6.5 Summary of potential groundwater impacts

In order to release CSG from the coal seams, the pressure in the coal seam must be reduced. This is practically achieved by pumping out the groundwater. Groundwater produced in association with CSG is typically a sodium-bicarbonate type water having a higher salinity and more sodium relative to other cations than local surface waters (as detailed previously in Table 6.2).

CSG water production will vary considerably in volume and quality and must be effectively managed during development. Legislation changes currently being discussed with Queensland Government will ensure that adequate water management practices are put in place to protect groundwater resources within CSG development areas Project planning will include protection of adjacent water rights and CSG rights through mitigation agreements and monitoring. The beneficial use of product water should be in agreement before extraction commences.

The choice of product water end-use can depend on economics, regulatory requirements, produced water quality, and local hydrogeologic conditions. These options for the Surat Basin are discussed in more detail in Section 7.

Table 6.6 summarise the identified potential groundwater impacts and how changes to legislation will adequately address concerns.

Table 6.6: Summary of potential groundwater impacts and relation to the Surat Basin CSG developments

	Concern	Summary of study assessment	Legislative measures in place to ensure protection of water resource	Summary of potential impact* from CSG development with the Surat Basin
1	Groundwater drawdown within the coal seams	Á Impact similar to existing open-cut coal mines within the Surat Basin in requirement to dewater coal seam(s) before release of gas Á The cone of depression due to extraction within the WCM unit is unknown at this stage, and depends on the intensity of CSG development and site-specific conditions	Á Development of Underground Water Impact Report Á Establishment of groundwater monitoring program Á Requirement for predictive modelling Á Commitment to 'make good' obligation in new legislation	LOW IMPACT Will depend on site-specific conditions. Requirements under proposed Petroleum and Gas (Production and Safety) Bill 2004 ensure sound water management practices to be implemented.
2	Hydraulic connection of the WCM to major aquifers within the GAB	Á Development requires dewatering of coal seams before release of gas Á Impact similar to existing open-cut coal mines within the Surat Basin in requirement to dewater coal seam(s) before release of gas Á Previous work in the Surat Basin found that the dewatering effects of coal mining had no direct impact on shallow alluvial environments (PPK, 2000). Á Assumed that overlying aquifers are less vulnerable to drawdown from CSG development due to low vertical hydrologic conductivity between units	Á Development of Underground Water Impact Report Á Establishment of groundwater monitoring program Á Requirement for predictive modelling Á Commitment to 'make good' obligation in new legislation	LOW IMPACT Will depend on site-specific conditions. Requirements under proposed Petroleum and Gas (Production and Safety) Bill 2004 ensure sound water management practices to be implemented.

	Concern	Summary of study assessment	Legislative measures in place to ensure protection of water resource	Summary of potential impact* from CSG development with the Surat Basin
3	Water storage/ pond leakage to shallow groundwater resource	Á Water storages such as evaporation ponds may have potential for vertical leakage of poor-quality CSG product water.	Á Establishment of groundwater monitoring program. Á Issuing of permits of water structures.	LOW IMPACT Will depend on site-specific conditions. Information from CSG companies indicates: Á water storage structures designed are either lined or compacted to standard to ensure no leakage Á design of water storages subject to the issuing of permits. Current practices include shallow monitoring of groundwater for water quality and water level adjacent to storages. Requirements under proposed Petroleum and Gas (Production and Safety) Bill 2004 ensure sound water management practices to be implemented.
4	Loss of supply to existing WCM groundwater users (due to drawdown from within coal seams)	Á Limited existing groundwater use from within the coal seams and restricted to stock watering. Á Local groundwater use is from coal seams within outcrop zones which are generally not prospective for CSG development.	Á Industry commitment to 'Make good' obligation in new legislation Á Development of Underground Water Impact Report	LOW IMPACT Will depend on site-specific conditions. Requirements under proposed Petroleum and Gas (Production and Safety) Bill 2004 ensure sound water management practices to be implemented.
5	Water management and beneficial re-use of resource	Á Surat Basin offers extensive opportunities to adjacent industries for beneficial re-use of product water. Á Most likely some of product water will be used for a number of purposes, including on-site re-use for CSG operations and beneficial re-use, with some transferred to evaporation ponds. Á Need to know quality and quantity of CSG product water to confirm beneficial end use	Á Depends on proposed end use of product water. Á Direct release of product water is unlikely due to generally poor quality of CSG water Á Development of Underground Water Impact Report	LOW IMPACT Will depend on site-specific conditions. Impact site-specific, relating to quality and quantity of CSG product water. Will depend on location of CSG development with respect to end use. Extensive opportunity for development of CSG industry and beneficial re-use of product water within the Surat Basin. Requirements under proposed Petroleum and Gas (Production and Safety) Bill 2004 ensure sound water management practices to be implemented.

* Potential impact has been based on current research presented in the main report and needs to be confirmed by detailed studies at the CSG development sites.

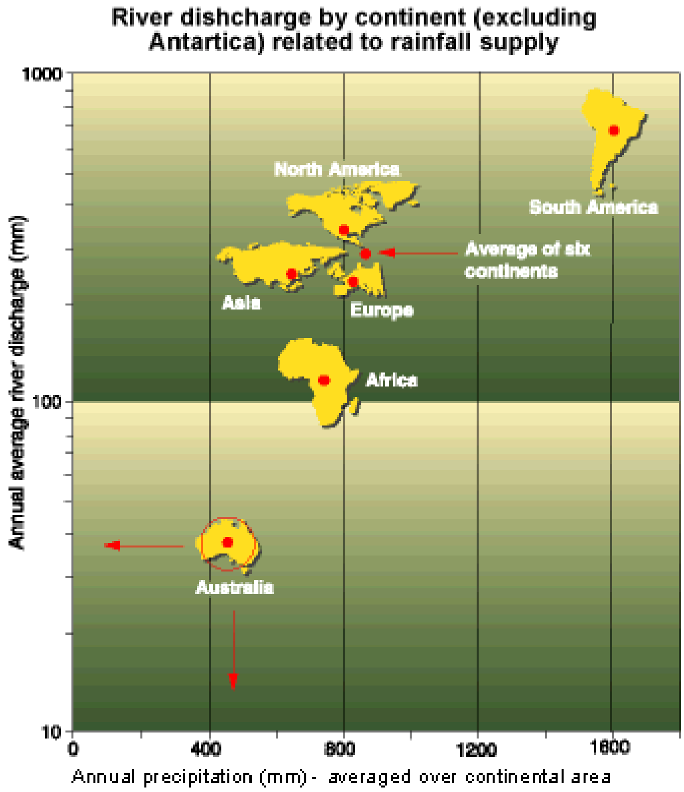
7. Water management options

7.1 Introduction

In Australia, and particularly Queensland, water is recognised as a resource of which we have limited supply. Australia is one of the driest continents on earth and as such water should be treated as a limited resource.

