosion and suspended solids (impact on surface water quality).		medium	medium	low	Effectiveness will depend on substrate (i.e. sand vs. bedrock)	Characterisation of streambeds in vicinity of proposed discharge points
	Constraint: ENVIRONMENTAL FLOWS: Potential for aquatic weeds to gain hold in continuous flowing water compared with ephemeral		medium	medium	medium		Being investigated as part of GLNG water study. Assessment of weed threats and characteristics (e.g. salinity tolerance)
	Constraint: WATER QUALITY: Temperature is a key issue, especially during the dry season.		medium	medium	medium	Potential for algal dominance. Evident at Fairview streamlines.	
	Opportunity: WATER QUALITY: Alternative 1: Improvement of existing surface water quality through dilution		medium	medium	medium	Discharge of associated water may lead to improvements in concentrations of certain parameters in receiving waters (e.g. nutrients)	Quality of associated water and receiving water. Estimation of the capacity of the surface water system to receive contaminant loads in the associated water.
	Constraint: ENVIRONMENTAL FLOWS: Alternative 1: Increased environmental flows resulting in increased cattle access.		medium	medium	medium	Increasing volumes may result in increased cattle access and associated degradation of streams	
	Constraint: ENVIRONMENTAL FLOWS: Alternative 1: Alteration of riparian vegetation and aquatic species through increased/altered environmental flows		high	high	medium	Creating continuous water flow as opposed to intermittent flows may lead to a shift in the dominant species within watercourse and possibly in riparian areas by creating a new aquatic environment. May lead to an increase in algae in vicinity of discharge streams.	Characterisation (and calculation) of existing environmental flows in receiving waters. Baseline assessment and ongoing monitoring of river health (riparian vegetation and macro invertebrates)
	Constraint: WATER QUALITY: Alteration of riparian vegetation and aquatic species due to difference in water quality of associated water compared with receiving waters		high	high	medium	Physical characteristics of associated water may lead to a shift in species in streamlines, particularly during low flow periods (i.e. less dilution of associated water)	Characterisation (and calculation) of existing environmental flows in receiving waters. Baseline assessment and ongoing monitoring of river health (riparian vegetation and macro invertebrates)
	Constraint: MEASUREMENT: Alternative 1: Measurement and stewardship challenges for water discharge to stream and removed downstream by customer/user.		not applicable	not applicable	not applicable	Not applicable as water becomes state resource once it enters a stream. Roma community may not be supportive if the water was delivered for use elsewhere.	
Social	Constraint: COMMUNITY: Community acceptance of discharging associated water instead of beneficial reuse.		low	low	low	Generally acceptable provided no impacts. Category 1 direct discharge should be perceived by the public as a high priority beneficial reuse, as the water can be withdrawn downstream for beneficial purposes, and costs of transport by pipeline are eliminated.	
	Constraint: LIMITED RESOURCE: Alternative 1: Impacts of removing the additional flow in surface water systems after the operating life of the project.		medium	medium	medium	Since DNRW is an intermediary it is their problem to manage - but Santos should engage and seek to ensure temporary rights are established rather than permanent. Promotion of short term industries is an opportunity. Economics of short term high value industries?	
	Constraint: COMMUNITY: Community perception of environmental impacts.		medium	medium	medium	True, but if approved in EMP then EPA problem?	
	Opportunity: WATER SUPPLY: Alternative 1: Water supply available for downstream users - municipal, industrial, agricultural.		medium	medium	medium	Probably need to utilise scenario planning approach here given uncertainties.	Estimation of likely available water supply.
	Constraint: MONITORING: Significant monitoring requirements imposed.		medium	medium	medium		Widespread telemetry system would be required to monitor flow and water quality

			Relevance Across CSG Field (refer colour key below)					
			high	medium	low	not applicable		
Factor	**Constraint/Opportunity Description**	**Threshold Values (if available/applicable)**	**Roma**	**Arcadia**	**Fairview**	**Comments**		**Data Needs/Gaps & Monitoring**
Economic	Constraint: INFRASTRUCTURE: Alternative 1: Pump and pipework capital and operational costs to the discharge point.	David Keith/Lili Pechey have developed a spreadsheet tool to estimate both capital costs and operating & maintenance costs based on three key inputs: pipeline length, hydraulic head and required flow rate.	medium	medium	medium	The size of pipes and pumps required for a particular application, and hence cost, is a function of several factors, including length, pipe diameter, hydraulic head and flow rate. As such, it is not easy to develop a generic unit cost (i.e.. $ per kilometre) for pipelines.		
	Opportunity: INFRASTRUCTURE: Alternative 1: Opportunity for joint funding with other CSG producers (Origin, Arrow, QGC) for pipeline infrastructure.		medium	medium	medium	TOR requires investigation into cumulative impacts.		
	Constraint: INFRASTRUCTURE: stabilisation works may be required at the point of discharge.		low	low	low	Localised erosion controls would be required		
	Constraint: INFRASTRUCTURE: Alternative 1: Temporary storage may be required to mimic natural flow conditions.	Depending on the storage purpose (i.e.. Storage & release of associated water, storage of binestream, storage and evaporation of ass. water and brine stream), dam type and capacity, capital costs range from between $6.6m to $55.2m. (GHD 2007 - estimates based on Fairview conditions)	medium	medium	high	Subject to Ecological Risk Assessment. Depending on the availability of appropriate sites, dams may be constructed either as a conventional embankment style dam in a valley, or as a 'turkey's nest', formed by creating a circular wall on a plateau. Expensive dams would be required to achieve this (see dam constraints sheet). Direct discharge into ephemeral streams may required dam storage of associated water treated effluent, but dam storage may be deemed to be component of treatment system.		
	Constraint: ENGINEERING: Alternative 1: Study to characterise associated water and receiving water quality, physical characteristics of the receiving system and impacts on the receiving water system.		medium	medium	medium	This is currently being undertaken, as part of the EIS Surface Water Study.		
	Constraint: TREATMENT: Pre-treatment desalination costs (if required) can be significant (capital and O&M costs).	Annualised capital and O&M costs for high quality water are estimated to range from $445,000 - $1.543m , depending on volume treated/day (URS 2007). For medium quality water the same costs range from $311,000 - $1.08m.	medium	medium	medium	Treatment will probably be required in most areas. Potential for shandying as mentioned above. TDS of associated is dependent upon the depth of the coal seam, the geology surrounding the coal seam, the amount of time the water reacts with the surrounding geology, and the quality of the water entering the coal seam. Based on a previous assessment undertaken by URS for the Santos GLNG project, reverse osmosis (RO) has been identified as the preferred water treatment technology. Considered very likely - although treatment is expensive and would not be socially responsible since low TDS water would be disposed of, rather than beneficially re-used.		
Regulatory	Constraint: APPROVALS: Not favoured by government departments (latest QLD EPA Policy on Associated Water deems this a Category 2 Non-Preferred strategy).		medium	medium	medium	Short term approval is given after water has been treated for temporary discharge, however studies of river health system and modelling are required to indicate that discharging does not have a negative impact on the watercourse or soil surface. NRW is considering associated water as an adjunct to yield for Nathan Dam. Although this could be a short-term option it would be necessary to demonstrate to the EPA that Category 1 Preferred Options would be explored and implemented.		
	Constraint: APPROVALS: Regulators are moving away from water discharge to stream and removed downstream by customer/user, with preference for pipe distribution.		medium	medium	medium	This is limited by Water Act 2000. Once water in-stream it becomes property of the state and then managed under the Water Act 2000 - Water Resource Plans and Resource Operations Plans (known as an un-allocated water resource).		
	Constraint: APPROVALS: EPA approval is required.		medium	medium	medium	EPA approval is required to discharge treated associated water (see above). To sell associated water to someone downstream you need to be a licensed water provider under the Water Act 2000.		
	Constraint: APPROVALS: Discharging to grade for an irrigation trial (depending on the size of the trial) requires submission of a Land and Water Management plan to NRW.		medium	medium	medium			

AGRICULTURAL RE-USE

Overview of Option

This option involves use of associated water for agricultural uses such as irrigation and stock watering

Categories
Alternative 1. Irrigation
Alternative 2. Stock Watering

EPA Classification
1. Category 1 (Preferred) - Direct Use

Spreadsheet Input from:
Philippa Kassianos
Lili Pechey - Economics
Benita Blunden - Regulatory
Jim Barker - General review
David Fuller - Surface Discharge
Paul Wilkinson - General review
Gary Smith - Treatment

			Relevance Across CSG Field (refer colour key below)				
			high	medium	low	not applicable	
Factor	**Constraint/Opportunity Description**	**Threshold Values (if available/applicable)**	**Roma**	**Arcadia**	**Fairview**	**Comments**	**Data Needs/Gaps & Monitoring**
Technical	Constraint: SITE CONDITIONS: Alternative 1: What variations occur in local infiltration rates?						Need to know infiltration rates in likely locations for irrigation, including substrate, and possible presence of pans or other limiting phenomena.
	Opportunity: WATER SUPPLY: Alternative 1: Potential for associated water used for irrigation to infiltrate to groundwater, potential for groundwater supply enhancement provided water is of suitable quality.						
	Constraint: SITE CONDITIONS: Alternative 1: Is enough land available in total, and in suitable sized parcels at suitable locations?					Is it best to irrigate land in small parcels near to each well, rather than in larger areas that require long supply lines.	
	Constraint: WATER SUPPLY: Alternative 1: Flexibilities that can be built into the irrigation to manage the likely range of available water.						
	Opportunity: WATER SUPPLY: Alternative 1: Flexibilities that can be built into the irrigation to manage the likely range of available water.						
	Opportunity: SITE CONDITIONS: Alternative 1: Small irrigation plots centred near wells (and therefore spread over very large geographic area) could create opportunity for local landowners to operate irrigation and harvesting activities.						
	Constraint: SITE CONDITIONS: Alternative 1: Small irrigation plots centred near wells (and therefore spread over very large geographic area) could make it difficult to manage irrigation and farming operations.						
	Opportunity: DECOMMISSIONING: Alternative 1: Consideration should be given to possible close down arrangements at end of productive life of well field and water extraction						
	Constraint: DECOMMISSIONING: Alternative 1: Consideration should be given to possible close down arrangements at end of productive life of well field and water extraction						
	Constraint: SITE CONDITIONS: Alternative 1: For irrigation to be successful, suitable soil properties (i.e. Sodium Absorption Rate - SAR) are required.	Soils mentioned in Table 4.2.5 of Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000) Volume 1: Chapter 4.2. SAR and EC range for stable soil structure in Figure 4.2.2 of above guideline.				DNRW is confident regarding the use of high SAR water at Fairview. Need to understand why. Drip irrigation can be used to avoid SAR problems. Associated water treatment is critical to allow irrigation at limiting SAR values.	Roma and Scotia typically have very dispersive soils, unsuitable for cropping.
	Constraint: SITE CONDITIONS: Alternative 1: Potential for associated water used for irrigation to infiltrate to groundwater (if shallow and depending on soil properties) and potentially contaminate (depending on water quality of associated water and groundwater).	Land selected 150m above rivers.				True, and not assessed as part of L&WMP for Fairview. If associated water treatment is provided prior to irrigation (SAR, TDS, Na are all within allowable limits), the potential for GW contamination becomes a low risk.	Local soil property information. Local aquifer information. Associated water quality information.
	Constraint: SITE CONDITIONS: Alternative 1: For irrigation to be successful, will depend on the quantity and seasonality of rainfall.					Main issue is how much leaching occurs due to high intensity rainfalls in wet season	Local rainfall information
	Constraint: SITE CONDITIONS: Alternative 1: For irrigation to be successful, there are topography constraints.	<4% gradient				Is this thinking inside the square? Greater slopes are irrigated elsewhere. Fairview and Arcadia are typified by extensive flat plateau areas which are significantly above groundwater. Roma is likely to have shallower groundwater and extensive, flat areas are not abundant. If this causes a significant constraint we could also investigate irrigating at lower application rates or with subsurface drippers.	Local topography information
	Constraint: WATER QUALITY: Alternative 1: Water Quality of associated water used for irrigation needs to be suitable for the plants being irrigated.	Plants and EC limits mentioned in Table 4.2.5 of Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000) Volume 1: Chapter 4.2				Main issues are SAR and salinity. Salt and drought tolerant species have been selected for Fairview with great success. Same species could be used elsewhere.	Associated water quality information. Suitable plant water quality requirements.

Factor	Constraint/Opportunity Description	Threshold Values (if available/applicable)	Relevance Across CSG Field (refer colour key below): Roma	Arcadia	Fairview	Comments	Data Needs/Gaps & Monitoring
Environmental	Constraint: WATER QUALITY: Alternative 1: High salinity in associated water used for irrigation, can cause reduced crop growth and yield loss because the plant must redirect energy from growing to extracting pure water from the saline water in it's root zone.	Depends on the type of crop.	high	high	high		Associated water quality information. Suitable plant water quality requirements.
	Constraint: WATER QUALITY: Alternative 1: Presence of sodium in soils reduces the associated water (via irrigation) penetration into and through the soil (SAR - Sodium Absorption Rate).	SAR values above 12	medium	medium	medium	Also sodic soils are more susceptible to surface crusting and erosion.	Associated water quality information.
	Constraint: WATER QUALITY: Alternative 1: Possible runoff of poor quality associated water (used for irrigation) to a surface water system (also increased sediments).		medium	medium	medium	Managed through a Land and Water Management Plan.	Associated water quality information.
	Opportunity: SITE CONDITIONS: Alternative 1: Irrigation provides opportunity for improvement of soil structure and moisture retention through improving humus content.		medium	medium	medium		
	Constraint: LAND DEGRADATION: Alternative 1: Irrigation has the potential to cause land degradation.	<4% gradient to avoid erosion. Deep rooted plant species to move salt below 3m.	medium	medium	medium	Depends on application method for irrigation.	
	Constraint: LIMITED RESOURCE: Alternative 1: water production will decline and irrigated crops will need to be able to survive in the long term or be harvested before the end of water supply.		medium	medium	medium	Therefore need to concentrate on opportunities for high value irrigated agriculture and consider economic life of 15-20 years. After 20 years the Eucalypt stands would be self-sufficient and would rely on natural rain water. Cropping activities would not be possible however as they would be dependent on irrigation. Need refinement of predictions for rate of extraction of water and variations over time, including upper and lower bounds.	Suitable plant information
	Constraint: SITE CONDITIONS: Alternative 1: Excessive rainfall will reduce the application of irrigation water and an alternative use for the associated water will be required.		medium	medium	medium	Require storage. A holding dam would need to be constructed (200ML capacity) to store water during the winter months during which rainfall levels are significantly higher. This adds additional costs and constraints associated with impoundments (see constraints sheet).	Local rainfall information
	Opportunity: SITE CONDITIONS: Alternative 1: Variable rainfall will provide opportunity for seasonal crops, particularly if storage is provided.		medium	medium	medium		Water supply/demand modelling to establish feasible extent of irrigation and likely supply reliabilities.
	Constraint: SITE CONDITIONS: Alternative 1: Risk of Fire	Allow 50m buffer zones and dense canopy from trees, water cannon at main irrigation facilities	medium	medium	medium	Need to consider the inefficient use of water - contrary to contemporary irrigation thinking but the aim is to get rid of water.	
Social	Constraint: WATER QUALITY: Who is responsible for the water quality monitoring - Santos or the landowner?		medium	medium	not applicable		
	Constraint: INFRASTRUCTURE: Who is responsible for the integrity of the holding dams i.e. designed appropriately, constructed appropriately, managed & monitored.		medium	medium	medium		
	Constraint: COMMUNITY: Alternative 1: Irrigation is not the traditional land-use and therefore there is likely to be community resistance.		medium	medium	medium		
	Opportunity: COMMUNITY: Alternative 1: Distance to end user: could be opportunity to install numbers of smaller irrigated areas near centres of population or other end users.		medium	medium	not applicable		
	Constraint: COMMUNITY: Alternative 1: Alignment with local communities		medium	medium	medium	What is the community attitude to GLNG project and potential local impacts? To what extent will agricultural reuse create issues and problems, or present opportunities?	
	Opportunity: COMMUNITY: Alternative 1: Alignment with local communities		medium	medium	medium	What is the community attitude to GLNG project and potential local impacts? To what extent will agricultural reuse create issues and problems, or present opportunities?	
Economic	Constraint: INFRASTRUCTURE: Alternative 2: Distance to end user (location of production area and proximity to agricultural lands).	David Keith/Lili Pechey have developed a spreadsheet tool to estimate both capital costs and operating & maintenance costs based on three key inputs: pipeline length, hydraulic head and required flow rate.	low	high	medium	The size of pipes and pumps required for a particular application, and hence cost, is a function of several factors, including length, pipe diameter, hydraulic head and flow rate. As such, it is not easy to develop a generic unit cost (i.e.. $ per kilometre) for pipelines. Arcadia is more remote and the distance to end-users may be prohibitive.	Existing land uses and water demands
	Constraint: MARKETABILITY: Alternative 2: Treated water offered to farmers is more expensive ($1.5/kL) than mains water ($0.87/kL).		medium	medium	medium	Irrigation water is currently being traded in the Condamine Balonne region for $100/ML. It should be noted that a very small volume of water is currently being traded. Treated associated water as irrigation water is more expensive on an apparent basis, but the actual cost of mains water should be factored in - including the highest use of that water for alternative uses such as drinking.	
	Constraint: MARKETABILITY: Alternative 2: Confidence of water extraction rates that can be guaranteed for beneficial use.		high	high	high	This is especially relevant given that some agricultural uses will required large capital investments to utilise the water, e/g/ luceana, plantation forestry cf. stock watering. Water could be given to farmers/landowners for free - they would need to be informed that the supply would be for a limited time only (20yrs or so).	
	Constraint: MARKETABILITY: Alternative 2: Water quality of associated waters.		low	low	low	Treated associated water can be marketed as a superior quality water supply resource for irrigation.	Associated water quality information.

Relevance Across CSG Field (refer colour key below): high | medium | low | not applicable

Factor	Constraint/Opportunity Description	Threshold Values (if available/applicable)	Roma	Arcadia	Fairview	Comments	Data Needs/Gaps & Monitoring
	Constraint: OWNERSHIP: Alternative 2: Responsibility of capital costs for beneficial use scheme.						
	Constraint: OWNERSHIP: Alternative 1: Land ownership is required for irrigation schemes (NRW Land Management Plan).						Land acquisition costs
	Constraint: TREATMENT: Alternative 2: For associated water to be suitable for agricultural re-use, treatment may be required.					This is likely to be the case for all parts of the field, which could make the potential re-use un-economic.	
	Opportunity: INFRASTRUCTURE: Alternative 2: Existing pipeline/water gathering infrastructure may be able to be used for transfer of associated water for agricultural re-use.						
	Opportunity: ???? Aquaculture					May require pre-treatment for some WQ parameters (Na, B, F, others?) and certainly pH control and aeration.	Investigate WQ control needs.
	Opportunity: OWNERSHIP: Alternative 1: Profit for Santos on sale of agricultural land at end of economic life of project.						
	Opportunity: ????: Alternative 1: Turn 'waste' water into economic gain.						
	Constraint: TREATMENT: Alternative 1: Cost of treating associated water to standard suitable for long term irrigation.						
Regulatory	Constraint: APPROVALS: Alternative 2: Regulators are moving away from water discharge to stream and removed downstream by customer/user, with preference for pipe distribution.					This is limited by Water Act 2000. Once water in-stream it becomes property of the state and then managed under the Water Act 2000 - Water Resource Plans and Resource Operations Plans (known as an un-allocated water resource).	
	Constraint: APPROVALS: Alternative 1: NRW - Land and Water Management Plan - irrigation only on land owned by Santos - only approved for 10 years.					Irrigation plans based on 10 year duration are consistent with the intended duration of CSG operations (20+ years). Would the same constraint apply to land where Santos has a long term lease? Is it likely o be difficult to obtain a renewal of the LMP approval after 10 years?	
	Constraint: APPROVALS: Alternative 1: As part of the Beneficial Reuse Application for using associated water for irrigation, EPA required a Resource Utilisation Plan OR an amendment to their Environmental Authority.	approx 18 months for approvals					
	Constraint: APPROVALS: DME only allow use of associated water for domestic purposes or stock purposes.					DME allows garden watering on quarter acre blocks and no increase in existing stock numbers i.e. water supply substitute only.	
	Opportunity: APPROVALS: Alternative 1: As agricultural reuse by irrigation is a highly favoured option, approval of a technically viable proposal should be simple.						
	Constraint: APPROVALS: Alternative 1: Gaining Land and Water Management Plan Approval					Is it likely to be difficult to obtain approval of LWMP?	
Other	Constraint: WATER QUALITY: In accordance with EPA guidelines, the associated water must have suitable water quality for the type of agricultural re-use (i.e. irrigation, livestock drinking water, aquaculture etc).	ANZECC and ARMCANZ 2000 Irrigation and general use: Volume 1: Chapter 4.2 and Volume 3: Chapter 9.2 Livestock drinking water: Volume 1: Chapter 4.3 and Volume 3: Chapter 9.3 Aquaculture: Volume 1: Chapter 4.4 and Volume 3: Chapter 9.4				Floride issue (2 or 4 mg/L) for stock watering.	Associated water quality information.
	Constraint: WATER QUALITY: Abrupt change in water quality (resulting in reduced animal growth and production or may cause illness or death).	ANZECC and ARMCANZ 2000 Irrigation and general use: Volume 1: Chapter 4.2 and Volume 3: Chapter 9.2 Livestock drinking water: Volume 1: Chapter 4.3 and Volume 3: Chapter 9.3 Aquaculture: Volume 1: Chapter 4.4 and Volume 3: Chapter 9.4				What treatment will be given/available to manage variations in water quality?	Associated water quality information.

MUNICIPAL RE-USE

Overview of Option

This option involves use of associated water for potable and non-potable municipal uses (such as irrigation and maintenance of community facilities).

Categories

Alternative 1. Potable Water
Alternative 2. Irrigation and Maintenance of Community Facilities

EPA Classification

1. Category 1 (Preferred) - Direct Use
2. Category 1 (Preferred) - Treated Use

Spreadsheet Input from:

Philippa Kassianos
Lili Pechey - Economics
Benita Blunden - Regulatory
Jim Barker - General review
Gary Smith - Treatment

Relevance Across CSG Field (refer colour key below)			
high	medium	low	not applicable

Factor	Constraint/Opportunity Description	Threshold Values (if available/applicable)	Roma	Arcadia	Fairview	Comments	Data Needs/Gaps & Monitoring
Technical	Constraint: WATER QUALITY: Alternative 1: Variety of water quality associated water from different wells over time - difficult to treat wide range.					Associated water treatment assumes a variable range of influent quality from CSG wells, and treatment methods are capable of	Associated water quality.
	Constraint: WATER SUPPLY: Varying quantity of associated water supply produced throughout the life of the project - difficult to design and size treatment facility					Associated water treatment will be designed with associated dam storage to allow equalisation of flow and volume to treatment processes.	Associated water quantity supply. Municipal demands (and demands over time, including population growth).
	Constraint: WATER SUPPLY: Seasonal variation in water demands.					Treated associated water demand will be high for various beneficial reuses, so that annual distribution can be planned for.	Municipal demands (and demands over time, including population growth).
	Constraint: SITE CONDITIONS: Alternative 2: Suitable soil properties (SAR), topography, seasonal rainfall						
	Constraint: SITE CONDITIONS: Alternative 2: Potential to infiltrate shallow groundwater aquifers						
	Constraint: WATER QUALITY: Alternative 2: Suitable for irrigation purposes and maintenance of community facilities						
Environmental	Opportunity: IMPACT REDUCTION: Use of associated water may take the pressure off existing municipal water supplies (i.e. help to promote aquifer recharge).						
	Constraint: WATER QUALITY: Alternative 2: Runoff from irrigation and maintenance of community facilities could enter surface water systems.						
Social	Opportunity: COMMUNITY: Alternative 2: Associated water used to water sports fields and supply feedlots.						
	Opportunity: COMMUNITY: Alternative 1: Treated associated water could be used as potable water.					Treated associated water could be used as potable water with sufficient treatment to drinking water criteria.	
	Constraint: COMMUNITY: Alternative 1: Community considers associated water as a waste and not suitable for potable water consumption.					Treated associated water can be demonstrated to have properties for various beneficial uses by monitoring and public distribution of WQ data.	
	Constraint: LIMITED RESOURCE: Alternative water supply would be required when associated water production declines.					Alternative water supply will be required in community areas whether or not treated associated water is available, therefore a 20+ year supply is a significant benefit.	
	Constraint: WATER QUALITY: Alternative 1: Municipality only accepting water that meets drinking water standards.	Australian Drinking Water Guidelines (NHMRC and ARMCANZ 1996)				Treated associated water can be demonstrated to have properties for various beneficial uses by monitoring and public distribution of WQ data.	
	Constraint: COMMUNITY: Alternative 2: Public health issues						

			Relevance Across CSG Field (refer colour key below)				
			high	medium	low	not applicable	
Factor	**Constraint/Opportunity Description**	**Threshold Values (if available/applicable)**	**Roma**	**Arcadia**	**Fairview**	**Comments**	**Data Needs/Gaps & Monitoring**
	Constraint: INFRASTRUCTURE: Distance to end user (location of production area and proximity to communities).	David Keith/Lili Pechey have developed a spreadsheet tool to estimate both capital costs and operating & maintenance costs based on three key inputs: pipeline length, hydraulic head and required flow rate.				The size of pipes and pumps required for a particular application, and hence cost, is a function of several factors, including length, pipe diameter, hydraulic head and flow rate. As such, it is not easy to develop a generic unit cost (i.e.. $ per kilometre) for pipelines. The location of CSG operations at Comet Ridge will require some type of transport to beneficial users. Direct discharge is one means to transport and withdraw water as required.	
	Constraint: MARKETABILITY: Confidence of water extraction rates that can be guaranteed for beneficial use.					Alternative water supply will be required in community areas whether or not treated associated water is available, therefore a 20+ year supply is a significant benefit.	
	Constraint: OWNERSHIP: Responsibility of capital costs for beneficial use scheme.					Capital costs will be allocated as required by QEPA regulations. Public agency assistance grants or loans may be available to communities to use treated associated water.	
	Constraint: COMMUNITY: Give the water to local councils (not sell, since the water is a regulated waste) for community benefit to towns and surrounding farm holdings.						
	Constraint: INFRASTRUCTURE: New pipe infrastructure and treatment facilities required for municipal re-use.	David Keith/Lili Pechey have developed a spreadsheet tool to estimate both capital costs and operating & maintenance costs based on three key inputs: pipeline length, hydraulic head and required flow rate.				The size of pipes and pumps required for a particular application, and hence cost, is a function of several factors, including length, pipe diameter, hydraulic head and flow rate. As such, it is not easy to develop a generic unit cost (i.e.. $ per kilometre) for pipelines.	
Economic	Constraint: TREATMENT: Alternative 1: Pre-treatment desalination costs (if required) can be significant (capital and O&M costs).	Annualised capital and O&M costs for high quality water are estimated to range from $445,000 - $1.543m , depending on volume treated/day (URS 2007). For medium quality water the same costs range from $311,000 - $1.08m.				TDS of associated is dependent upon the depth of the coal seam, the geology surrounding the coal seam, the amount of time the water reacts with the surrounding geology, and the quality of the water entering the coal seam. Based on a previous assessment undertaken by URS for the Santos GLNG project, reverse osmosis (RO) has been identified as the preferred water treatment technology.	
	Constraint: MONITORING: May require more rigorous sampling and monitoring than conventional water supplies.					Additional monitoring may be required for treated associated water, but should not be a significant percent of total project cost.	
	Constraint: INFRASTRUCTURE: Alternative 2: Dual reticulation systems capital costs.						
	Opportunity: TREATMENT: Municipal water supply systems already have infrastructure in place for treatment.					Treated associated water could be blended with treated municipal water supplies to avoid duplication of treatment.	Information on the municipal water treatment systems.
	Opportunity: TREATMENT: Agreement with local council to cover the cost of treating associated water in exchange for the supply of associated water.	Annualised capital and O&M costs for high quality water are estimated to range from $445,000 - $1.543m , depending on volume treated/day (URS 2007). For medium quality water the same costs range from $311,000 - $1.08m.				It is likely that the capital and O&M cost of treating associated water will be greater than treating surface water or GW for municipal water supply. Therefore, cost arrangements will be required for selling or granting of treated associated water supply. TDS of associated is dependent upon the depth of the coal seam, the geology surrounding the coal seam, the amount of time the water reacts with the surrounding geology, and the quality of the water entering the coal seam. Based on a previous assessment undertaken by URS for the Santos GLNG project, reverse osmosis (RO) has been identified as the preferred water treatment technology.	

Relevance Across CSG Field (refer colour key below)			
high	medium	low	not applicable

Factor	Constraint/Opportunity Description	Threshold Values (if available/applicable)	Roma	Arcadia	Fairview	Comments	Data Needs/Gaps & Monitoring
	Constraint: MARKETABILITY: Price of existing municipal water. If intending to sell the water to users (or the council), it would have to be competitive.	For residential, rural and rural residential water users in Roma, the price of water in 2006/07 was $456.96 for the first 750 kilolitres, and $0.75 for every kilolitre used once the 750kL allowance was exhausted (Roma Regional Council, 2006).					
Regulatory	Constraint: MONITORING: May require more rigorous sampling and monitoring than conventional water supplies.					Additional monitoring may be required for treated associated water, but should not be a significant percent of total project cost.	
	Constraint: APPROVALS: Municipal use would require agreement with local government, approval by the EPA and ministerial consent under the Petroleum Act 1923.	Beneficial Reuse Application - approx 18 months approval time.				Approval is also required for the infrastructure required to support this reuse (i.e. load out facility or pipeline). This approval is covered under the EA - known as supporting infrastructure. QEPA and other regulatory authorities are likely to approve beneficial uses that support municipal water supply in a drought area.	
Other	Opportunity: WATER SUPPLY: Supplement proposed Nathan Dam					Blending with other water supply such as proposed Nathan Dam is a preferred method to use treated associated water as a water supply supplement.	
	Opportunity: WATER SUPPLY: provide associated water to SunWater for blending and treatment prior to on-sale					Blending with other water supply such as proposed Nathan Dam is a preferred method to use treated associated water as a water supply supplement.	
	Constraint: WATER SUPPLY: Santos is not a water supplier (i.e. not their core business) and does not want to be responsible for implementing Hazard Analysis and Critical Control Points (HACCP).					Santos would only be interested in supplying raw water to current water treatment plants.	

Overview of Option
This option involves use of associated water for other industries such as coal mining (dust suppression & wash plant), feedlots, power station (cooling tower water).