The Bureau of Meteorology (BOM 2004) notes:

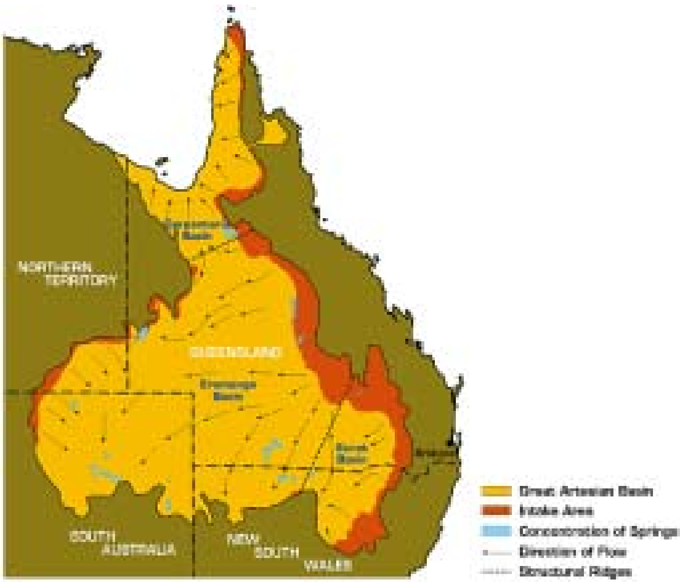
> Australia's rainfall is easily the lowest of the five continents (excluding Antarctica). Low rainfall combined with very high evaporation (particularly in inland Australia) leads to low surface water flows and seasonal river systems. (Figure 7.1) shows that discharge of Australia's rivers into the sea is by far the lowest of any of the continents.
>
> Given Australia's low and variable rain, there is environmental concern about the sustainable management of surface water, its use, its quality and even its very existence in some places.



Source: BOM 2004

Figure 7.1: River discharge by continent

Australia relies heavily on underground water supplies, particularly from the Great Artesian Basin (GAB). The extent of the GAB is shown in Figure 7.2. The pressures in the GAB are known to be declining due to overuse and additional water sources that may reduce the reliance on the GAB would help maintain this resource for future use. The Surat basin CSG production area lies above the GAB and thus use of produced water would aid the protection of the GAB.



Source: NRM&E, 2003

Figure 7.2: Great Artesian Basin

The use of produced water for beneficial purposes provides CSG operators with an opportunity to provide unique and substantial benefits to the community.

7.2 Stakeholders

The stakeholders potentially affected by the beneficial re-use options of produced water from CSG operations include but are not limited to:

Gas production companies

The companies have a financial stake in the management of the produced water. In addition these companies may have a public relations stake in this issue. A positive view of a company seen to be utilising a resource for beneficial purposes is likely to be taken by the public.

Government

Government is ultimately responsible for the management of the county's recourses and the protection of the environment.

Landholders and agricultural industry

Generally, CSG resources lay below or adjacent to private landholders in the agricultural business. A continuing issue for agriculture in Australia is the location of a reliable source of water. Produced water from CSG operations could provide water for landholders.

Nearby communities

The location of reliable sources of water for rural communities in the Surat Basin is an ongoing issue. Again produced water from CSG activities may provide a source for town supply.

In addition, nearby communities may benefit from recreation uses of produced water.

Nearby industrial users

Produced water from CSG activities could provide an alternative source of water for industrial activities in the vicinity of production areas.

Environment

Ultimately the environment is a major stakeholder in the management of produced water. Disposal of water be it directly from produced water or post treatment for beneficial use will impact on the environment. This impact must be minimised and managed effectively.

7.3 Estimation of internal industry demands

Although the total estimated demands have been provided previously in Section 6, Table 6.1, a percentage of water can be applied for internal site water use. It is assumed that water is used on-site for purposes including:

- drilling water;
- haul road watering; and
- construction of site infrastructure such as water holding dams.

From the information collated by NRM&E it is assumed that between 12% and 50% of produced water will be used on-site without treatment. Again, as with the assessment of potential impact on the groundwater environment, the volume of water extracted and therefore to be applied for potential beneficial use and/or reapplied on site for development operations, is site specific.

7.4 Water management options

For this overview study a significant range of water management options has been presented. For each option, the applicability, recognised constraints and data requirements have been briefly assessed where possible. For all options of use of CSG product water, two key factors must be known, the quality and quantity of supply. While some of the options presented may not be applicable in the short term, the aim is to present as many water use options as possible.

The key water management options available for management of produced water include (but not limited to):

- surface discharge;
- underground injection;
- impoundment with no re-use (evaporation, recharge); and
- beneficial uses.

It is likely that a production area will require a combination of management options for produced water. It may be that a portion of the produced water is used on site, a portion is used for a beneficial use and part is disposed. Water management options will be site specific and will be influenced by some or all of the following factors:

- location of production area and proximity to communities, industries, agricultural lands;
- confidence of water extraction rates that can be guaranteed for beneficial use;
- water quality of produced waters;
- environmental sensitivity of surrounds;
- responsibility of capital costs for beneficial use scheme; and
- philosophy of the company.

Due to the water quality characteristic of the coal seam water within the Surat Basin, it is assumed that all or some of the management options chosen by industry may require treatment of the produced water to meet the required water quality. Treatment options will be discussed later in this report. However, if a treatment option is utilised it should be recognised that it is likely that the waste stream from the treatment will require disposal.

7.5 Potential uses of water

If produced water was to be used for a beneficial use it may include but not be limited to:

- agriculture;
- aquaculture;
- niche/cottage industries — algae farming;
- industrial — coal mining, cooling water;
- municipal potable water supply;
- community water supply and recreational activities; and
- environmental — recharging streams/aquifers, minimum environmental flows, wildlife water supply and habitat creation.

Again the quality and quantity of CSG product water must be known in order to determine suitability of end use, reliability of supply to end use and level of treatment required.

7.6 Surface discharge

7.6.1 Introduction

This option is generally perceived as the easiest and cheapest way to dispose of water produced from CSG operations. It involves the release of produced waters to surface water systems either via a direct discharge or via overland or subsurface flow paths.

This method of re-use is widely used in the United States where water produced from CSG operations is of relatively high quality. However for the Surat Basin, it should be noted upfront that while this has been included in the discussion as a potential water management option, the complexity of regulatory approvals and the poor water quality of CSG product water against the water quality of the receiving environment, does not allow for this option to the directly viable, from an environmental and social acceptance perspective.

7.6.2 General applicability

Surface discharge of produced water can have a number of positive and negative effects on the surrounding environment.

<u>Positives</u>

Environmental Flows

Potentially surface discharge may supplement decreasing flows in surface water systems due to extraction and use of surface water. In order to maintain minimum environmental flows produced water could be discharge to heavily allocated systems. This may enable the maintenance of riparian vegetation and wildlife habitat and provide a constant water source for wildlife during periods of extreme drought. However, the nature of the receiving system would need to be such that additional flows would mimic natural flow conditions. This may not be the case in the Surat Basin as many of the surface water systems are normally dry systems.

The quality of released water is also important in this instance. It may be necessary to provide treatment of water prior to release to maintain the natural level of water quality.

Surface water extractions

In addition, discharged water may provide an additional water source for downstream extractors. Again, the quality of the water released will be an important consideration.

However, regulators are moving away from this form of distribution with preference for pipe distribution. It is unlikely that this form of distribution will be allowed in the Surat Basin.

<u>Negatives</u>

Environmental Sensitivity

The surface water systems above the Surat Basin fall within Drainage Division IV which outlets to the Murray Darling River system (Figure 7.3). The Murray Darling river system is under enormous pressure with respect to salt loading due to the effects of deforestation, irrigation and dryland salinity.