Categories
Alternative 1. Coal Mine Use
Alternative 2. Animal Feeding Operations (Feedlots)
Alternative 3. Cooling Tower Water (Power Stations and other industrial applications)
Alternative 4. Enhanced Oil Recovery (Not applicable)
Alternative 5. Aquaculture (Not applicable)
Alternative 6. Fire Protection (Not applicable)
Alternative 7. Other Industrial Uses (Not applicable)

EPA Classification
1. Category 1 (Preferred) - Direct Use
2. Category 1 (Preferred) - Treated Use

Spreadsheet Input from:
Philippa Kassianos
Lili Pechey - Economics
Benita Blunden - Regulatory
Jim Barker - General review
Gary Smith - Treatment

Relevance Across CSG Field (refer colour key below)			
high	medium	low	not applicable

Factor	Constraint/Opportunity Description	Threshold Values (if available/applicable)	Roma	Arcadia	Fairview	Comments	Data Needs/Gaps & Monitoring
	Constraint: WATER SUPPLY: Seasonal variation in water supply requirements.						
Technical	Constraint: WATER QUALITY: Alternative 3: Poor water quality can cause problems with scaling and corrosion when used in cooling tower applications.	Neither corrosive or scale (calcium carbonate) forming. Ryznar Index = 6 is the optimum position (Index below 6 = scaling and above 6 = corrosion).					Associated water quality information. Specifically test for ryznar stability index (to test for scale production or corrosive potential)
Economic	Constraint: INFRASTRUCTURE: Distance to end user (location of production area and proximity to industries)	David Keith/Lili Pechey have developed a spreadsheet tool to estimate both capital costs and operating & maintenance costs based on three key inputs: pipeline length, hydraulic head and required flow rate.				The size of pipes and pumps required for a particular application, and hence cost, is a function of several factors, including length, pipe diameter, hydraulic head and flow rate. As such, it is not easy to develop a generic unit cost (i.e.. $ per kilometre) for pipelines.	Identification of location of suitable end-users
	Constraint: MARKETABILITY: Confidence of water extraction rates (and reliability) that can be guaranteed for beneficial use.					Typically, industries are sensitive to supply disruptions or variation. This issue will require design to manage treated supply for uniform distribution.	Associated water supply rates.
	Constraint: MARKETABILITY: Limited resource - alternative water supply would be required when associated water production declines.					Santos CSG production plan provides for a 20 + year supply. This should fit into the planning for most industries.	
	Constraint: OWNERSHIP: Responsibility of capital costs for beneficial use schemes.					Industry general plans capital cost for water supply well in advance of needs. Capital cost allocation for treated associated water should not be a high risk issue.	
Regulatory	Constraint: WATER QUALITY: Alternative 1: Environmental Authorities for coal mines in Queensland generally list Electrical Conductivity (directly related to TDS) as a discharge condition. Mines may be reluctant to accept associated water with high TDS, that may exceed or make it difficult to meet their discharge criteria.	Maximum EC generally ranges between 1000 µS/cm - 4500 µS/cm				Santos has already committed to treatment of associated water to reduce TDS to required levels for intended beneficial uses.	Associated water quality information

C.1 Overview

The purpose of this section is to outline the best practice approach to the design, construction, operation and decommissioning of containment facilities (referred to as a water management dam) required to store associated water produced during the GLNG project. This also extends to include brine containment ponds which are likely to be required to manage the brine stream following RO treatment (prior to crystallisation, natural evaporation and/or injection).

The potential risks associated with inappropriate dam design include; (i) contamination of soil and shallow groundwater due to excessive seepage, (ii) contamination of surface waters due to regular uncontrolled releases (iii) harm or loss of flora and fauna dependent on the contaminated surface or groundwater resources, and (iv) potential for harm to infrastructure, stock and people living downstream of the dam (either due to dam failure or contamination of potable/stock water supplies). All of these impacts can be largely mitigated by best practice design, which includes monitoring procedures to detect and address potential problems before they cause environmental harm. Santos is committed to adopting the best practice measures as described in the following sections.

C.2 Design and Construction

Factors that should be considered during the design of a dam include the physical characteristics of the dam site (topography, soils, geology), the availability of suitable competent materials for construction, the hydraulic performance criteria (determined according to potential for harm to the wider environment, including people and property, were overtopping or failure to occur) and overall stability of the structure.

When assessing the *general* environmental hazards associated with a dam, the following should be reviewed:

- proposed layout of storage areas;
- environmental values of the area – including:
  - typical soils and geology,
  - surface contours to a suitable scale, including watercourses,
  - flora and fauna,
  - groundwater and surface water resources,
  - human habitation and property; and
- estimates of the project lifetime, and expected volume and nature of waste products or by-products.

C.2.1 Site selection

The potentially negative impacts of a new dam on the environment can be largely mitigated through careful site selection. A baseline study of existing flora and fauna, as well as surface water and groundwater resources should be undertaken to inform the dam location. Dams should be sited above the ARI 100 yr flood level (if there are surrounding streams) and designed to limit contributing catchment areas. Typically, a turkey's nest type design should be adopted, particularly for small storages, to reduce the contributing catchment, and areas containing flora or fauna of high ecological importance should be avoided.

C.2.2 Hydraulic Performance Criteria

Prior to designing a dam, it is first necessary to establish the hydraulic performance criteria. This requires an assessment of the dam hazard category, by a suitably qualified and experienced engineer, in accordance with the recent draft guidelines produced by the EPA (Manual for Assessing Hazard Categories and Hydraulic Performance of Dams Version 1.0, 21 August 2008), which are due to be formally published in October 2008. That hazard assessment will determine whether a dam is a regulated dam for the purpose of the Operators (i.e. Santos) Environmental Authority (EA) or Development Approval (DA).

Under the new EPA guidelines, the hazard category of a dam can be based on a number of factors, including height, contaminant concentration, and the potential for environmental harm caused as a result of failure to contain and dam break.

A dam is considered a regulated dam if it is likely to contain contaminants outside set concentrations or pH limits, at any time when the volume contained within the dam is greater than 50% of the dam crest volume, and the dam has a crest volume greater than a certain amount (see Table 3 of the Manual for Dams v1.0). Since the dams are likely to contain water with an Electrical Conductivity (EC) greater than 4,000 µs/cm (equivalent to a TDS of 2680mg/L) and/or fluoride concentrations greater than 2mg/L, any dam (regardless of size) which is used to store associated water will be classified as 'regulated'.

An assessment must then be made as to whether the dam is either significant or high hazard. This is determined by assessing the consequences of failure to contain or dam break on downstream environmental values (harm or loss to environmental values, humans, stock or economy). The hydraulic performance criteria (comprising the Design Storage Allowance (DSA), the Mandatory Reporting Level (MRL) and spillway capacity) will be dependent of this classification (see Manual for Assessing Hazard Categories and Hydraulic Performance of Dams Version 1.0, 21 August 2008.

Furthermore, where a dam is assessed as being in the significant or high hazard category (a 'regulated dam'), then certified documentation of the design performance and annual inspection reports will be required to be lodged (see Section C.6).

C.2.3 Seepage

One of the primary design criteria for regulated dams is to control seepage of associated water into the natural ground and through the dam embankment (thus preventing potential contamination of surface and groundwater). How much seepage is acceptable is difficult to quantify, as there are no specific EPA regulations or guidelines. It has been found that seepage expression can be significantly reduced by use of a clay liner. Previous studies found that a 600 mm-thick clay liner is expected to be sufficient to control seepage by limiting expression to the surface during the design life. This is further improved by the use of HDPE liners, which are likely to be a requirement of the EPA (especially for evaporation ponds).

The performance of seepage control measures can be monitored using a well installed downstream of a dam. A monitoring well may consist of a screened PVC standpipe set in a borehole roughly 15 metres deep. Monitoring may be carried out on a semi-annual basis by reading water level and collecting water samples for quality sampling, that is, if water is encountered. A monitoring well provides a means to verifying that seepage does not infiltrate beyond the dam footprint.

C.2.4 Embankment Stability

A stability analyses should be conducted to evaluate the performance of the water management dam under static and seismic conditions. The objective of the stability analyses is to evaluate the stability of the embankment immediately after construction, throughout the design life of the structure and seismic loading conditions. It is recommended that dam stability under seismic loading conditions be assessed using a pseudo static approach, which is suitable because the containment dam design is comprised of non-liquefiable materials. ANCOLD (1998) recommends the pseudo-static method used by the US Army Corp of Engineers (1984).

C.2.5 Other Considerations

It is recommended that the inlet pipes be placed over the embankment dam in a manner that will not disturb or cause damage to the dam. Under no circumstances should inlet piping pass through embankment dam walls or foundations.

Rainfall events during the construction and operation of the dam could cause erosion and transport of sediments from the site. These sediments shall be controlled and contained by use of silt fences, check dams or other appropriate means to prevent release to nearby watercourses.

C.3 Operation and Maintenance

Dam Visit and Operations Log

A dam visit should be performed as indicated in the Operations Schedule (see Table below). Combine other operations activities with the dam visit if practical. All dam visit information should be recorded on an Operations Log form.

The Operations Log should contain comprehensive documentation of all activities at the dam. General items that should always be recorded in the Operations Log include, but are not limited to:

- Date
- Weather Conditions
- Reservoir Water Surface Elevation
- Attendance: The name of every person present should be recorded.
- Signature: Every Operations Log sheet should be signed after completion by Santos personnel.

Details should be recorded in the Operations Log on the date they occur

Operations Schedule

		Weekly	Monthly	Quarterly	Semi-Annually	Annually	Every 2.5 Years	Every 5 years	Every 10 years	Occasional Occurrence
STANDING OPERATION										
Operations	Dam Visit		✓							
	Transmit Log & Forms			✓		✓				
Instrumentation	Reservoir Water Surface Elevation		✓							
	Piezometers		✓							
Inspection	Dam Inspection		✓			✓ (2)				
Maintenance	Mow Grass				✓					
	Control Vegetation				✓ (1)					
	General Maintenance				✓					

C.3.1 Reservoir Operations

Mandatory Reporting Level

The holder of the environmental authority must notify the EPA immediately when the level in the regulated dam reaches the Mandatory Reporting Level (MRL) to minimise any actual or potential environmental harm. For a Significant Hazard dam the MRL is the lowest of either the 72 hour duration storm, AEP 0.01 (ARI 100yr) or a wave allowance freeboard at the same AEP.

Filling

As the volume of water stored in the dam nears the design storage capacity, the dam water surface elevation should be closely monitored.

This means that once the water level is within 1 metre of the FSL, weekly readings shall be recorded. Care should be taken to ensure that over-filling of the dam does not occur. Once filling operations have terminated, the water level readings may revert back to a monthly frequency

C.3.2 Maintenance

It is recommended that maintenance inspections be carried out on a semi-annual basis, and after significant blockage of drains, to ensure that timely action is taken to prevent or minimize any actual or potential environmental harm. Preventive maintenance works should be undertaken by approved contractors only, and should not detriment the stability or competency of the dam structure.

A brief summary of key maintenance activities is provided below:

Instrumentation - Piezometers

Flushing - Sediment sometimes builds up within the PVC pipe of a piezometer. This can cause inaccurate readings. To remove the sediment, gently agitate the sediment with a pipe or wire that is longer than the piezometer is deep. Be careful not to damage the piezometer screen or loosen the joints of the piezometer pipe. Then bail the water and sediment with an appropriately sized well bailer. Fill the piezometer with water and repeat until the bailed water is relatively clear, or the pipe can be lowered to the bottom of the piezometer without "feeling" sediment.

The riser pipes should be repaired if damaged.

Earthworks

Repair ruts or settlement on the dam crest.

Animal Damage and Control

Any animal burrows observed on the dam embankment should be repaired. The burrow should first be assessed to eliminate the possibility of any seepage or piping through or near the burrow. If any seepage or piping is observed, immediately inform the Dam Operator. The burrow location should be recorded and the hole should be completely backfilled and compacted.

Riprap

Maintain a uniform riprap surface. Reposition any riprap that becomes displaced. Replace any riprap that becomes deteriorated or is missing. Remove any vegetation in riprap areas.

Vegetation Control

Mow the grass areas and remove excessive vegetation, woody vegetation, or tall brush on: the upstream slope, downstream slope, the spillway, and 3 metres from the downstream toe of the dam. Remove all of the roots when removing vegetation. The holes remaining should be backfilled and compacted.

C.3.3 Monitoring Program

A monitoring program should be established to provide feedback on the overall performance of the constructed dam and the effectiveness of environmental management controls. Acquired data should be assessed on a regular basis and presented in a series of regular reports. It is envisaged that in the early stages of the establishment period, a monitoring report would be produced at the end of the wet season and the end of the dry season, with an annual report being prepared for presentation to Santos management. Based on the findings of the current project, the main monitoring parameters to be included in the program should include:

1) Vegetation Establishment and Sustainability
2) Geotechnical Stability
3) Erosion Monitoring
4) Storm Water Drainage Monitoring

5) Water Quality

6) Groundwater /seepage monitoring

7) Cover Performance

C.4 Decommissioning/Rehabilitation

The rehabilitation of a water management dam site is a process of land reclamation not unlike that undertaken at mine sites for tailings impoundments or waste rock piles. The key difference here is that the water management dams will contain contaminants that are not acid generating and pose minor environmental risk. If the associated water management strategy calls for permanent surface storage then land works would not be necessary. However, if the management strategy leads to removal of stored water, reclamation of the land would be the next step. This would involve earthworks and revegetation measures to restore the land to a more natural state.

Decommissioning of dams and rehabilitation of the site to other purposes is required when the primary need for the dam ends, in order to minimise the potential consequences of failure that may be present during operation. Dam removal must be carefully planned, giving full attention to the economic and environmental consequences of such removal. Disposal of residual saline waste materials that would have accumulated in the liner system and foundation must be cleaned up or isolated. The associated water also must be removed to make way for earthworks.

C.4.1 Land Reclamation Earthworks

Seepage of saline water of up to several metres into the underlying ground could occur, even with seepage control measures (such as a clay and HDPE liners). Excavation, transport and storage of such a quantity of impacted soils in a landfill are conceivable but not practical. It is therefore recommended that contaminated soils are isolated to limit transport of salts and other contaminants to the surface.

Earthworks can be undertaken to cover the impacted soils and reshape the landscape to prevent ponding of surface water at the site. The dam designs allow for excess cut which can be stockpiled for reclamation works (this will require a suitable clay liner to prevent capillary rise of salt residues). The sections that follow describe concepts of revegetation and cover design.

C.4.2 Revegetation Strategy

It is recommended that additional testing and analysis of potential topsoil (or equivalent) materials be completed as part of the design for the dam rehabilitation in order to assess the need for additional treatment, such as the addition of gypsum, fertiliser and mulch, to promote vegetative growth across the rehabilitated surfaces.

C.4.3 Vegetation Establishment

The following comments are provided to promote favourable conditions for the establishment of vegetation across the surface of the cover:

1) Topsoil type material must be suitably moisture conditioned prior to placement to minimise loss of material to dust during placement and to ensure that the topsoil has an acceptable structure for sowing seed. The preparation of a loose and friable seedbed is essential for good vegetation establishment from seed. If it is very dry when cultivated, the soil will shatter and lose its structure, leading to surface sealing. If it is very wet, the soil may become compacted.

2) All topsoiled areas should be contour ripped and/or tined (after topsoil spreading) to a depth of at least 300mm to create a “key” between the topsoil and the subsoil. This operation will leave the soil surface in a roughened condition and should be undertaken immediately prior to sowing. Ripping should be undertaken on the contour to minimise erosion and maximise the moisture regime for vegetation establishment and the tines should be lifted for approximately 2 m every 200 m to reduce the potential for channel erosion.

3) The rehabilitation earthworks should ideally be completed during the winter or early spring months to allow seed sowing to be undertaken during the period October to November prior to summer rain. There is a limited window of opportunity for sowing of seed (*i.e.* spring) and ideally, all sowing should be complete by mid-November. Whilst summer rain can be intense, it is relatively more reliable than autumn and winter rain.

4) Should the summer rains fail to provide sufficient rainfall to promote germination of the grass seed then gravity fed drip irrigation could be considered for irrigation.

C.4.4 Erosion Protection

The topsoiled surface of the cover will be susceptible to erosion from wind and rain immediately after construction and during the vegetation establishment period. Erosion protection will be required to minimise erosion and the loss of seed and fertiliser from the surface of the cover. A range of options is available to provide erosion protection including a number of proprietary surface mat products, straw mulching or hydro mulching.