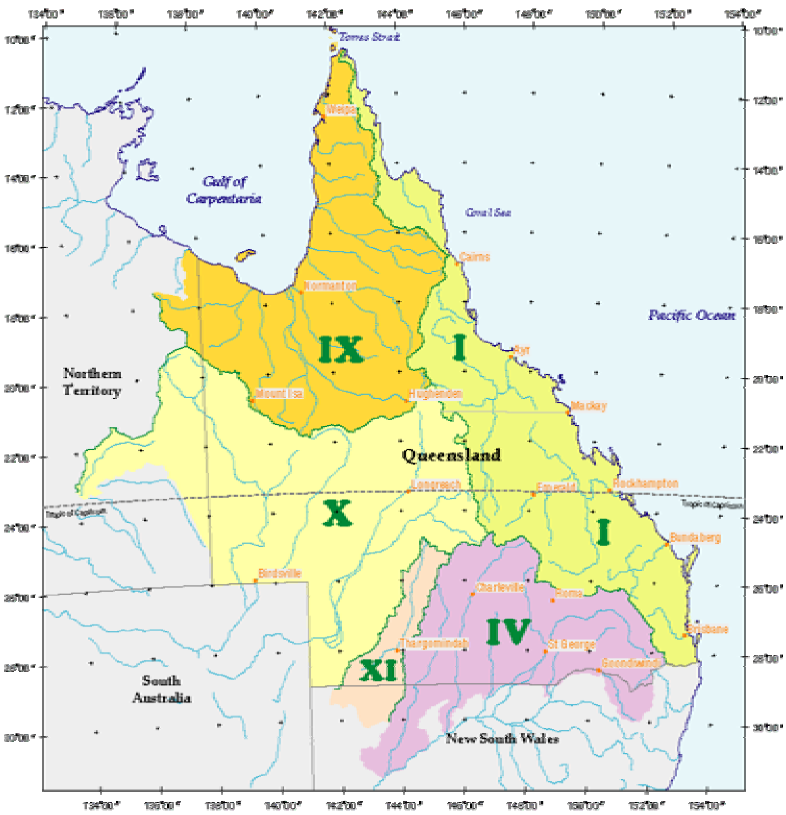
From industry compiled water quality data of produced water in the Surat Basin to date the TDS of the water ranges between 1000 mg/L and 5000 mg/L. These concentrations are significantly higher than the observed TDS in the surface water systems of the area and it is therefore unlikely that a poorer quality water would be directly released into the surface water environment. Undertaking this practice may have long-term detrimental impacts on the ecology and water quality of the surface water system.

Streamflow monitoring indicates the surface water systems in the Condamine-Balonne catchment have TDS concentrations usually less than 180 mg/L in the areas upstream of

Warwick and in the tributaries around Dalby, and between 800 mS/cm (480 mg/L[2]) and 300 mS/cm (180 mg/L) between Warwick and Chinchilla. Higher conductivities (frequently exceeding 800 mS/cm (480 mg/L)) are observed in the Condamine River tributaries including Hodgson, Oakey and lower Allora creeks. (CCMA, 2001).

In order to minimise the impacts of surface discharge control of releases would need to be such that the water quality in the existing surface systems was not depleted. This may be achieved through quality controlled releases or flow threshold controlled releases.

Total salt loading of the system would also require investigation and control.



Source: Department of Natural Resources, Mines and Energy 2004a

Figure 7.3: Drainage divisions

In addition to water quality, the impacts of increased flows in surface systems must also be controlled. Any releases would need to be such that an increase in the flow in the system would not cause detrimental effects such as bank erosion, bed scour and/or increased risks of flooding during high flow events.

The applicability of this type of re-use will be dependant on the specific site conditions. If the receiving water can be protected from potential impacts then this discharge option may be applicable.

[2] Approximate EC conversion 1 mS/cm x 0.6 = mg/L

Limited Resource

Although the discharge of produced water may be assessed as beneficial for the environment by increasing environmental flows and improving habitat it must be kept in mind that the life of a CSG project is generally between 15 and 20 years. The impacts of removing the additional flow in surface water systems after the operating life of the project must also be considered. Will the ecosystems that have adjusted to the increased flows and established as a result of releases survive if this water ceases to be released?

If the release of water to a surface water system also benefits downstream users of this resource the limited life of the releases should also be taken into account. The downstream users must be aware that at the end of operation an alternative water source must be found to supplement supplies.

7.6.3 Regulatory requirements

Operations within the lease will be controlled by the requirements of the Petroleum Act 1923 and/or the new *Petroleum and Gas (Production and Safety) Bill 2004*.

Any surface water discharge of produced water will require approval by the EPA and relevant stakeholders. Impacts of surface discharge will likely be assessed against existing planning instruments for the surface water system. These instruments might include natural resource management plans with key water quality indicators and targets and water resource management plans with environmental flow objectives. Such instruments may be the Queensland Murray Darling Basin Natural Resource Management Plan (QMDC, 2003) and the WRP for the Condamine Balonne catchment.

7.6.4 Technical considerations

The following issues would require examination prior to approval and implementation of a surface discharge scheme.

- Produced water characterisation — water volume and quality.
- Receiving waters characterisation — flow patterns and quality.
- Capacity of the surface water system to receive contaminant loads in produced waters.
- Limits and standards of contaminant loads in receiving waters.
- Physical impact of increasing/changing existing flow regimes in receiving waters.

7.6.4.1 Data sources

The Department of Natural Resources, Mines and Energy web site (NRM&E, 2004b) provides:

- access to gauging station information, streamflow data summaries and chemical analyses of water samples from the surface water data archive of the Department of Natural Resources;
- the flow summary information supplied is based on data recorded and calculated by the Department's hydrographic staff; and
- water quality summary information is based on chemical analysis at the laboratories of Queensland Health Scientific Services of samples collected by hydrographic staff.

NRM&E collects the following data at Flow monitoring sites:

- stream gauge height and water quality information from automatic recorders (time series data);
- gauged flow rates (streamflow measurements);
- surveyed cross sectional information;
- water samples at gauging stations for analysis; and
- field measurement of a variety of water quality parameters.

7.6.4.2 Produced water characterisation

The chemical constituents of the produced water must be known prior to determination of the appropriateness of surface discharge. In order to determine the possible impact on receiving waters the quality and volumes of water to be discharged must be know with reasonable accuracy. Produced water should be subject to full water quality analysis.

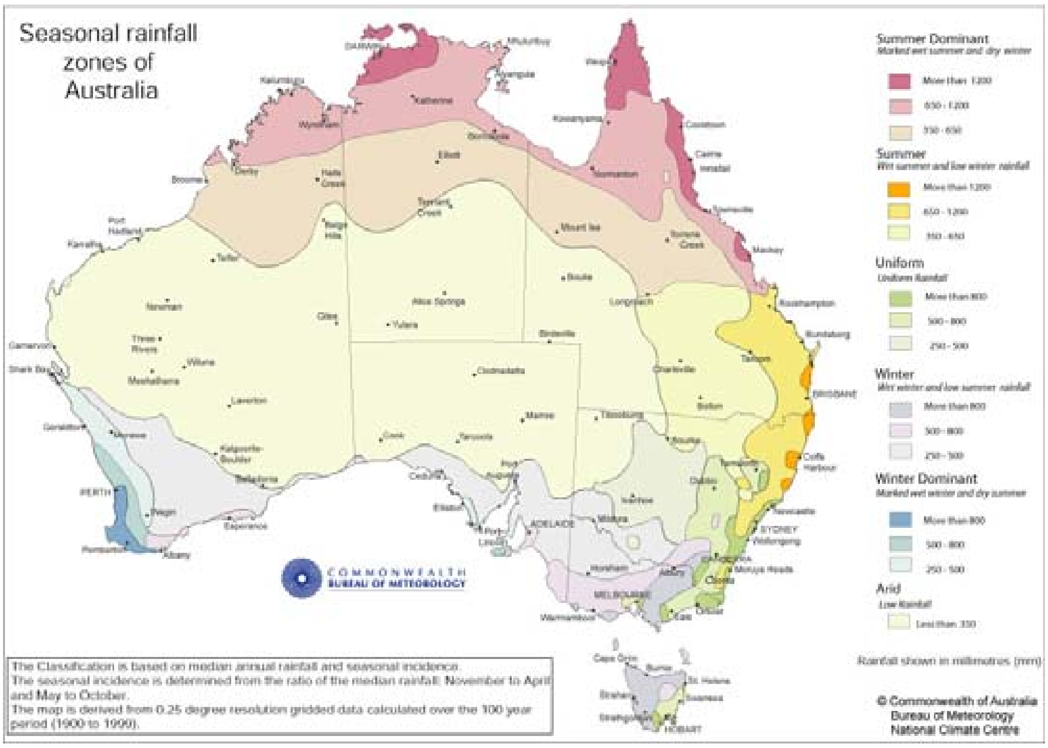
It may be possible from pilot testing results to compile a picture of the likely produced water quality. In addition water quality test results from the area and similar aquifers may be used as a guide.