C.4.5 Cover Integrity

The integrity of the proposed cover has been considered in the design of the cover layers, the surface water management system, and re-vegetation work. The main factors that could compromise the integrity of the cover system at a dam include:

1. Erosion (*e.g.* gully erosion) through poor performance of stormwater drainage works. This could arise through poor implementation of the cover design and it is expected that strict contractor supervision and survey control will be required during cover construction. It is expected that ongoing maintenance work will be required to the storm water drainage system during the vegetation establishment phase.

2. Fire and extreme climatic events. Fire and extreme climatic events such as extended periods of drought could impact upon the integrity of the cover system and increase the likelihood of significant erosion or drying/cracking of the clay growth layer. Extreme climatic events may also restrict the establishment of vegetation across the surface of the cover.

3. Slope Stability. The 1V in 3H perimeter slopes (overall) of the dam are considered to have an adequate factor of safety against slope failure.

4. Cover penetration by vegetation. Revegetation of the surface of the dam will include grass cover and shallow rooted shrub and tree species. Deep-rooted tree species could be introduced by wind or animal activity[4]. However a vigorous cover of grasses should limit the ability of wide spread colonization. It is expected that maintenance work will be required during the establishment of the vegetated cover to prevent weed growth (*e.g.* parthenium). Weed inspection and spraying should be undertaken at the beginning of autumn and spring.

5. Cover penetration by animal/insect activity. Insect and animal activity is inevitable in the long-term. However, these impacts are expected to be localised in extent. The depth of growth layer has been

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[4] In the long-term, it is inevitable that some deep-rooted tree species will naturally colonize the rehabilitated cover.

selected to minimise the potential impacts of animal activity. Grazing animal management should be undertaken, including fencing to exclude livestock.

6. Cracking of clay materials. Cracking of the clay growth layer is possible under extreme dry periods. However, the depth of the growth layer has been selected to minimise the impacts of these extreme periods. Minor cracking of this layer is expected to "self heal" when rain falls and the moisture profile is reestablished within the cover layer.

C.4.6 Implementation of Rehabilitation Works

Implementation of the dam design strategy at will require Santos to select appropriately skilled and experienced employees/contractors and equipment to undertake the work. As discussed above, strict contractor supervision and survey control will be required during cover construction to prevent a storm water drainage and erosion problems related to poor implementation of rehabilitation works. While large equipment can be used to excavate, load and haul the cover materials to the surface of the dump, specialized equipment including graders will be required to achieve accurate placement of the correct layer thicknesses and construction of the surface water management works.

C.5 Regulatory Approvals Process

The EPA is the main regulator for all dams and containment structures. Applications to create or amend an EA should be lodged directly with the EcoAccess Customer Service Unit (ECSU) of the EPA.

Any application involving dams must contain sufficient information to justify the assessment of hazard category for all dams. Where an application involves dams, that part of the *conditions* applicable to 'all dams' will be inserted in the current or proposed EA or DA by the EPA.

A dam assessed as being in the significant or high hazard category (a 'regulated dam'), requires specific authorisation in the EA or DA. That part of the conditions applicable to 'regulated dams' will be inserted in the current or proposed EA or DA by the EPA.

For all new 'regulated dams', a certified design plan must be lodged with the EPA before construction of that dam commences. This should include the following:

- all investigation and design reports;
- plans and specifications sufficient to hand to a contractor; and
- planned decommissioning and rehabilitation outcomes.

As stipulated by the EPA, once constructed, each regulated dam must be inspected annually by a suitably qualified and experienced person. The holder of the EA or DA should provide the annual inspection report to the EPA through the ECSU (EcoAccess Customer Service Unit). At each annual inspection, the condition and adequacy of each regulated dam must be assessed for dam safety and against the necessary structural, geotechnical and hydraulic performance criteria.

C.6 Summary

Throughout the GLNG project, each containment facility (for the short term appraisal or long term development stages) or evaporation pond required as part of the overall water management strategy will be designed, constructed, operated and maintained to an engineering standard appropriate to its circumstances and the purpose for which it is intended, in line with EPA requirements and the procedures outlined in this section.

Furthermore, the condition of dams/ponds and their operations will be monitored on a regular basis by a suitably qualified and experienced person, and timely action will be taken to prevent or minimize any actual or potential environmental harm.

Water Management Strategy Selection - Risk Assessment

Appendix D

FINAL REPORT

Water Management Strategy Selection - Risk Assessment

Prepared for

Santos Ltd

Level 14
60 Edward Street
BRISBANE QLD 4000

24 November 2008

42626220

Project Manager:

……………………………
Paul Wilkinson
Principal Water Engineer

URS Australia Pty Ltd

Level 6, 1 Southbank Boulevard
Southbank VIC 3006
Australia
T: 61 3 8699 7500
F: 61 3 8699 7550

Project Director:

……………………………
Michel Raymond
Principal Water Engineer

Author:

……………………………
Adrian Bowden
Director Busness Risk Strategies

…………………………
Marita Giles
Enviornmental Engineer

Date:	24 November 2008
Reference:	42626220
Status:	Final

URS (Australia) provides this proposal/report in both printed and electronic format. URS considers the printed version to be binding. The electronic format is provided for Santos Ltd' convenience and URS requests that Santos Ltd ensures the integrity of this electronic information is maintained. Storage of this electronic information should at a minimum comply with the requirements of the commonwealth Electronic Transactions Act (ETA) 2000.

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Appendices

1.1 Introduction

Management of associated water in the gas field area will be complex and the potential water management options vary substantially, depending on location, water volume availability, water volume constraints, regulator preferences, community perceptions, economic costs and timing.

Santos has indicated that it wants to progressively evaluate and select associated water management methods that are most appropriate and reasonably consider the above variables. A risk-based screening method for selecting future preferred scenarios for the management of associated water has been developed. The methodology developed can be constantly updated and adapted as new information becomes available.

In this report, the term “management methods” refers to the various alternatives available for disposal of associated water, such as irrigation and injection. The combination of selected management methods are referred to as scenarios. All of the management methods have been considered when selecting a scenario for each of the locations in order to select the scenario of least risk. To address the complex issues surrounding coal seam gas associated water Santos, has used a specifically developed Options Model that takes into consideration the risk to the wider environment of implementing management methods within the region. This model allows for comparison of various scenarios that have been generated and identification of the most appropriate scenario. Using this tool Santos has a process for rationally comparing and identifying management methods on the basis of risk to the wider environment.

This section on potential risk provides an overview of the basis for decision-making with respect to external (EIS) risk and offers a set of preliminary preferred options that are appropriate to the current project knowledge. The section describes the potential EIS risk (risk to wider environment) assuming that appropriate risk mitigation actions have been carried out. Risk profiles of both preferred and possible alternative associated water management scenarios that have been put forward by Santos have been included. As the project in only in the early stages the preferred scenarios that have been selected are preliminary and may need to be updated to reflect project design changes and as more knowledge of risk levels becomes available.

1.2 Approach to Risk Management

A formal, quantitative method (the RISQUE method) was applied to evaluate the risk.

Risk is a condition resulting from the prospect of an event occurring and the magnitude of its consequences. Therefore, risk is an intrinsic combination of:

- The likelihood of an event and its associated consequences occurring (this incorporates consideration of the frequency of the event and the probability of the consequences occurring each time the event occurs); and
- The magnitude of potential consequences of the event.

In quantitative terms, “risk” is defined by a risk “quotient”, which is:

Risk Quotient = Likelihood x Consequence

The risk quotient is therefore a numerical value that describes the level of risk posed by an event.

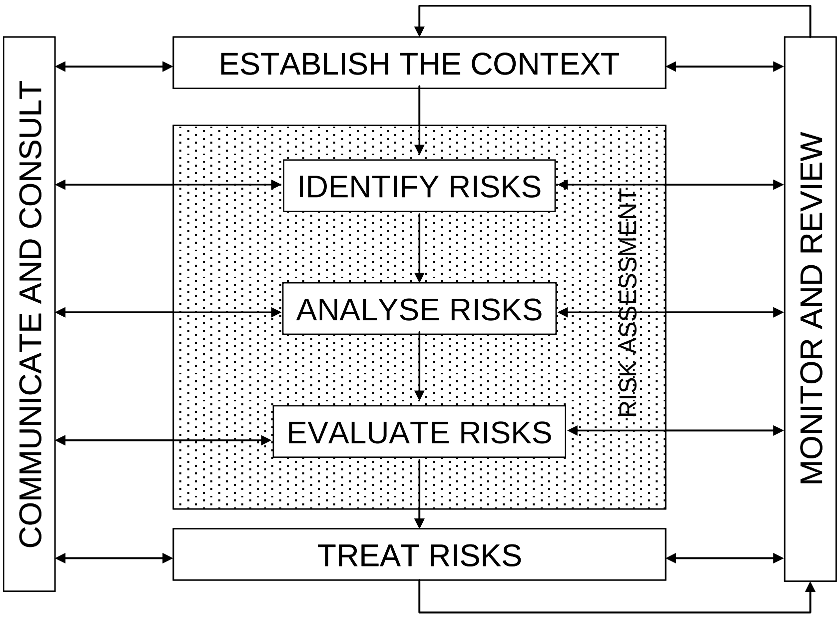
The RISQUE method involves a process of identifying likelihoods and consequences, estimating risk, and developing risk reduction strategies.

Section 1 Risk Assessment

The RISQUE method proceeds as a staged process, summarised in this report. Further information is provided in Bowden, A.R., Lane, M.R. and Martin, J.H., 2001, *Triple Bottom Line Risk Management – Enhancing Profit, Environmental Performance and Community Benefit*, Wiley, New York.

The flow chart of Figure 1-1 shows the key steps in our approach. The method is consistent with AS 4360.

Figure 1-1 The RISQUE method process



1.3 Establish the Context

The context of the risk assessment has been established in the overall chapter on the Associated Water Management Strategy.

Within given areas, various combinations of associated water management methods are possible. The regulators have clear views on the relative preference with respect to beneficial use. The associated water management methods that were included in the risk assessment are listed below, and are ordered in EPA preference, from most preferred to least preferred option.

- Potable Water (Treated);
- Untreated Irrigation and Maintenance of Community Facilities;
- Treated Irrigation and Maintenance of Community Facilities;
- Treated Irrigation (large scale);
- Untreated Irrigation (large scale);
- Untreated Farm Uses (stock/irrigation);
- Treated Industrial Re-use;

- Injection of Untreated Water;
- Injection of Treated Water into Freshwater Aquifer;
- Constructed Wetlands;
- Recreation;
- Evaporation Ponds;
- Dams (Store and Release for Irrigation or injection);
- Treated direct discharge to surface water; and
- Untreated direct discharge to surface water.

The associated water management methods are explained in detail in the Associated Water Management Strategy chapter of the overall GLNG Environmental Impact Statement (EIS) report.

1.4 Risk Identification

A workshop was held on Wednesday 23rd July and attended by a range of subject matter specialists. These workshop attendees are listed below:

- Dennis Reid (Santos);
- Bill Lazarus (Santos);
- Emma Hicks (Santos);
- John Baker (Santos);
- Graeme Bartrim (Santos);
- Shalene McClure (Santos);
- Murray James (Santos);
- Paul Renouf (Santos);
- Chris Connell (Santos);
- Ann Stewart (Santos);
- Steven Taylor (Santos);
- Adrian Bowden (URS);
- Marita Giles (URS);
- Jim Barker (URS);
- Benita Blunden (URS);
- Paul Wilkinson (URS);

- Gary Smith (URS);
- Christophe Bruillard (URS);
- David Fuller (URS);
- Tom Silverman (URS);
- Penny Flukes (URS);
- Natalie Webb (for Wayne Schafer) (GHD);
- Nick Hudson (GHD);
- John Harbison (for Bonnie O'Neal) (Matrix Plus); and
- Andrew Perry (Matrix Plus).

During the workshop, the subject matter specialist used their expert knowledge to validate existing inputs and provide reality check of firstly the risk issue categories and secondly the quantification of likelihood and consequence.

1.4.1 Risk Categories

Using knowledge gained from previous workshops and existing project experience an extensive preliminary list of risk events was developed. A large amount of data on the constraints and opportunities associated with each of the general disposal options (i.e. injection, storage, surface discharge, municipal re-use, agricultural re-use and industrial re-use) had been collated prior to the workshops. The information gained during a previous workshop was used to develop a broad list of risk issues which covered all of the risks identified by the subject matter specialists. The list of preliminary risk issues is included in Appendix A. This full list of risk events covered many different risk issues and needed to be simplified without losing any significant information. An in-depth review of preliminary constraints was conducted to summarise and categorise these issues. The simplified set of risk categories could then be used to evaluate each management option in each location, to ensure consistency between the management options. The following list shows the risk issue categories:

- Contamination of surface water;
- Contamination of groundwater;
- Inadequate technical capability;
- Regulators delay;
- Regulators refuse;
- Community opposes;
- Not enough demand;
- Not enough physical capacity;
- Water quality;
- Resources loss;

- Waste stream disposal; and
- Other issue.

The category 'Other issue' captures any additional risk issues that are unique to particular management options, for example 'changed flow regimes' and 'erosion'.

The subject matter specialists provided a thorough check and validation of the risk issue categories to ensure all of the risks were covered by the overall categories.

1.4.2 Estimating Likelihoods and Consequences

Following the confirmation of the risk issue categories the inputs for the likelihood and consequences for many of the management options were validated by subject matter specialists.

The quantification of likelihood and consequences was consistent with the risk assessment for the overall GLNG Environmental Impact Assessment. For details on estimating likelihoods and consequences and consequence categories see the chapter on '*Hazard and Risk*' in the overall EIS.

1.5 Risk Analysis

The risks were initially evaluated assuming a baseline volume of 1 to 5 ML/ day for all management methods except for the two large scale irrigation methods, which assume substantially greater water volumes as a base case. This range was used during the workshop to assess the current situation and the existing risk posed by the various issues. The baseline risk profiles enable assessment of the risk for each management method to assist with selection of the most suitable scenario (combination of management methods). Using the baseline risk profiles, Santos can identify the lowest risk scenario in relation to affects on assets of public health and safety, economics, social, environment and infrastructure and property. The risk profiles show the risk after the implementation of risk mitigation measures identified by Santos. It is assumed that these mitigation measures will be incorporated into project to reduce the level of risk to as low as reasonably practicable.

Santos has indicated that it will continually update and evaluate the risk assessment model to reflect any changes to the overall project or improved knowledge. Therefore the risk profiles that have been generated are expected to change as the likelihood and consequence inputs are refined with greater knowledge of the project.

1.5.1 Baseline Risk Profiles

The risk profiles for Roma, Fairview and Arcadia (Figures 1-2 to 1-4) show the risk in relation to the effect of the management methods on public health and safety, economics, social, environmental and property/ infrastructure.

The risk profiles in Figures 1-2 to 1-4 show the risk quotient for each management method, which is indicated by the height of the vertical bars on the graph. The colours within the bars represent the proportion of risk contribution from each of the five consequence categories (Property and Infrastructure, Environment, Social, Economic and Public Health and Safety). For example, the Roma risk profile of Figure 1-2 shows that the overall risk for large scale irrigation of treated water is around 4. The colours within the bar show that around 90% of that risk is related to environmental issues (green block), and the remaining 10% (yellow block) is in connection with social issues.

The management methods are ordered broadly in relation to EPA preference, with the most preferred at the left hand side of the x axis and least preferred towards the right of the axis.

Section 1 Risk Assessment

The 'Risk Target' (red line) provides an example of the level of risk posed at a risk quotient of 10. This target is consistent with the risk target used in the overall GLNG project risk assessment. The risk target level of 10 was used because any event with a risk quotient greater than 10 was considered to be high risk[1].The intervals between horizontal gridlines on the graph represent an order of magnitude change in risk level. As the explanatory note on the graph states, a total risk value of 1 means that there is around a 1 in 10 chance of a Moderate (Level = 10) consequence, or similarly, around a 1 in 100 chance of a Major (Level = 100) consequence'.

The "accuracy" of the risk assessment is at the order of magnitude level because the likelihoods that were input into the risk assessment were often low (below around a 1 in 10 chance of occurrence) and were recognised to vary by orders of magnitude. This level of variation translates directly into the calculated risk quotients.

The Roma risk profile (Figure 1-2) shows that, by and large, the lower risk management options are relatively high on the EPA hierarchy of preferred options. Exceptions are 'Treated- potable water' and 'Untreated – irrigation (large scale)', both of which lie within the highest risk group (one third) of management options and present a level of risk greater than the risk target.

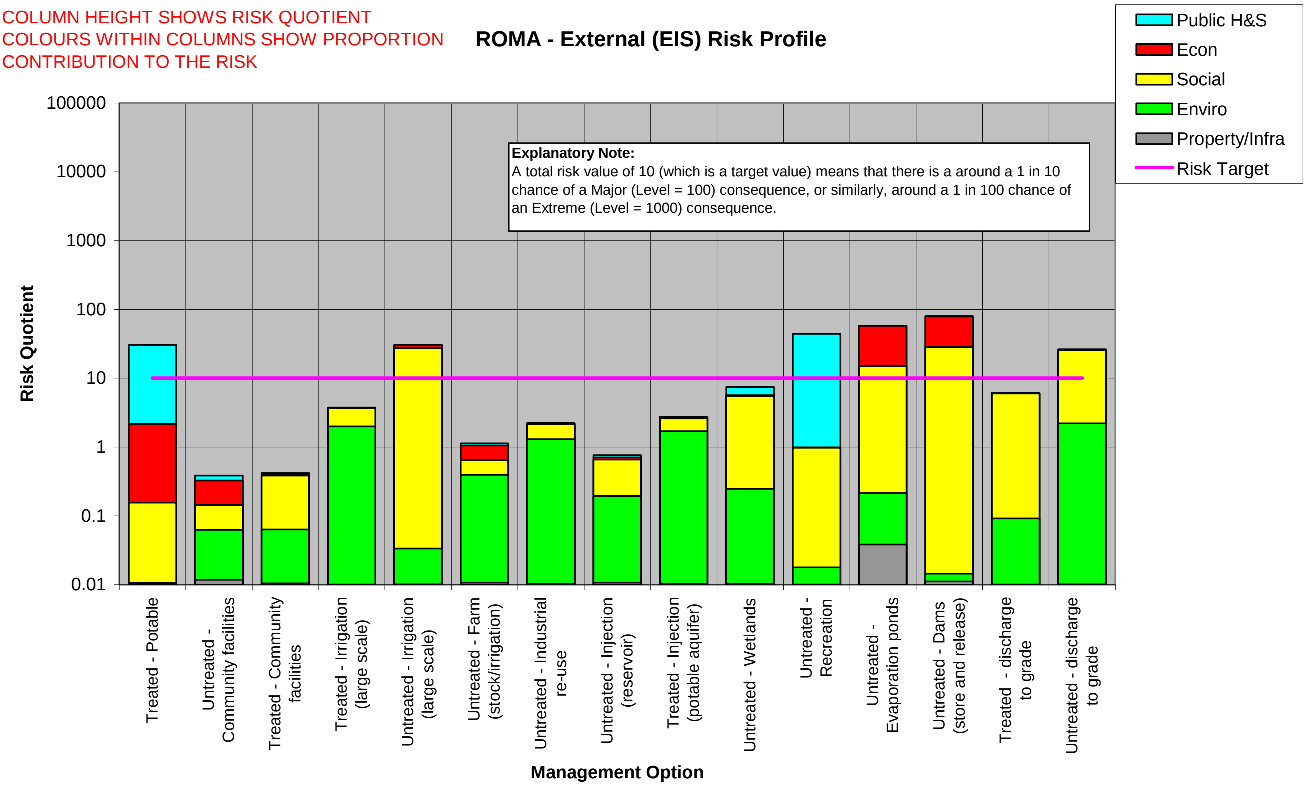
The Roma risk profile (Figure 1-2) also shows that some of the methods of management that involve untreated associated water pose the highest risk. 'Untreated Dams (store and release)' has the highest risk quotient, 'Untreated – Evaporation ponds' poses the second highest risk, followed by 'Untreated- Recreation'. The management methods that pose the least risk for the Roma area are 'Treated- Community facilities' and 'Untreated – Community facilities'.

The management method 'Treated- Potable' risk is posed equally to public health and safety, economic assets and social assets. Across all of the management methods it can be seen that the majority of the risk is posed to environmental assets (green) and social assets (yellow). Economic and public health and safety assets face a minor amount of risk and only one management method poses a risk to property and infrastructure assets.

All of the risks for the Roma area are either below or within an order of magnitude above the risk target. Considering the order of magnitude "accuracy" of the assessment results, the levels of risk posed by the management methods are not significantly above the risk target and therefore it is reasonable to assume that none of the management options pose an inherently unacceptable level of risk.

[1] This definition of a high risk event was originally used in the Port Phillip Bay dredging risk assessment, on which the methodology for this risk assessment is based.

Figure 1-2 Roma - External (EIS) Risk Profile



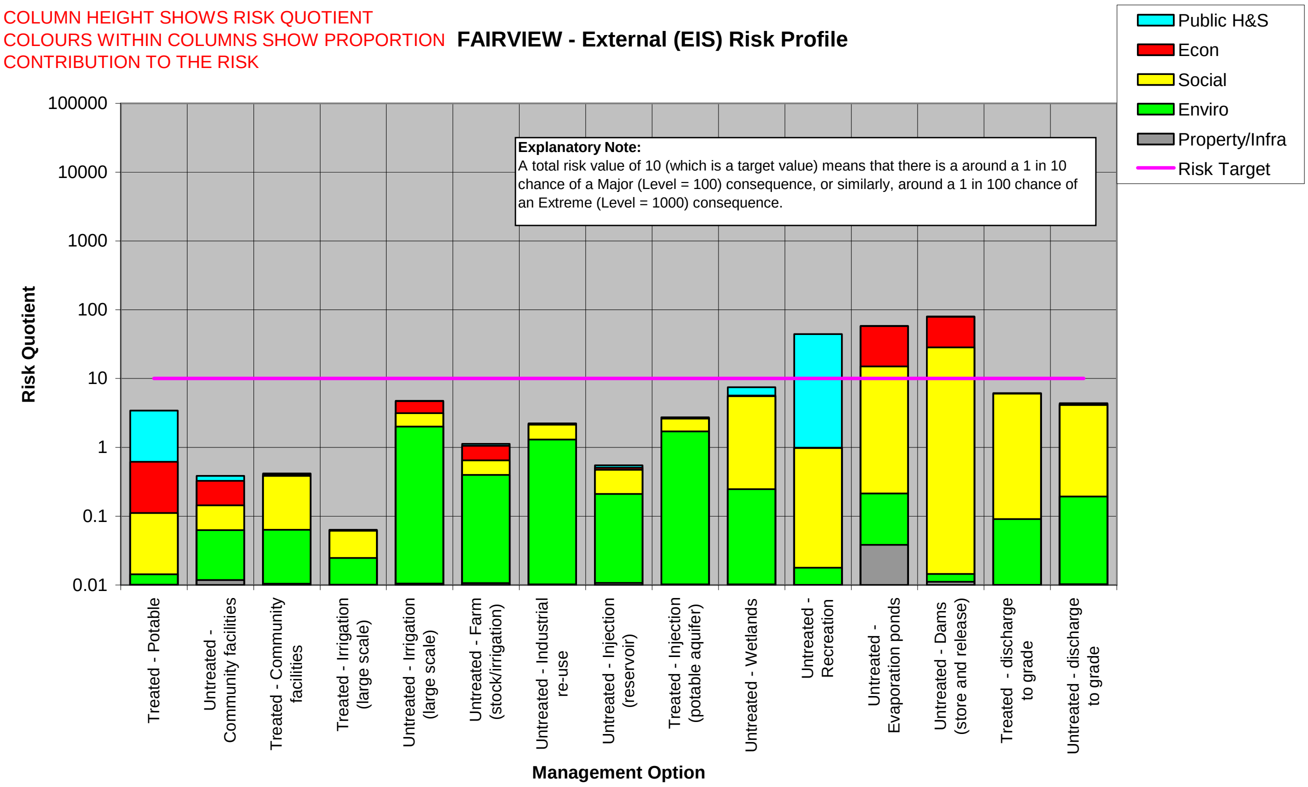
The Fairview risk profile (Figure 1-3) shows that the 'Untreated Dams (store and release)' has the highest risk quotient and is therefore the highest risk management method. The risk posed by this management method is posed mostly to social assets with smaller levels of risk posed to economic assets, environmental assets and property and infrastructure. The second highest risk management method is 'Untreated – Evaporation ponds' followed by 'Untreated- Recreation'. The management method that poses the least risk for the Fairview area is 'Treated - Irrigation (large scale)'.

Only three of the management methods have risk quotients higher than the risk target. Compared to the Roma baseline risk profile (Figure 1-2), which has six management methods above the risk target, the risk associated with the Fairview area is relatively low. Similarly to the Roma risk profile the majority of the risk posed by the management methods is to environmental and social assets.

All of the risks for the Fairview area are either below or within an order of magnitude above the risk target. Considering the order of magnitude "accuracy" of the assessment results, the levels of risk posed by the management methods are not significantly above the risk target and therefore it is reasonable to assume that none of the management options pose an unacceptable level of risk.

Section 1 Risk Assessment

Figure 1-3 Fairview - External (EIS) Risk Profile



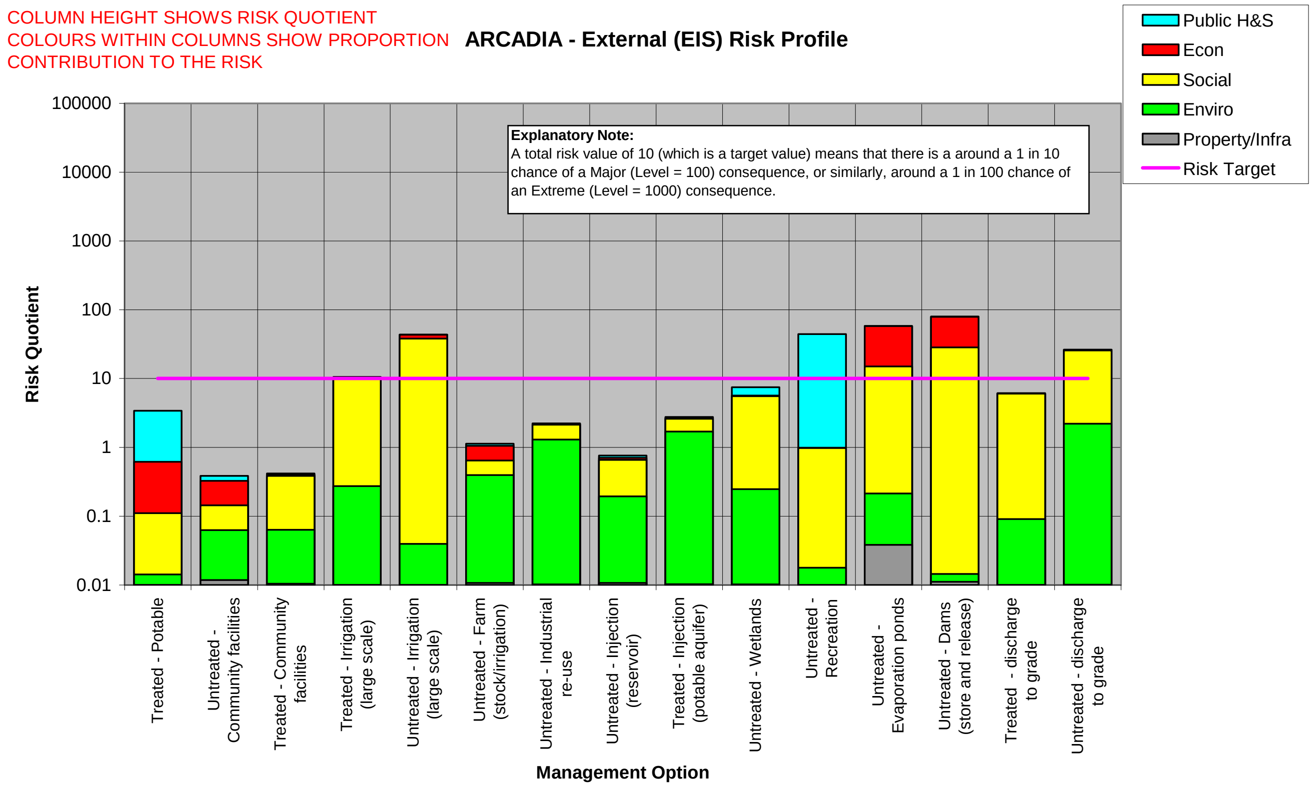
The Arcadia risk profile (Figure 1-4) is similar to the Roma risk profile and shows that the 'Untreated Dams (store and release)' has the highest risk quotient and therefore is the management method that poses the highest risk for this location. The second highest risk management method is 'Untreated – Evaporation ponds' followed by Untreated- Recreation'. The management methods that pose the least risk for the Arcadia area are 'Treated- Community facilities' and 'Untreated- Community facilities'.

Around 50% of the risk posed by 'Treated- Community facilities' is due to environmental assets and 50% to social assets.

Similarly to both the Roma and Fairview risk profiles, the majority of the risk is to environmental and social assets. Only five of the management methods have risk quotients above the risk target.

All of the risks for the Arcadia area are either below or within an order of magnitude above the risk target. Considering the order of magnitude "accuracy" of the assessment results, the levels of risk posed by the management methods are not significantly above the risk target and therefore it is reasonable to assume that none of the management options pose an unacceptable level of risk.

Figure 1-4 Arcadia - External (EIS) Risk Profile



1.6 Preferred Scenario Selection

A spreadsheet options selection model (WATERMAN) has been specifically developed by URS to help Santos use a risk-based approach to comparison and selection of preferred associated water management scenarios for each area. For any combination of associated water management methods, WATERMAN applies the baseline risk profiles, adjusts for water usage, and shows the relevant risk profile.

Santos has used WATERMAN to select a preferred scenario for each of the locations and in addition, has selected either one or two possible alternatives. The alternative scenarios for each location are included in the following Section.

The selection of preferred scenarios is appropriate for the current understanding of the project however the most suitable scenario may differ depending on changes to the project design and as knowledge of the project becomes more refined. Any changes to the baseline risk profiles will directly affect the selection of the preferred scenario. Santos has indicated that WATERMAN will be continually updated to ensure it reflects the current risk posed by the project. Therefore it is most appropriate to review the selected scenario when changes have been made to the baseline risk profile.

The workshop participants thought that the level of risk posed by a management method was dependent on the amount of water being disposed (i.e. the more water needing to be managed, the greater the risk). To account for this relationship WATERMAN includes a scaling factor that accounts for the increased exposure to risk as the volume of water being disposed increases. Therefore the level of risk in the preferred scenario risk profiles may differ compared with the baseline risk profile as the scaling factor has been applied to account for the varying level of risk. For example, in the Roma baseline risk profile (Figure 1-2) the management method 'Untreated- Industrial- re-use' has a risk quotient of 2.1 compared with a risk quotient of 0.67 in the preferred option profile (Figure 1-5). The reduction in the risk quotient is due to a scaling factor of 0.3 as less water has been used in the preferred scenario compared to the baseline risk profile. The proportion of risk posed to each of the asset categories (Public Health and Safety, Economics, Social, etc) for the selected management options remains the same as the baseline risk profile.