7.6.4.3 Existing surface water characterisation

Site specific details of a proposed discharge location will be required to determine to potential impact of discharges. Details should include existing stream water quality and quantity.

Existing stream flow patterns are vital for determining impacts and possible discharge arrangements. Australia's weather patterns vary considerably over the continent with the Surat basin climate being dominated by summer rainfall and thus generally larger stream flows during summer (Figure 7.4).

The stream type (perennial, intermittent or ephemeral) will also influence the applicability of discharge and the control of discharges. If a stream is perennial and as limited variation in flows during summer and winter it may be possible for surface discharge to occur at a constant rate year around (rate based). However, in a stream which has a large seasonal variation in flow it may be necessary to control discharge based on the stream flow (flow controlled). Therefore, a detailed assessment of historic steam flow should be completed.



Source: BOM 2004

Figure 7.4: Seasonal rainfall zones of Australia

In addition to stream flow the quality of the receiving water should be determined prior to discharge approval. This will allow assessment of the ability of the receiving water to assimilate the discharge and reduce the risk of impacting the current condition of the system.

Parameters of interest may include but not be limited to:

- Total Dissolved Solids (TDS)
- Electrical Conductivity (EC)
- Dissolved Oxygen
- pH
- Temperature
- Total Alkalinity as $CaCO_3$
- Total Hardness as $CaCO_3$
- Phenols
- Total Petroleum Hydrocarbons
- Chloride
- Fluoride
- Nitrate and Nitrite as N
- Selenium
- Lead

7.6.5 Direct discharge to surface water

7.6.5.1 Applicability

The applicability of this type of use was discussed in the previous sections. Unless the impacts of the end use could be minimised to an acceptable level as ascertained by regulatory authorities it is unlikely that this form of end use will be applicable to the Surat Basin area, particularly in areas where surface water systems are part of the Murray Darling Basin. This surface water system is under existing pressures in terms of water quality.

From current information produced water quality will be significantly lower than the current surface system water quality.

7.6.5.2 Potential constraints

Constraints include:

- obtaining appropriate approvals from the EPA and relevant authorities;
- imposed restrictions of discharge conditions (rate based or flow controlled);
- significant monitoring requirements imposed; and
- community perception of environmental impacts and waste of resources.

7.6.5.3 Data needs

As discussed previously the approval of this type of end use will likely require relatively detailed information on the following:

- produced water quality and volumes;
- water quality and flow data for receiving waters;
- assessment of the potential impacts of releases;
- development and approval of release plans; and
- monitoring of receiving waters to assess impacts.

7.6.5.4 Economics

This alternative is likely to be the ‘cheapest’ and ‘easiest’ in terms of capital expenditure but capital cost will be site specific and will depend on the required level of detail in investigation prior to discharge approval and the imposed monitoring requirements. In addition the environmental and social costs of this solution may be high and difficult to quantify.

These requirements are difficult to cost but may include:

1. an initial study to characterise produced water and receiving water quality, physical characteristics of the receiving system and any impacts on the receiving system;
2. the development of a management plan for discharges to minimise impacts; and
3. a monitoring program to ensure the protection of the receiving waters.

Cost associated with the discharge will include pump and pipe work capital costs to the discharge point. This cost will depend on the geographic location of the discharge point compared to the extraction point. Some bank stabilisation works may also be required at the discharge point which will again be site specific.

In addition, there may be some temporary storage required if discharge conditions are imposed to control the rates of discharge.

If treatment of the produced water is required prior to discharge costs of this alternative would increase significantly. The costs of various treatment alternatives will be discussed later in this document.

7.6.6 Other discharge alternatives

Other discharge alternatives involve indirect surface discharge including irrigation with possible runoff to a surface water system and discharge to an impoundment with possible leakage to a subsurface aquifer and eventually to a surface water system.

Where these alternatives are considered they must be investigated in terms of the end costs of the system. If discharge is to eventually enter the surface water system, potential environmental and social costs within the receiving system must be included in the investigation, which will impact on the viability of this disposal option.

These alternatives are dealt with in later sections of this report.

7.7 Underground injection

7.7.1 Introduction

Underground injection has been used successfully in the petroleum industry and in the CSG industry in the US for many years.

This option involves the injection of produced waters into underground aquifers being either the aquifer from which the water was extracted or another formation with appropriate characteristics to receive the water.

7.7.2 General applicability

The coal measures being targeted for CSG production in the Surat Basin lay between productive and highly utilised aquifers. The alluvium aquifers above the formations are generally high quality and utilised for agriculture and domestic and municipal water supplies. The lower Hutton sandstone aquifer, which is generally of higher quality than produced water in the basin, forms part of the Great Artesian Basin and is utilised by large farms and industry. However, it is claimed by industry representatives that some information is available that indicates that the Hutton water may in fact be of similar or poorer quality than the produced water in some areas across the Surat Basin. No data has been provided to PB as part of this study, to date to substantiate this claim.

Use of the productive aquifers is controlled and regulated by the Department of Natural Resources, Mines and Energy (NRM&E). Injection into these aquifers would require approval from the NRM&E and the EPA.

It is unlikely that injection of CSG produced water of a quality of between 1000 mg/L and 5000 mg/L TDS will be allowed to be injected into the productive aquifers surrounding the coal measures in the Surat Basin. However, injection into deeper aquifers or aquifers were water quality is comparable to the produced waters may be a viable option.

Injection into a coal seam can be divided into re-injection into the producing coal seam and injection into another coal seam.

Injection of produced waters back into the same coal measures, or re-injection, in theory, provides a method of end use that eliminates the full range of impacts related to surface treatment, disposal or reuse. In addition, the re-injection of produced waters maintains/re-establishes the hydrostatic pressure of the aquifers.

Thomas Schneider, an industry leader in the petroleum, oil and gas industry in America states 'Reinjection (recycling) of unaltered CBM produced water (back) into the CBM producing zones is the only responsible method to substantially preserve and restore the hydrostatic balance in the coal bed aquifers' (Schneider, 2001).

However, re-injection poses some significant technical difficulties. The concept seems to contradict the concept of CSG production. In order to release CSG the hydrostatic pressure of the coal seam must be reduced by removing water. To re-inject the produced water would appear to increase the hydrostatic pressure in the aquifer and may result in decreased gas production. This will be discussed further below.