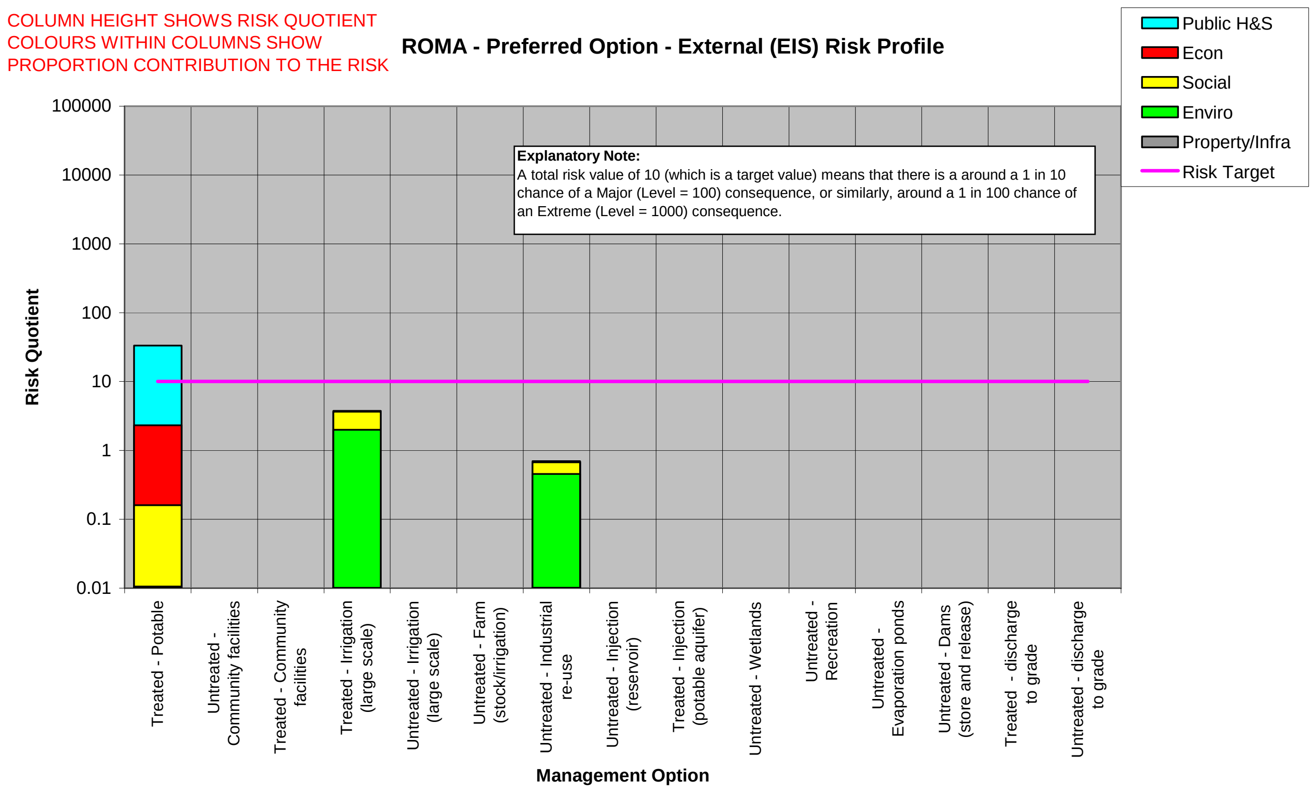
The WATERMAN model that is used to select the preferred scenario incorporates other constraining factors in the management of associated water. The selection of the preferred scenario includes consideration of risk to the wider environment, practicality, cost effectiveness and site specific constraints such as the water disposal capacity of a particular management option.

The preferred scenario selected for Roma includes:

- 22% (4.4 ML/d) of the 20 ML/d total volume of associated water that will require management that would be allocated to the municipal water supply (Treated- potable);
- 12% (2.4 ML/d) allocated to industrial re-use; and
- 66% (13.2 ML/d) allocated to treated irrigation (large scale).

Figure 1-5 shows the external risk profile for Roma which is similar to Figure 1-2 however the risk profile below only shows the management methods selected as part of the preferred scenario. The management methods 'Treated- irrigation (large scale)' and 'Untreated- industrial re-use' are both relatively low risk and have risk quotients below the risk target. The management method 'Treated- Potable' is shown to have a moderate level of risk however this method has significant benefits to the community by contributing to the municipal water supply.

Figure 1-5 Roma - Preferred Option - External Risk Profile



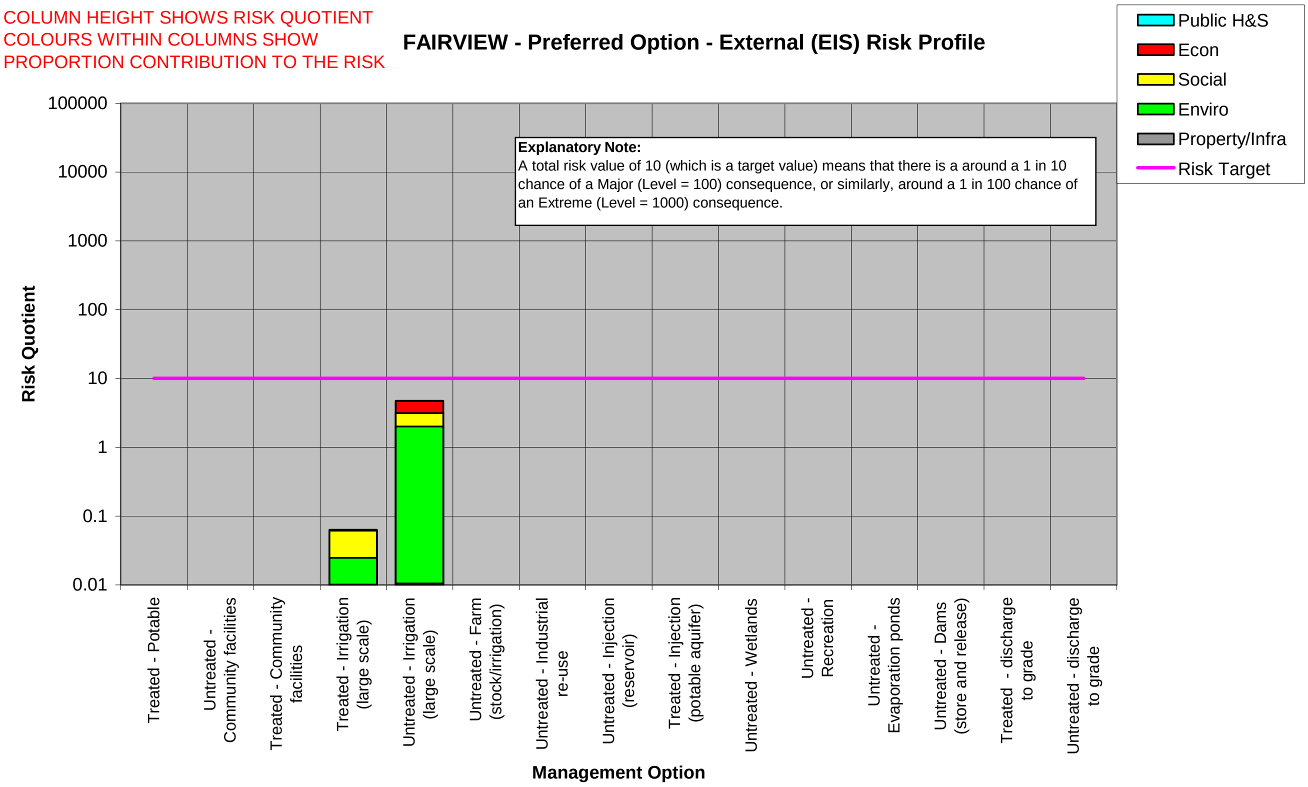
Section 1 Risk Assessment

The preferred scenario selected for Fairview includes:

- 12% (6.6 ML/d) of the 55 ML/d total volume of associated water that will require management that would be allocated to large scale irrigation of treated water (Treated- irrigation (large scale); and
- 88% (48.4 ML/d) allocated to large scale irrigation of untreated water (Untreated- irrigation (large scale).

Figure 1-6 shows the contribution of the asset categories for the selected management methods. The management method 'Treated- irrigation (large scale)' is the lowest risk issue for Fairview (as can be confirmed by Figure 1-3). 'Untreated- irrigation (large scale)' poses a moderate level of risk and is below the risk target level. Note that for treated and untreated large scale irrigation it is assumed a large volume of water is used, hence a scaling factor is not required and therefore the risk quotients for the selected scenarios are the same for both the baseline risk profile (Figure 1-3) and the preferred option risk profile (Figure 1-6).

Figure 1-6 Fairview - Preferred Option - External Risk Profile

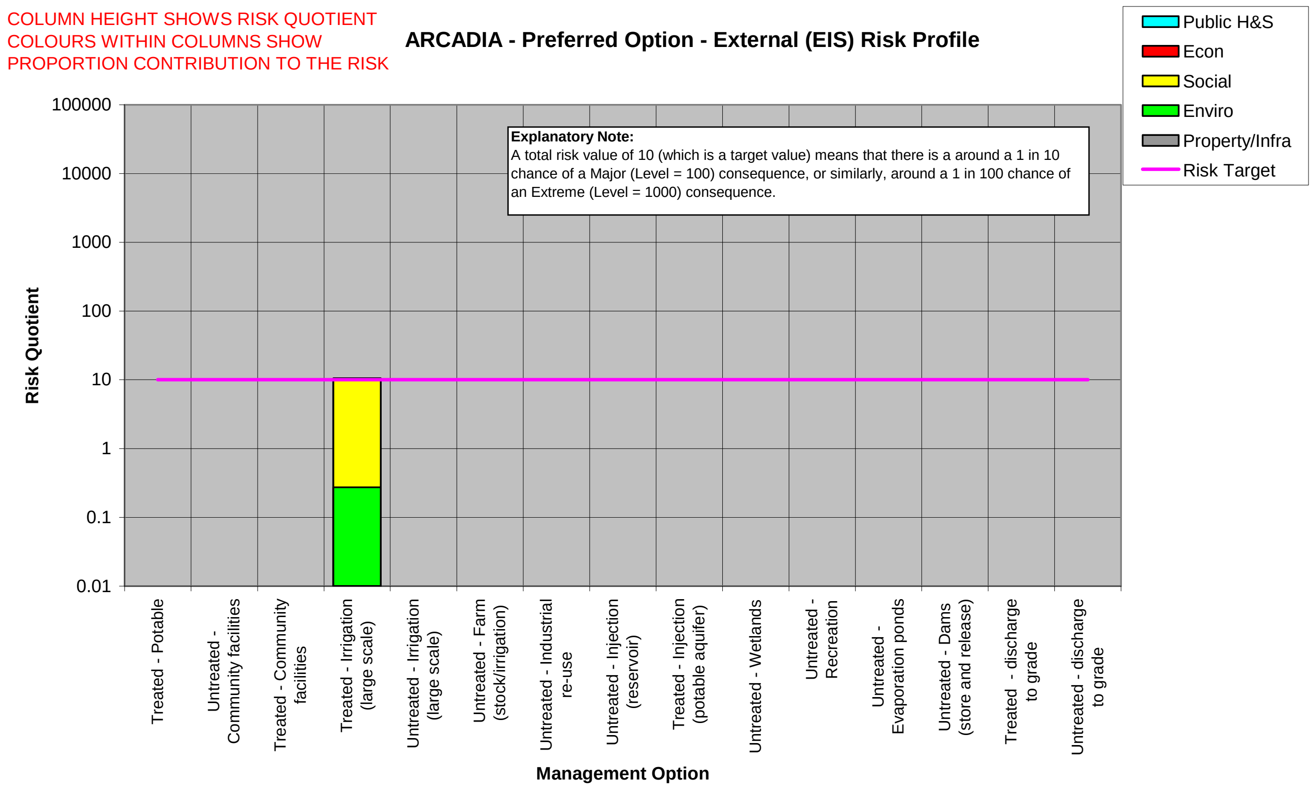


The preferred scenario selected for Arcadia includes:

- 100% of the 28 ML/d total volume of associated water that will require management that would be allocated to large scale irrigation of treated water (Treated- irrigation (large scale).

The preferred option for Arcadia is 100% of the total water available to be allocated to treated irrigation (large scale). This management method poses a medium level of risk with a risk quotient of 10 which is the same as the risk target.

Figure 1-7 Arcadia - Preferred Option - External Risk Profile

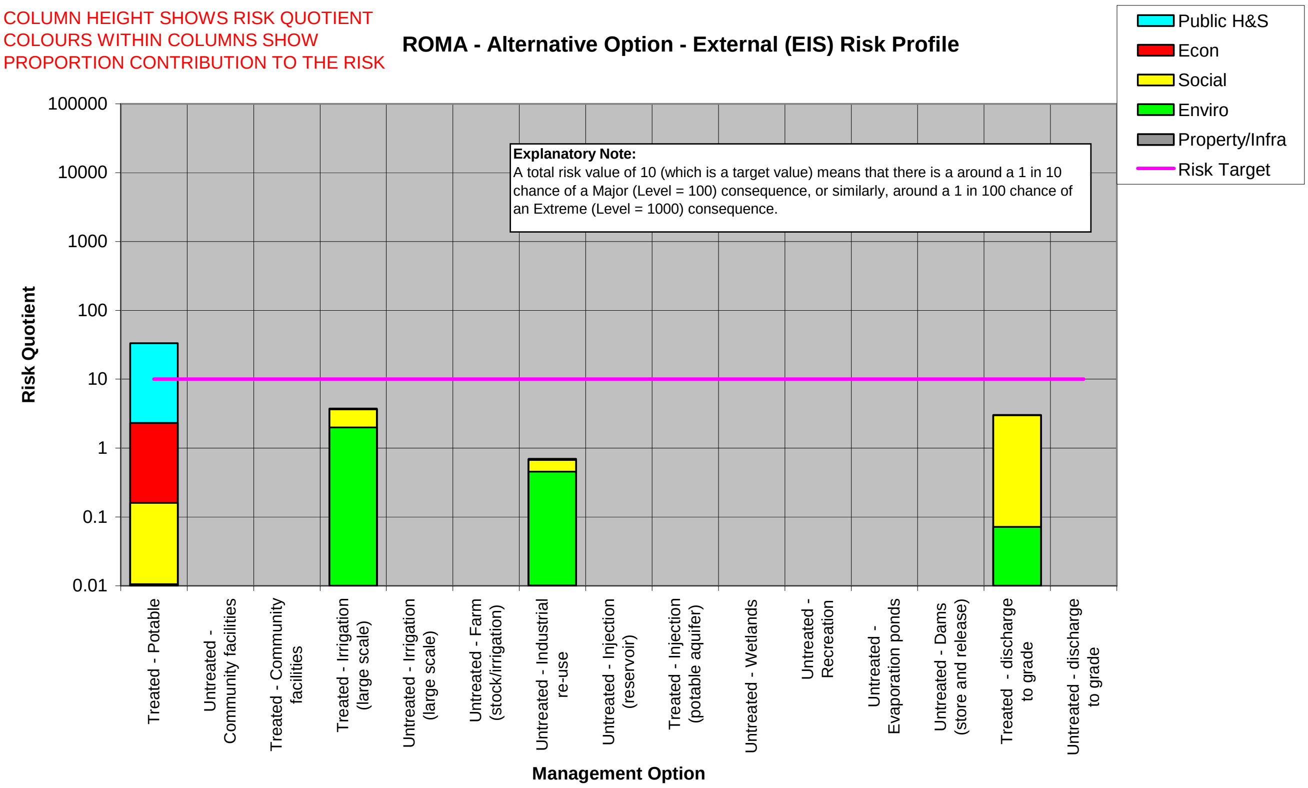


1.7 Alternative Scenario Selection

The first alternative scenario selected for Roma involves 22% allocated to the municipal water supply and 12% to industrial re-use, which is the same as the preferred scenario, however only 51% has been allocated to treated irrigation and the additional water has been allocated to treated discharge to grade.

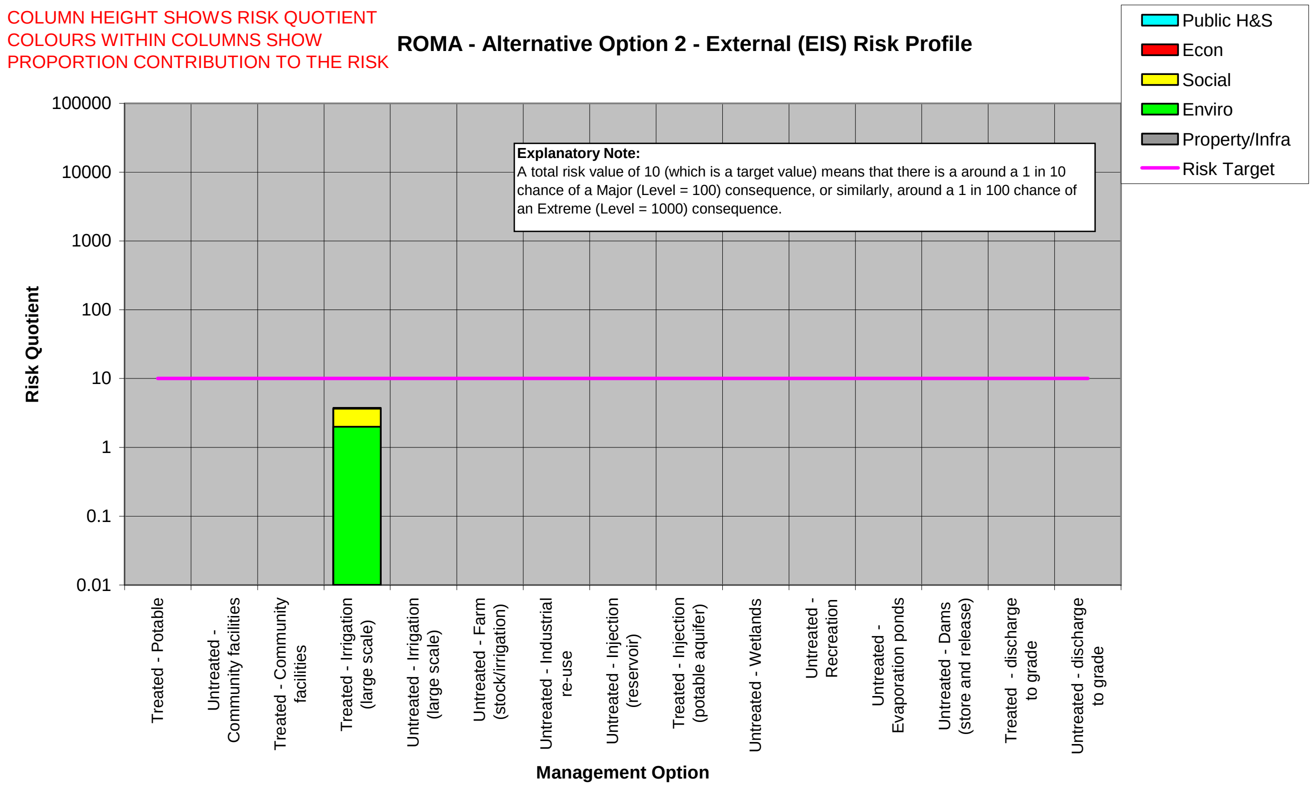
Section 1 Risk Assessment

Figure 1-8 Roma – Alternative Scenario – External Risk Profile



The second alternative scenario has 100% of the water allocated to large scale treated irrigation.

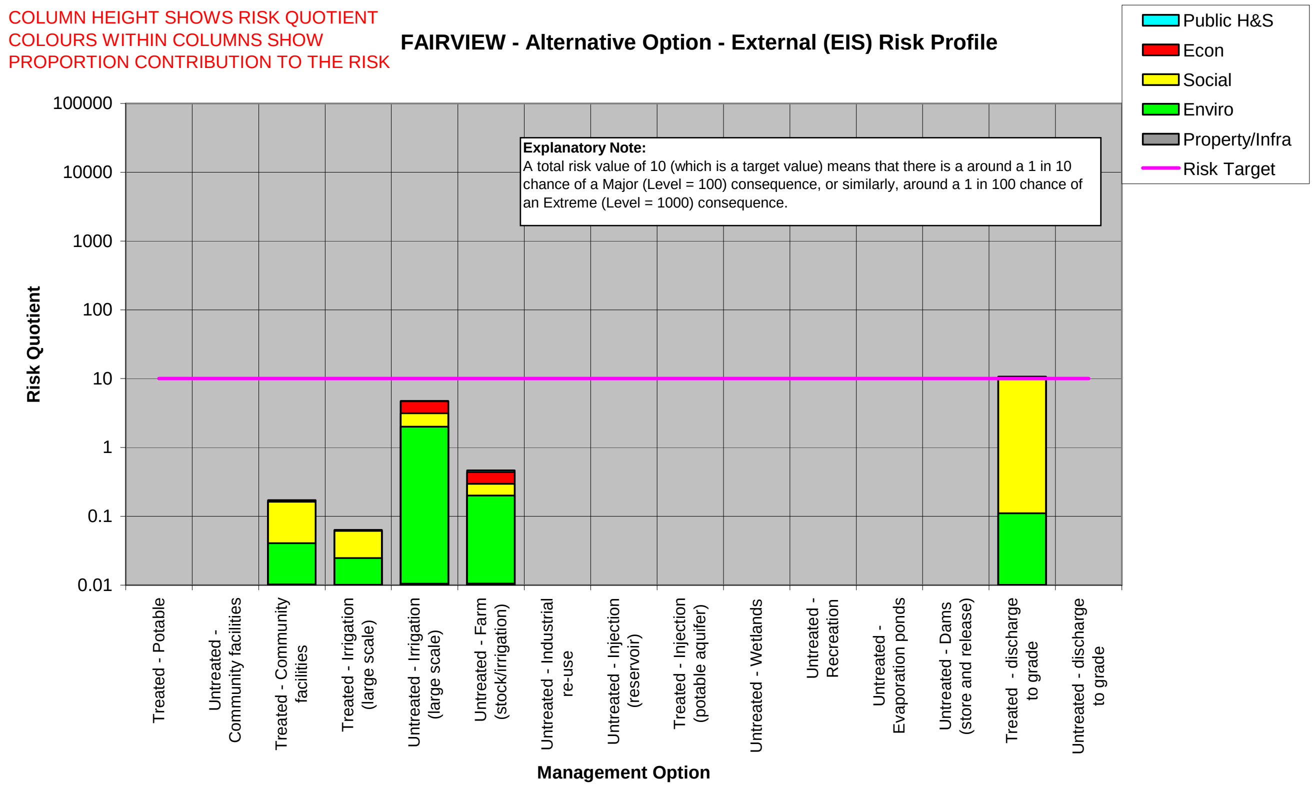
Figure 1-9 Alternative Option 2- External Risk Profile



Section 1 Risk Assessment

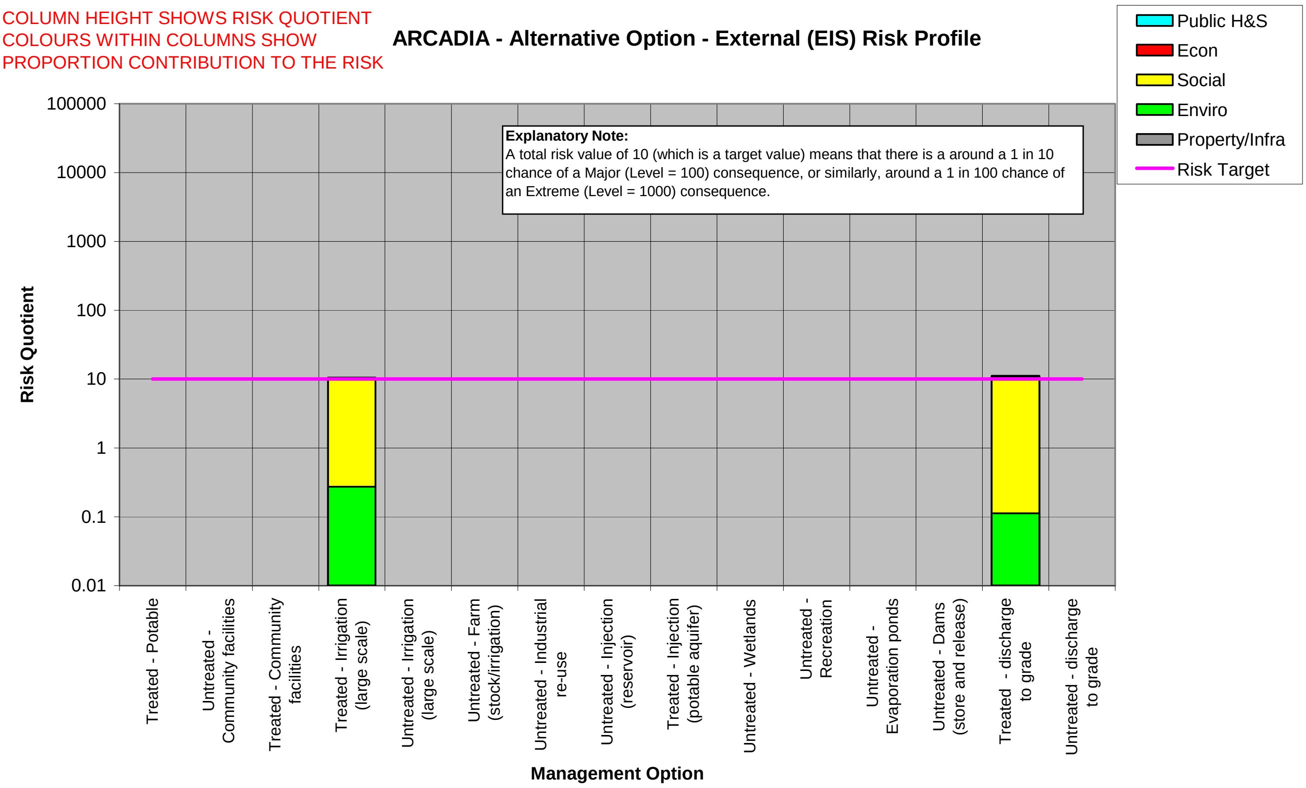
The alternative scenario selected for Fairview has 12% of the available water allocated to treated irrigation similarly to the preferred scenario however only 68% was allocated to treated irrigation. The additional water was allocated to treated discharge to grade (10%), untreated farm (5%) and treated community facilities (5%).

Figure 1-10 Fairview- Alternative Scenario- External Risk Profile



The alternative scenario for Arcadia involves 80% of the available water allocated to treated irrigation and 20% to treated discharge to grade, rather than 100% allocated treated irrigation as in the preferred scenario.

Figure 1-11 Arcadia- Alternative Scenario- External Risk Profile



1.8 Mitigation Measures

As stated above, it is assumed that appropriate risk management activities will be incorporated into any selected water management scenario. Several risk management actions have been identified for each management method to cover the property/infrastructure, environmental, social, economic and public health and safety risks. The mitigation measures reduce the risk of the management methods by reducing the likelihood or the consequences associated with the risk events. Specific risk management plans have not been developed at this early stage as the preferred scenarios have not been confirmed.

Examples of strategic actions that have already been identified include:

- Instrumentation and monitoring of raw water; surface water and groundwater;
- Identify and purchase suitable (location, physical, etc) land;
- Develop local employment plan, public awareness program, effective regulator engagement plan; detailed scientific Land and Water Management Plan;
- Comprehensive investigation of injection and modelling of reservoirs;
- Biological control methods to limit water borne disease from mosquitoes; and

- Engineering design to minimise discharge to the receiving surface water and groundwater environments.

In addition, more specific actions would need to be fully developed into risk mitigations plans when preferred scenarios are identified. A formal risk management plan would need to include the person responsible for the plan, person who will implement the plan, estimated cost of mitigation, date of commencement and date of completion.

Details on mitigation strategies for each of the water management options for Roma, Fairview and Arcadia are included in Appendix B.

1.9 Conclusions

The external EIS risk profiles for the associated water show that the potential management methods pose variable levels of risk to the wider environment.

In order to dispose of associated water in any of the three areas, Roma, Fairview and Arcadia, Santos needs to select a range of management methods, depending on disposal volumes, water quality and local conditions. The assessment of risk posed to the wider environment by the management methods has been used as a basis to select the most appropriate risk scenario. Considering the order of magnitude “accuracy” of the risk assessment the risk profiles for the three locations show that the management methods pose risk levels that are within, or relatively close to the selected risk target.

At this preliminary stage of the project, the preferred scenarios that have been selected include: Treated-potable, industrial re-use and treated irrigation for Roma; treated irrigation and untreated irrigation for Fairview; and treated irrigation for Arcadia. These scenarios are subject to change as further information becomes available.

The selection of the preferred scenario also involves consideration of practicality, cost effectiveness and site specific constraints.

Preliminary List of Risk Issues

Appendix A

Table A-1 Roma - Preliminary List of Risk Issues

Roma	
Water Use	Risk
Untreated water distributed to local farm holdings upstream of Roma for appropriate use depending on water quality	Groundwater contamination from irrigated farm areas prevents disposal
Untreated water distributed to local farm holdings upstream of Roma for appropriate use depending on water quality	Water quality varies over the life of the field resulting in irrigation/stock watering without treatment being non-viable
Untreated water distributed to local farm holdings upstream of Roma for appropriate use depending on water quality	Soil quality not suitable for irrigation with associated water
Untreated water distributed to local farm holdings upstream of Roma for appropriate use depending on water quality	Application of associated water results in runoff into local surface water systems
Untreated water distributed to local farm holdings upstream of Roma for appropriate use depending on water quality	Topography constraints make irrigation non-viable
Untreated water distributed to local farm holdings upstream of Roma for appropriate use depending on water quality	Higher than predicted rainfall causes reduction in demand for associated water
Untreated water distributed to local farm holdings upstream of Roma for appropriate use depending on water quality	Distance to end user makes irrigation unworkable
Untreated water distributed to local farm holdings upstream of Roma for appropriate use depending on water quality	Regulatory constraints limit application of non treated water for agricultural purposes
Untreated water distributed to local farm holdings upstream of Roma for appropriate use depending on water quality	Insufficient uptake by farmers
Untreated water distributed to local industry	Water quality varies over the life of the field resulting in use without treatment being non-viable
Untreated water distributed to local industry	Distance to end user makes industrial use unworkable
Untreated water distributed to local industry	Insufficient customers to consume water as planned
Untreated water distributed to local industry	Regulatory constraints limit application of non treated water for industrial purposes
Untreated water distributed to local industry	Contracts with end-users may be required to include clauses (e.g.. quantity/quality of water) that Santos cannot commit to meeting over the lifetime of the project
Treated water provided to Roma and surrounding towns for high value uses	Commitment to supply quantity cannot be met
Treated water provided to Roma and surrounding towns for high value uses	Community opposition (perception) to associated water supply
Treated water provided to Roma and surrounding towns for high value uses	Unable to meet Municipal water quality standards for supply