Injection into another coal seam, which may be a seam that has already been used for CSG production, is also an alternative that would appear to be a responsible method of end use. The applicability of this alternative will depend on the availability of an alternative coal seam and the technical feasibility of using this seam for injection. It may be possible to utilise infrastructure in place for water and gas removal as injection wells after production has ceased.

7.7.3 Regulatory requirements

The injection and re-injection of produced water would require approval from NRM&E and the EPA. The feasibility of this option would ultimately lay with the regulatory authorities in Australia.

Use of the aquifers of the Surat Basin area is highly regulated and the protection of the aquifers from contamination is of great importance for existing and future users. In addition, the overlying/underlying aquifers typically have better water quality than the coal seams. Therefore injection would not be appropriate.

The United States has developed an Underground Injection Control Program (UIC) which was initiated to protect underground sources of drinking water from contamination through injection programs. If injection or re-injection were determined to be viable methods of end use of CSG produced water in Australia it may be necessary to initiate a similar control program.

7.7.4 Technical considerations

The technical feasibility of either injection or re-injections is dependant on geologic, economic and engineering considerations. In terms of hydrogeologic issues the following will require consideration for any proposed injection scheme:

- formation stability
- isolation
- porosity

- permeability
- storage capacity
- reservoir pressure
- water quality

These issues would require resolution on a site specific basis.

7.7.5 Alternative 1 — Injection into a non-coal aquifer

7.7.5.1 Constraints

As discussed previously the aquifers surrounding the producing coal measures are highly valued and utilised and generally of better water quality than the coal seam aquifers. Although these aquifers would like have suitable hydrogeologic characteristics for injection the difference in water quality between the existing aquifers and the produced water would lead to some contamination of the aquifers. This will likely be seen as unacceptable by regulatory authorities and the community.

7.7.5.2 Data needs

If this option were to be investigated further the hydrogeologic characteristics of the proposed injection aquifer as listed in the technical considerations above would be required. It is likely that the movement of the injected waters within the aquifer would require modelling to assess the likely impacts on existing and future users of the resource.

7.7.5.3 Economics

The costs associated with underground injection into a non-coal aquifer will be dependant on the technical and regulatory considerations. It is likely that the regulatory authorities including the EPA and NRM&E will require extensive investigation into the potential impacts of this form of disposal. The sensitivity and value of the aquifer supplies in the region will require protection and this would required at least a review of environmental factors and possibly some predictive groundwater modelling to determine the impacts on the receiving aquifers. These studies could be significant in terms of cost.

In addition this type of disposal will likely require implementation of monitoring programs to ensure the protection of the aquifer. This will add ongoing costs to the disposal option.

Technically, the aquifer characteristics will determine the costs of well construction and infrastructure required. The rate at which water can be injected will determine the size of the buffer storage required and thus influence the cost of the option.

If some treatment of the water is required prior to injection the costs of this option could be increased significantly. Many schemes in the US require sterilisation prior to injection (ALL Consulting, 2003). Desalination prior to injection will significantly increase costs.

7.7.6 Alternative 2 — Injection into a coal seam aquifer

7.7.6.1 Constraints

This alternative can be divided into to sub-alternatives; injection into a non-producing coal seam and re-injection into the producing seam.

The technical feasibility of re-injection into the producing seam is difficult to ascertain. As previously noted, as the production of gas from most wells required a reduction in the hydrostatic pressure of the aquifer the re-injection of produced water would seem to reduce the efficiency of gas removal from the wells. However, with more detailed investigation it may be possible for re-injection to be completed successfully and it has certainly been successful in CSG producing areas of America such as Montana (Schneider, 2001).

Injection into another coal seam, generally a seam from which CSG production has ceased, may also be constrained for technical reasons. The extraction process will be affected by the aquifer properties. As the hydrostatic pressure of a seam is reduced it can undergo a one time compaction event which causes the volume of the aquifer to decrease so that the aquifer can no longer store the same volume of water (ALL Consulting 2003). Investigation of the receiving coal seam characteristics would be required to determine the feasibility of this option.

Appropriate coals seam must also be identified for injection and ideally, the injection system would need to be a closed system that does not subject the product water to the environment that may alter the hydrochemistry of the water. Initially no previously depleted seams would be available for injection purposes.

7.7.6.2 Data needs

Substantial investigation of the coal seam properties post extraction is required to determine the feasibility of either injection or re-injection alternatives. Further investigation is required in the Surat Basin to determine the effect extraction will have on available storage volume in the coal measures.

Permeability of the coal seams will be an important determination for the viability of injection. In situ testing will be required.

7.7.6.3 Economics

The costs associated with injection into a coal seam cannot be estimated in a generalised fashion. These costs will be dependant on the infrastructure required and available for injection, the rate and pressure at which injection is achieved and the transport distance from the production wells to the injection sites.

Factors discussed in the injection Alternative 1 (section 7.7.5.3) will also influence costs of this alternative.

7.8 Constructed storages

7.8.1 Introduction

Constructed storages may be used for either disposal or beneficial use of produced waters or be a combination of both through secondary benefits. The storage may be an excavation or dam structure and is typically constructed by traditional methods.

The size and dimensions of the storage will be dependant on the purpose or end use of the water.

7.8.2 General applicability

The applicability of using a constructed storage will depend on location of the CSG production site, the purpose of the storage and the surrounding environment.

7.8.3 Regulatory requirements

The regulatory requirements will be dependant on the quality of water to be stored and the purpose of the storage and the size and location of the storage.

Generally, the EPA and NRM&E will be required to approve the construction of a storage to contain produced waters in accordance with the Water Act 2000 and any regulations contained in the new *Petroleum and Gas (Production and Safety) Bill 2004)*.

7.8.4 Storage design and construction considerations

On-channel and off-channel surface storages

The location of a storage, either within an overland flow path or defined water course or off channel, will be important in determining the regulation of the storage. In Queensland, regulation of a surface storage which collects overland flow is controlled under the *Water Act 2000*. In some areas construction of an overland flow storage will be restricted by a moratorium preventing the construction of new storages within a catchment.

The potential for discharge from an on-channel storage will also be greater than from an off-channel storage such as a turkey nest construction due to the existence of an external catchment. This potential for discharge will be important where the quality of water stored is poor and the potential contamination of surface water systems is a high risk.

Topography

The topography of the site will be a determinant in the construction of a storage. Areas of low relief but above the 100 year flood inundation area would be highly suitable for storage construction. The minimisation of physical modification to the land will keep the cost of construction low.

Subsurface and Surface Hydrology

The presence of high groundwater may interfere with the construction of a storage and increase construction costs.

Any connection to the groundwater system must also be considered. If the purpose of the storage is to allow infiltration to groundwater then the impacts on the groundwater system would need to be determined. If the purpose of the storage is to prevent infiltration then the risks to the underlaying aquifers should infiltration occur will need to be determined.

The surface hydrology could influence storage design in terms of potential surface water inflows to the storage, risks to surface water systems in the case of failure of the storage and erosion of and around the storage.

Geology and Subsurface

The geology of the area proposed for storage construction will influence the design in the following ways.

- Subsurface properties will determine to interaction of the stored water with the groundwater through infiltration. A physical barrier may be required to avoid infiltration such as a liner.
- The stability of the structure and the engineering design of the storage will be based on the appropriate subsurface properties.
- The efficiency of infiltration ponds will be based on the underlying geology.
- Excavation and construction costs will be dependant on the subsurface conditions encountered.