Preliminary List of Risk Issues

Roma	
Water Use	Risk
Treated water provided to Roma and surrounding towns for high value uses	Regulatory constraints may limit use of associated water by municipality
Treated water provided to Roma and surrounding towns for high value uses	Distance to end user makes municipal use unworkable
Treated water provided to Roma and surrounding towns for high value uses	Municipality may not be able/willing to take all water allocated to them
Untreated water provided to Roma and surrounding towns for low value uses	Groundwater contamination from irrigated farm areas prevents disposal
Untreated water provided to Roma and surrounding towns for low value uses	Water quality varies over the life of the field resulting in irrigation without treatment being non-viable
Untreated water provided to Roma and surrounding towns for low value uses	Soil quality not suitable for irrigation with associated water
Untreated water provided to Roma and surrounding towns for low value uses	Application of associated water results in runoff into local surface water systems
Untreated water provided to Roma and surrounding towns for low value uses	Formation has inadequate capacity to take all brine
Untreated water provided to Roma and surrounding towns for low value uses	Distance to end user makes option unworkable
Untreated water provided to Roma and surrounding towns for low value uses	Regulatory constraints limit application of non treated water for low value uses
Waste stream from treatment process injected into suitable formation with surface storage less than 24hrs via existing borehole infrastructure	Formation has inadequate capacity to take all brine
Waste stream from treatment process injected into suitable formation with surface storage less than 24hrs via existing borehole infrastructure	Contamination of groundwater prevents disposal
Waste stream from treatment process injected into suitable formation with surface storage less than 24hrs via existing borehole infrastructure	Need for buffer storage for greater than 24hrs prior to injection
Waste stream from treatment process injected into suitable formation with surface storage less than 24hrs via existing borehole infrastructure	Reinjection may impact other CSG Operators
Waste stream from treatment process injected into suitable formation with surface storage less than 24hrs via existing borehole infrastructure	Regulatory constraints limit the option of brine injection
Waste stream from treatment process injected into suitable formation with surface storage less than 24hrs via existing borehole infrastructure	Voidage used preferentially for gas storage and recovery to ramp up supply

Preliminary List of Risk Issues

Table A-2 Fairview - Preliminary List of Risk Issues

Fairview	
Water Use	Risk
Untreated water to irrigate large scale Chinchilla White Gum plantations	Groundwater contamination from irrigated farm areas prevents disposal
Untreated water to irrigate large scale Chinchilla White Gum plantations	Water quality varies over the life of the field resulting in irrigation without treatment being non-viable
Untreated water to irrigate large scale Chinchilla White Gum plantations	Application of associated water results in runoff into local surface water systems
Untreated water to irrigate large scale Chinchilla White Gum plantations	Higher than predicted rainfall causes reduction in demand for associated water
Untreated water to irrigate large scale Chinchilla White Gum plantations	Regulatory constraints limit application of non treated water for irrigation purposes
Untreated water to irrigate large scale Chinchilla White Gum plantations	Soil quality degrades over time due to irrigation with associated water
Untreated water to irrigate large scale Chinchilla White Gum plantations	Insufficient suitable land available
Untreated water to irrigate large scale Chinchilla White Gum plantations	Inadequate water available for irrigating crop
Treated water to irrigate large scale Leucaena crops	Inadequate treated water available for irrigation
Treated water to irrigate large scale Leucaena crops	Potential for water used to irrigate to leach materials from soil and contaminate groundwater
Treated water to irrigate large scale Leucaena crops	Application of treated water results in runoff and contamination of surface water
Treated water to irrigate large scale Leucaena crops	Higher than predicted rainfall causes reduction in demand for associated water
Treated water to irrigate large scale Leucaena crops	Regulatory constraints limit application of non treated water for irrigation purposes
Treated water to irrigate large scale Leucaena crops	Soil quality degrades over time due to irrigation with associated water
Treated water to irrigate large scale Leucaena crops	Irrigation causes soil erosion
Waste stream from treated water injected into Timbury Wells formation with surface storage less than 24hrs to Fairview 77 & 82	Formation has inadequate capacity to take all brine
Waste stream from treated water injected into Timbury Wells formation with surface storage less than 24hrs to Fairview 77 & 82	Reinjection may reduce gas yields
Waste stream from treated water injected into Timbury Wells formation with surface storage less than 24hrs to Fairview 77 & 82	Contamination of groundwater
Waste stream from treated water injected into Timbury Wells formation with surface storage less than 24hrs to Fairview 77 & 82	Need for buffer storage prior to injection
Waste stream from treated water injected into Timbury Wells formation with surface storage less than 24hrs to Fairview 77 & 82	Reinjection may impact other CSG Operators
Waste stream from treated water injected into Timbury Wells formation with surface storage less than 24hrs to Fairview 77 & 82	Regulatory approval may be difficult to obtain

Preliminary List of Risk Issues

Table A-3 Arcadia - Preliminary List of Risk Issues

Arcadia	
Water Use	Risk
Untreated water to the Fairview 140 irrigation area for Chinchilla White Gum plantations	Groundwater contamination from irrigated farm areas prevents disposal
Untreated water to the Fairview 140 irrigation area for Chinchilla White Gum plantations	Water quality varies over the life of the field resulting in irrigation without treatment being non-viable
Untreated water to the Fairview 140 irrigation area for Chinchilla White Gum plantations	Application of associated water results in runoff into local surface water systems
Untreated water to the Fairview 140 irrigation area for Chinchilla White Gum plantations	Higher than predicted rainfall causes reduction in demand for associated water
Untreated water to the Fairview 140 irrigation area for Chinchilla White Gum plantations	Regulatory constraints limit application of non treated water for irrigation purposes
Untreated water to the Fairview 140 irrigation area for Chinchilla White Gum plantations	Soil quality degrades over time due to irrigation with associated water
Untreated water to the Fairview 140 irrigation area for Chinchilla White Gum plantations	Insufficient suitable land available
Untreated water to the Fairview 140 irrigation area for Chinchilla White Gum plantations	Inadequate water available for irrigating crop
Untreated water to the Fairview 140 irrigation area for Chinchilla White Gum plantations	Pipeline to transfer water not available/or lacking capacity/Distance to end user limits the amount of water that can be utilised by farmers/irrigators
Untreated water to the Fairview 140 irrigation area for Chinchilla White Gum plantations	Fairview unable to accept all associated water as planned
Untreated water to local farmers/local irrigation schemes	Inadequate associated water available for irrigation as committed to local landowners
Untreated water to local farmers/local irrigation schemes	Groundwater contamination from irrigated farm areas prevents disposal
Untreated water to local farmers/local irrigation schemes	Water quality varies over the life of the field resulting in irrigation without treatment being non-viable
Untreated water to local farmers/local irrigation schemes	Application of treated water results in runoff and contamination of surface water
Untreated water to local farmers/local irrigation schemes	Higher than predicted rainfall causes reduction in demand for associated water
Untreated water to local farmers/local irrigation schemes	Irrigation causes soil erosion
Untreated water to local farmers/local irrigation schemes	Distance to end user limits the amount of water that can be utilised by farmers/irrigators
Untreated water to local farmers/local irrigation schemes	Regulatory constraints limit application of non treated water for irrigation purposes
Untreated water to local farmers/local irrigation schemes	Soil quality degrades over time due to irrigation with associated water
Untreated water to local farmers/local irrigation schemes	Formation has inadequate capacity to take all brine
Untreated water to local farmers/local irrigation schemes	Topography constraints limit the area suitable for irrigation reducing the volume of water that can be utilised

Mitigation Strategies

Appendix B

Table B-1 Risk mitigation strategy for the Roma area

Management Options	Risk Mitigation Strategy
Potable Water (Treated)	Obtain legal indemnity. Public awareness program. Blending and injection of brine.
Untreated Irrigation and Maintenance of Community Facilities	Instrumentation and monitoring of raw water, surface water and groundwater. Specific as required. Regular review. Develop viable fall-back option. Develop water management plan.
Treated Irrigation and Maintenance of Community Facilities	Instrumentation and monitoring of raw water, surface water and groundwater. Specific as required. Regular review. Develop viable fall-back option. Develop water management plan.
Treated irrigation (large scale)	Develop effective regulator engagement plan. Identify and purchase suitable (location, physical etc) land. Develop local employment plan. Public awareness program. Blending and injection of brine.
Untreated irrigation (large scale)	Instrumentation and monitoring of raw water, surface water and groundwater. Specific as required. Regular review. Develop water management plan. Develop effective regulator engagement plan. Identify and purchase suitable (location, physical etc) land. Develop local employment plan. Public awareness program.
Untreated farm uses (stock/irrigation)	Investigate suitability of water quality for intended farm uses. Contract with farmers regarding water use management. Water resource utilisation plan (includes specific monitoring). Develop effective regulator engagement plan. Obtain legal indemnity.
Industrial re-use	Develop effective regulator engagement plan. Obtain legal indemnity.
Injection of Untreated Water	Comprehensive investigation, modelling. Monitor injection water for contaminants, monitor reservoir and aquifers, verify reservoir capacity, confirm alternative gas storage availability, public awareness program. Develop effective regulator engagement plan.
Injection of Treated Water into Freshwater Aquifer	Comprehensive investigation, modelling. Adequate compensation. Monitor injection water for contaminants, monitor reservoir and aquifers, verify reservoir capacity, confirm alternative gas storage availability, public awareness program. Develop effective regulator engagement plan. Blend the brine stream.
Constructed wetlands	No strategic actions needed
Recreation	No strategic actions needed
Evaporation Ponds	Identify suitable sites. Appropriate, compliant engineering design, operations and maintenance. Rehab strategy. Instrumentation and monitoring of surface water and groundwater. Specific as required. Regular review. Develop effective regulator engagement plan. Public awareness program.
Dams (store and release for irrigation or injection)	Identify suitable sites. Develop release strategy. Appropriate, compliant engineering design, operations and maintenance. Rehab strategy. Instrumentation and monitoring of surface water and groundwater. Specific as required. Regular review. Develop effective regulator engagement plan. Public awareness program.
Treated direct discharge to surface water	Blending and injection of brine. Develop effective regulator engagement plan. Public awareness program. Consider lobbying for water allocations downstream. Pipe direct to Balonne River. May be seen as beneficial resource to Murray

Mitigation Strategies

Management Options	Risk Mitigation Strategy
	Darling Basin
Untreated direct discharge to surface water	Establishment and compliance with discharge water quality objectives. Instrumentation and monitoring of raw water, surface water and groundwater. River health monitoring. Specific as required. Regular review. Develop effective regulator engagement plan. Public awareness program. Consider lobbying for water allocations downstream.

Table B-2 Risk mitigation strategy for the Fairview area

Management Options	Risk Mitigation Strategy
Potable Water (Treated)	Obtain legal indemnity. Public awareness program. Blending and injection of brine.
Untreated Irrigation and Maintenance of Community Facilities	Instrumentation and monitoring of raw water, surface water and groundwater. Specific as required. Regular review. Develop viable fall-back option. Develop water management plan.
Treated Irrigation and Maintenance of Community Facilities	Instrumentation and monitoring of raw water, surface water and groundwater. Specific as required. Regular review. Develop viable fall-back option. Develop water management plan.
Treated irrigation (large scale)	Develop effective regulator engagement plan. Perform an exploration and injection development program. Develop local employment plan. Public awareness program. Blending and injection of brine.
Untreated irrigation (large scale)	Instrumentation and monitoring of raw water, surface water and groundwater. Specific as required. Regular review. Develop water management plan. Develop effective regulator engagement plan. Develop local employment plan. Public awareness program.
Untreated farm uses (stock/irrigation)	Investigate suitability of water quality for intended farm uses. Contract with farmers regarding water use management. Water resource utilisation plan (includes specific monitoring). Develop effective regulator engagement plan. Obtain legal indemnity.
Industrial re-use	Develop effective regulator engagement plan. Obtain legal indemnity.
Injection of Untreated Water	Comprehensive investigation, modelling. Monitor inj water for contaminants, monitor reservoir and aquifers, verify reservoir capacity, confirm alternative gas storage availability, public awareness program. Develop effective regulator engagement plan.
Injection of Treated Water into Freshwater Aquifer	Comprehensive investigation, modelling. Adequate compensation. Monitor inj water for contaminants, monitor reservoir and aquifers, verify reservoir capacity, confirm alternative gas storage availability, public awareness program. Develop effective regulator engagement plan. Blend the brine stream.
Constructed wetlands	No strategic actions needed
Recreation	No strategic actions needed
Evaporation Ponds	Identify suitable sites. Appropriate, compliant engineering design, operations and maintenance. Rehab strategy. Instrumentation and monitoring of surface water and groundwater. Specific as required. Regular review. Develop effective

Management Options	Risk Mitigation Strategy
	regulator engagement plan. Public awareness program.
Dams (store and release for irrigation or injection)	Identify suitable sites. Develop release strategy. Appropriate, compliant engineering design, operations and maintenance. Rehab strategy. Instrumentation and monitoring of surface water and groundwater. Specific as required. Regular review. Develop effective regulator engagement plan. Public awareness program.
Treated direct discharge to surface water	Blending and injection of brine. Develop effective regulator engagement plan. Public awareness program. Consider lobbying for water allocations downstream. Pipe direct to Dawson River downstream of Dawsons Bend.
Untreated direct discharge to surface water	Establishment and compliance with discharge water quality objectives. Instrumentation and monitoring of raw water, surface water and groundwater. River health monitoring. Specific as required. Regular review. Develop effective regulator engagement plan. Public awareness program. Consider lobbying for water allocations downstream. Pipe direct to Dawson River downstream of Dawsons Bend.

Table B-3 Risk mitigation strategy for the Arcadia area

Management Options	Risk Mitigation Strategy
Potable Water (Treated)	Obtain legal indemnity. Public awareness program. Blending and injection of brine.
Untreated Irrigation and Maintenance of Community Facilities	Instrumentation and monitoring of raw water, surface water and groundwater. Specific as required. Regular review. Develop viable fall-back option. Develop water management plan.
Treated Irrigation and Maintenance of Community Facilities	Instrumentation and monitoring of raw water, surface water and groundwater. Specific as required. Regular review. Develop viable fall-back option. Develop water management plan.
Treated irrigation (large scale)	Develop effective regulator engagement plan. Investigate suitable (location, physical etc) land. Develop local employment plan. Public awareness program. Investigate blending and injection of brine.
Untreated irrigation (large scale)	Instrumentation and monitoring of raw water, surface water and groundwater. Specific as required. Regular review. Develop water management plan. Develop effective regulator engagement plan. Investigate suitable (location, physical etc) land. Develop local employment plan. Public awareness program.
Untreated farm uses (stock/irrigation)	Investigate suitability of water quality for intended farm uses. Contract with farmers regarding water use management. Water resource utilisation plan (includes specific monitoring). Develop effective regulator engagement plan. Obtain legal indemnity.
Industrial re-use	Develop effective regulator engagement plan. Obtain legal indemnity.
Injection of Untreated Water	Comprehensive investigation, modelling. Monitor inj water for contaminants, monitor reservoir and aquifers, verify reservoir capacity, confirm alternative gas storage availability, public awareness program. Develop effective regulator engagement plan.
Injection of Treated Water into Freshwater Aquifer	Comprehensive investigation, modelling. Adequate compensation. Monitor inj water for contaminants, monitor reservoir and aquifers, verify reservoir capacity,

Mitigation Strategies

Management Options	Risk Mitigation Strategy
	confirm alternative gas storage availability, public awareness program. Develop effective regulator engagement plan. Blend the brine stream.
Constructed wetlands	No strategic actions needed
Recreation	No strategic actions needed
Evaporation Ponds	Identify suitable sites. Appropriate, compliant engineering design, operations and maintenance. Rehab strategy. Instrumentation and monitoring of surface water and groundwater. Specific as required. Regular review. Develop effective regulator engagement plan. Public awareness program.
Dams (store and release for irrigation or injection)	Identify suitable sites. Develop release strategy. Appropriate, compliant engineering design, operations and maintenance. Rehab strategy. Instrumentation and monitoring of surface water and groundwater. Specific as required. Regular review. Develop effective regulator engagement plan. Public awareness program.
Treated direct discharge to surface water	Blending and injection of brine. Develop effective regulator engagement plan. Public awareness program. Consider lobbying for water allocations downstream. Pipe direct to eith Dawsons River (approx. 100km but up elevation of approx 100m if heading due east) or to the McKenzie River (unsure if a viable option, but terrain is much flatter, approx 100km distance). Providing downstream resource for the community.
Untreated direct discharge to surface water	Establishment of and compliance with discharge water quality objectives. Instrumentation and monitoring of raw water, surface water and groundwater. River health monitoring. Specific as required. Regular review. Develop effective regulator engagement plan. Public awareness program. Consider lobbying for water allocations downstream.