Climate

The climate will dictate the design of a storage as the effects of rainfall and evaporation in the area will determine the size of the storage.

The climate of the area may also be important in the purpose of the storage. For example the warm temperatures, high evaporation rates and low rainfall of the Surat Basin will make an evaporative pond highly efficient.

Construction and Component Design

Finally the purpose of the design will be influential in the construction and component design of the storage. An evaporative pond will operate most efficiently as a large shallow pond whereas a pond designed for aquaculture will require a depth adequate for fish growth and movement.

Specific design requirements for the intended purpose will influence the costs of the option.

Risks associated with contamination of subsurface and surface waters will need to be addressed in the design phase of any constructed storage.

7.8.5 Alternative 1 — Wildlife and livestock watering

7.8.5.1 Applicability

The estimated quality of the produced waters from the Surat Basin makes it borderline in terms of direct use as a source of water for wildlife and livestock. The costs of treatment of this water prior to release would likely outweigh the benefits to the CSG companies for this option.

The applicability of this option will again be highly dependant on the location of the production area. If a wildlife population, suitable for supply, could be identified in close proximity to the production area may be a viable option.

Supply of a wildlife population would need to be considered in context of the natural supply regime. The supply of additional water to predominately dry communities may introduce problems into an ecosystem that out way the benefits.

Negotiation with the landholder on which production is occurring or adjacent landholders would determine the applicability of using produced water for livestock watering.

If large transport costs are required to an area of demand then the attractiveness of this option will be reduced.

In the US, this option has been successful in reducing impacts on surface water systems by providing an alternative to watering livestock in streams. The use of watering ponds reduces the issues associated with stock having direct access to streams including bank erosion, increased sediment loads, contaminated waters due to manure, increased nutrient availability and depleted oxygen levels (ALL Consulting, 2003).

Water quality requirements for stock watering will be discussed later in this report.

An issue that must be considered in the applicability of these options is that the produced water is a limited and decreasing resource over the life of the production area. If wildlife watering is supplemented by produced water and populations increase or establish in the area then the impact of reducing or removing that supply must be assessed.

Similarly, a landholder must be aware that the supply of water for livestock is limited and an alternative source will be required in the future.

7.8.5.2 Potential constraints

The largest constraint for this option is the quality of the produced water. If the water is of such a quality that is can be directly used for wildlife and livestock watering then the options is likely to be highly attractive to the CSG companies.

Concern has been identified with respect to fluoride levels in water produced to date in parts of the Surat Basin. Although analyses have shown water quality to be within guidelines for stock watering for most constituents the levels of fluoride observed has been between 2.0 mg/L and 4.5 mg/L. The Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZECC, 2000) sets 2.0 mg/L as the general trigger value for livestock drinking water. Although other countries such as South Africa set a fluoride a level of 4.0 mg/L for livestock. Similar concerns are likely for use of untreated produced water with wildlife.

The individual water quality at each production site will constrain the applicability of this option.

In addition the identification of a demand in close proximity to the production site will also be a constraint. Although, sites in the Surat Basin will likely be located near farms with livestock as the activity of the area is mainly agricultural.

Finally, the assessment of the impacts on the removal of the water source post production may constrain this alternative. If it is assessed that an alternative water source could not be found to sustain wildlife populations when production ceases the alternative may not be considered viable.

7.8.5.3 Data needs

The characterisation of the produced water at the site will be required to determine if the produced water is suitable for direct use for wildlife and livestock watering.

The identification of wildlife populations or potential sites for the establishment of wildlife populations will be required or negotiations with landholders with a demand for the water will need to be undertaken.

Assessment of the impacts of the cessation of supply will need to be assessed.

7.8.5.4 Economics

This option is likely to be a relatively cheap option for proposed end use of produced waters. The design of the storage will be relatively simple but will be dependant on site specific costs such as discussed above in storage design and construction considerations.

7.8.6 Alternative 2 — Fisheries

7.8.6.1 Applicability

This alternative is basically the construction of small to medium sized ponds to be stocked with fish and used for recreational purposes. The applicability to large scale aquaculture will be discussed in a later section of this report.

The applicability of this option will depend on the identification of potential sites for fishponds and the responsiveness of landholders to the idea.

The quality of produced water will also determine if direct use in a pond is applicable. ‘Many fish species are susceptible to high or elevated levels of phosphates, heavy metals, salts, and pH’ (Eisler, 1999 from ALL Consulting, 2003). If treatment prior to use is required the attractiveness of this option will be reduced.

Also the volume of water that could be disposed of via this option is limited unless large or many areas could be found for construction within reasonable proximity to the production site. Other than an initial volume to fill the ponds the only losses would be through evaporation and these ponds would not be designed in a manner to facilitate rapid evaporation.

This option may be an alternative that could be used in conjunction with other alternative to manage produced water.

7.8.6.2 Potential constraints

The identification of potential locations for the construction of fish ponds is likely to be the largest constraint on this alternative. A landholder would have to be identified with a need or want for a private fish pond for recreation.

7.8.6.3 Data needs

Potential site identification and characterisation will be required.

Agreement with the landholder on construction and maintenance of the pond would be required.

7.8.6.4 Economics

Again this option should be relatively cheap if the water quality is such that direct use can occur. The cost will be dependant on the complexity of the pond design, the proximity to the production area and site factors such as soil and terrain.

Generally the costs of maintaining the ponds would fall on the landholder.

7.8.7 Alternative 3 — Recharge Ponds

7.8.7.1 Applicability

Recharge ponds are used to allow water to pass into shallow aquifers and restore depleted groundwater sources.

In the case of the Surat Basin shallow aquifers are generally high quality and highly utilised for stock, irrigation and drinking water supply. The quality of produced water in the Basin to date is of much lower quality than the shallow alluvial aquifers. Therefore, it is seen as unlikely that this alterative is applicable to the Surat Basin.

An alternative is to allow recharge of the producing coal seam through a recharge pond located at an outcrop of the seam. It is unlikely that an appropriate location for a recharge pond could be found that allows the recharge of the producing coal seams. This requires the coal seam outcrop in relatively close proximity to the production area. Considering the depth of producing seams in the Surat basin is between 300 m and 700 m below ground level and the geology of the area would require the recharge ponds to be located at least 20 to 50 km for the production area it is unlikely that this option is viable.

7.8.7.2 Potential constraints

The water quality of produced water to date in the basin is the major constraint with respect to this alternative.

The potential for contamination of a highly utilised shallow aquifer will likely eliminate the use of a recharge pond above the alluvium.

The location of a suitable seam outcrop for coal seam recharge is unlikely.

7.8.8 Alternative 4 — Recreation

7.8.8.1 Applicability

Recreation has traditionally been seen as a secondary benefit of water storage reservoirs and natural lakes. However, the creation of an artificial lake has the potential to provide communities nearby to CSG production areas with recreation alternative not otherwise available.

The benefits of the construction of a recreational storage may include:

- Fishing
- Sailing/boating
- Water sports
- Swimming
- Picnic locations
- Wildlife observation

The uses would depend on the water quality, the volume available from produced waters and the areas available for the construction of such a pond.

It may be possible that the construction of such a storage could encourage the development of enhanced recreation activities such as a wave pool, a cable skiing operation or a jet boat operation.

It is likely that the addition of a large body of water could provide additional habitat for resident and migratory birds (ALL Consulting, 2003) and act as a wildlife watering hole. Additional wildlife activity may attract interest in study and observation from further a field than nearby communities.

However, the impact of the produced water having a finite life and the sustainability of the system after the end of production must be considered. It may be possible to design the lake as a self sustaining entity post production or to locate an alternative water source to sustain water levels in the lake.

7.8.8.2 Potential constraints

The potential constraints of this alternative will include the following.

- The identification of an appropriate location with sufficient area and appropriate characteristics for storage construction and that is sufficiently close to a community that will derive benefit from the project.
- Funding of the project may be a constraint in that there is a large benefit for a community and thus the CSG Company may not want to bear the entire cost. It may be possible to involve government and local communities in the project or parts of the project such as the provision of facilities near the lake.
- Ownership of the lake would need to be established such that ongoing repair and maintenance responsibilities could be allocated and legal responsibility for public liability could be established.
- Sustainability of the lake must be established from the planning stage to ensure that after gas production ceases the water levels in the lake can be maintained. Without ongoing supplementary water from the produced water will water levels in the pond be maintained? If not, is there an alternative water sources or will the area be decommissioned after gas production?

7.8.8.3 Data needs

Requirements for the construction of artificial lakes are relatively well established thus limited investigation on design should be required. The proposed site will require selection and assessment for appropriateness of construction.

The feasibility of ownership and maintenance arrangements will require further investigation.

7.8.8.4 Economics

The cost of this option will depend on the scale of the facility constructed. The cost could be substantial if recreation facilities are to be installed and public assess is to be allowed.

7.8.9 Alternative 5 — Evaporation ponds

7.8.9.1 Applicability

Evaporative ponds are designed to allow natural evaporative processes to occur and water to enter the atmosphere. 'As evaporation occurs "pure" water is removed from the pond resulting in an increase in the TDS for the remaining water' (ALL Consulting, 2003 p. 5-64).

No beneficial use is associated with this alternative. However, the impacts of the end use are limited to the evaporation area.

Considering the climatic conditions of the Surat basin this alterative is seen as a highly suitable method of produced water management. The average annual pan evaporation in the area is above 1600 mm (Figure 7.6).

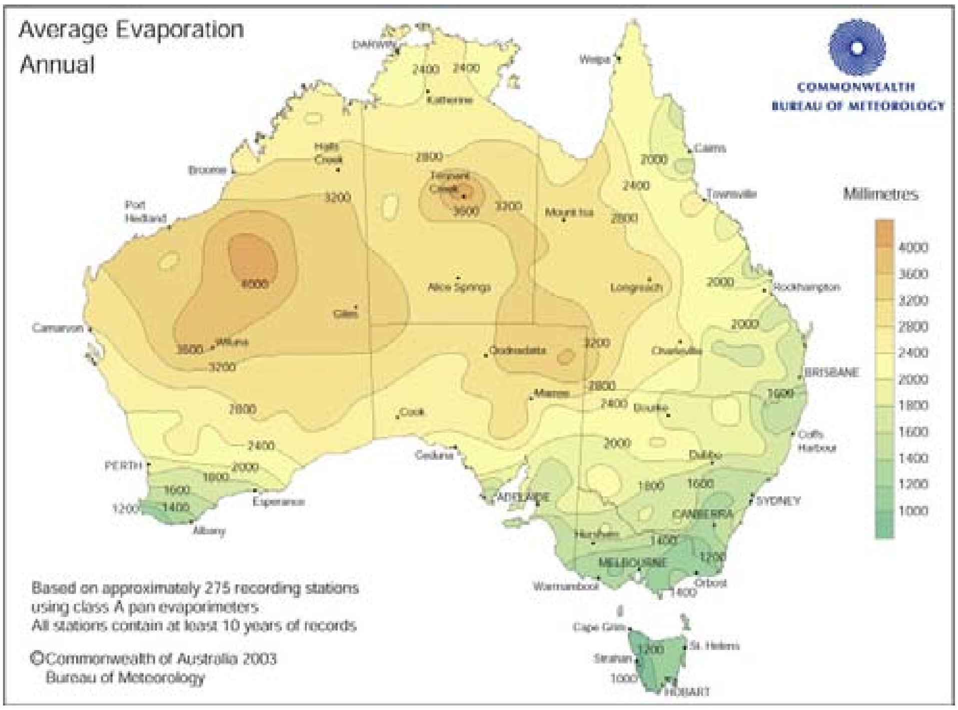


Figure 7.5: Average annual evaporation

This method will be particularly suitable for disposal of water with very poor quality and waste streams from water treatment. Various options for the improvement of water quality will be discussed later in this report, however, most options produce a highly concentrated waste stream requiring disposal. Evaporation ponds are seen as the best method of disposal of these waste streams.

The CSG industry in the Surat basin currently operates a number of evaporation ponds. These ponds are constructed to the standard required by regulation and to sound engineering principles to minimise the risk of leakage to underlying aquifers.

7.8.9.2 Potential constraints

There are several issues that can constrain the use of evaporative ponds (ALL Consulting, 2003) including:

- landscape and topography;
- landowner considerations;
- flooding of the area; and
- seasonal variations.

Landholders may object to the use of large areas of land for evaporation ponds. The design of an efficient evaporation pond requires a large shallow pond and thus the placement of the ponds should be agreed upon with the landholder.

However, the suitability of the Australian climate would appear to outweigh any constraints of evaporative pond construction.

7.8.9.3 Data needs

Data needs will include site specific data for construction of the storage as well as climate data for sizing of the basin. A basin must be sized such that the evaporation from the basin exceeds the inflow rate and inflows from rainfall.

Depending on location it may also be necessary to protect the basin from inundation during flood events. Therefore, it may be necessary to determine flood levels in the vicinity of the basin. Inundation may be a particular issue as the water quality in the basin decreases with increasing concentration of constituents with time.

7.8.9.4 Economics

Cost associated with the construction of evaporation ponds will vary depending on the ground conditions of the selected location. A major concern with evaporation ponds is the potential contamination of underlying soil and groundwater. As evaporation occurs the chemical constituents in the remaining solution concentrate.

Depending on ground conditions a liner may be required to prevent infiltration of this concentrate to underlying soil and groundwater. The type and extent of lining required can add significant costs to the construction of the basin.

Finally the basin is left dry with a solid salt on the basin floor. The decommissioning of these basins may require significant costs in salt removal and or capping and allowance should be made for these costs on initiation of the project. Depending on the concentration of the produced water or waste brine an evaporation basin may also required the removal of concentrated sludge during the life of the project.

7.8.10 Alternative 6 — Constructed wetlands

7.8.10.1 Applicability

A constructed wetland provides a solution between an evaporation pond and a wildlife watering pond and provides some improvement in water quality through the process. A constructed wetland consists of a relatively shallow basin planted with hydrophilic vegetation. The *Handbook on Coal Bed Methane Produced Water* (All Consulting, 2003) states that 'wetland hydrology is present when it influences vegetation and soil due to anaerobic and reducing conditions.'

Constructed wetland systems operate by reproducing the natural filtering observed in wetlands and remove organic matter, suspended matter, and certain pathogenic elements. A research project in America designed to determine the ability of a wetland system to treat CSG produced water, particularly SAR, Fe and Ba, showed that the wetland could 'effectively treat iron and possibly barium but not SAR' (ALL Consulting, 2003).

The study concluded that 'an increase to iron and barium loading rates received by the wetland system would be necessary to ascertain the system's filtering potential' (ALL Consulting, 2003). They also concluded that the wetland system was not useful in achieving a reduction in SAR based on one year treatment data results (ALL Consulting, 2003).

From this research it would appear that a constructed wetland to receive produced water is not an effective treatment alternative however it will provide the combined benefits of providing wildlife habitat and acting as an evaporative basin.

As with the wildlife and livestock watering alternative the applicability of this alternative will be dependant on the quality of produced water. As noted above the quality of produced waters to date appear to be suitable for livestock with the exception of Fluoride.

The addition of wetland vegetation to a waterhole is likely to provide habitat for amphibians and increase the level of diversity that develops around the storage.

The relatively shallow design of a wetland will still provide a level of evaporation for produced water.

As with a wildlife watering pond consideration must be made as to the sustainability of the wetland system after the productive life of the operation. Can the system be sustained by an alterative water source as the production of water from gas wells reduces?

An alternative to the construction of a new wetland would be to restore an existing wetland system that may have suffered due to surface or groundwater extraction. Again this option will depend on the existence of an altered wetland system in close proximity to the operation and on the quality of the produced water.

7.8.10.2 Potential constraints

The potential constraints are similar to that of a wildlife pond. Water quality will restrict not only the suitability of wildlife watering but also the suitability of vegetation. Halophytes are generally able to tolerate elevated salt levels or alkalinity.

The potential impacts from the cessation of supply to an ecosystem that has developed purely as a result of the produced water may also constrain development if a sustainable system cannot be developed or an alternative water source cannot be identified.

The *Handbook on Coal Bed Methane Produced Water* (All Consulting, 2003) also notes the long term effects of SAR on soil permeability as a potential constraint on wetland development and success. It is noted that the ‘accumulation of certain constituents present in CBM (coal bed methane) produced waters could reach toxic levels if not properly controlled’ (ALL Consulting, 2003).

7.8.10.3 Data needs

The water quality of produced waters will be required for wetland design.

Selection of appropriate plant species will be required based on water quality.

7.8.10.4 Economics

Costs of wetlands will be dependant on site characteristics such as topography, geology, hydrology, and climate and will depend on regulatory and land owners requirements.

7.8.11 Secondary impoundment uses

It has already been seen that impoundments may provide a number of benefits and uses. The quality of the produced waters will vary across the basin and will dictate primary and secondary uses of produced water contained in storages.

Secondary uses that have not been noted above may include but not be limited to:

- growth of algae for intensive feed lots;
- generation of electricity through solar ponds; and
- development of residential estates around artificial water bodies.

7.9 Agricultural use of produced water

7.9.1 General applicability

Much of the Surat Basin contains high water use agricultural activities such as cotton production. Surface water and groundwater systems are under increasing pressure and resources are depleting. The supplementation of water demands with produced water has the potential to alleviate pressure on over allocated resources in the basin.

Table 7.1 compares the quality of the produced water to date with values obtained from the *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC, 2000).

Table 7.1: Comparison of produced water with Guideline values for irrigation and stock watering

	Unit	Upper limit for cotton irrigation	Upper limits for livestock with no product loss	Water range of produced water to date in the Surat Basin
Total Dissolved Solids (TDS)	mg/L	1200 ppm	8000 beef 10,000 sheep 6000 pigs	2260 – 5060
Bicarbonate	mg/L	——	——	1120 – 2060
pH	——	Exceed 5–6	——	8.4 – 8.9
Chloride	mg/L	700	——	548 – 2060
Sodium	mg/L	460	——	918 – 1840
Fluoride	mg/L	2	2 – 4	2.9 – 4.5
SAR		Approx. 10	——	107 – 160

It can be seen based on the guideline values produced water to date is not appropriate for direct irrigation in cotton. Produced water qualities are within guidelines for livestock watering except for the level of fluoride observed.

Effects of high levels of fluoride in drinking water of livestock are generally observed after long term exposure. Therefore, it may be possible to use produced water for livestock watering on a rotational basis with an alternative water source.

Alternatively it may be possible to combine CSG produced water with a water source of higher quality such as a surface water source in order to meet livestock drinking guidelines.

7.9.2 Regulatory requirements

The supply of livestock will require ministerial consent under the Petroleum Act 1923.

7.9.3 Alternative 1 — Stock watering

7.9.3.1 Applicability

A general guide to the response of livestock to various levels of drinking water quality provided in Table 7.2.

Table 7.2: Livestock response to water quality limits

TDS (mg/L)	Livestock Watering Comments
Less than 1000	Excellent for all classes of livestock
1000 to 2999	Very satisfactory for all classes of livestock. May cause temporary and mild diarrhoea in livestock not accustomed to them.
3000 to 4999	Satisfactory for livestock, but may cause temporary diarrhoea or be refused at first by animals not accustomed to them.
5000 to 6999	Can be used with reasonable safety for dairy and beef cattle, sheep, swine, and horses. Avoid use for pregnant or lactating animals.
7000 to 10,000	Considerable risk in using for pregnant or lactating cows, horses or sheep, or for the young of these species. In general, use should be avoided although older ruminants, horses, poultry, and swine may subsist on them under certain conditions.
Over 10,000	This water is considered unsatisfactory for all classes of livestock.

Source: ALL Consulting 2003

The use of water for stock watering will be dependant on the quality of produced waters. The above table indicates that produced water with a TDS of up to 7000 mg/L could be used with 'reasonable safety'. Thus based on TDS the produced waters appear appropriate for use as stock water. However, full product water analysis including fluoride should be undertaken prior to the approval of use as stock water.

7.9.3.2 Potential constraints

Water quality of produced water will be the major constraint for this management option.

7.9.3.3 Data needs

The complete characterisation of produced water quality will be required prior to approval for use as stock watering.

7.9.3.4 Economics

There is potential for the economic benefits of this option to be positive for CSG companies and landholders receiving produced water.

The costs will be dependant on the transfer distance to livestock and on the regulatory conditions placed on the use. Since production wells can be spaced over large areas wells can be used to provide point sources of water for livestock over a property minimising the costs associated with transfer infrastructure. Spreading the water supply across a property has the potential to allow utilisation of areas of the property that would not otherwise be possible due to lack of water sources. Alternatively water can be transferred by pipeline or open drains to an area of demand.

If the produced water quality can be used with limited treatment, which may include sterilisation, then the costs associated with this option may be relatively low. However, if regulatory authorities require additional treatment such as reduction in salinity the costs associated with this option may make it an unviable alternative as treatment costs may far outweigh the value placed on the additional water.

7.9.4 Alternative 2 — Irrigation

7.9.4.1 Applicability

Potential impacts from agricultural irrigation with CSG water are related to the quality of the water. To determine these impacts, the quality characteristics of the CSG water can be compared to generally accepted irrigation water quality requirements (ANZECC, 2000).

The *Handbook on Coal Bed Methane Produced Water* (ALL Consulting, 2003) highlights three major considerations with respect to effects of salt in irrigation; salinity, sodicity and toxicity. In order for produced water to be utilised for irrigation treatment to reduce salinity would be required.

7.9.4.2 Data needs

Water, soil and plants form an interacting system and the suitability of water for irrigation is influenced by a number of factors including: irrigation water quality; soil properties; plant salt tolerance; climate; landscape (including geological and hydrological features); water and soil management.

Ideally all these factors should be considered when evaluating the suitability of water for irrigation. If however an initial assessment shows that the water is grossly unsuitable a detailed study is probably not warranted. If the analysis suggests that the water is more suitable a more detailed assessment may have to be undertaken. A detailed assessment should include all the factors that were listed in this section and should follow steps and guidelines given in (ANZECC, 2000) and summarised in Figure 7.7.

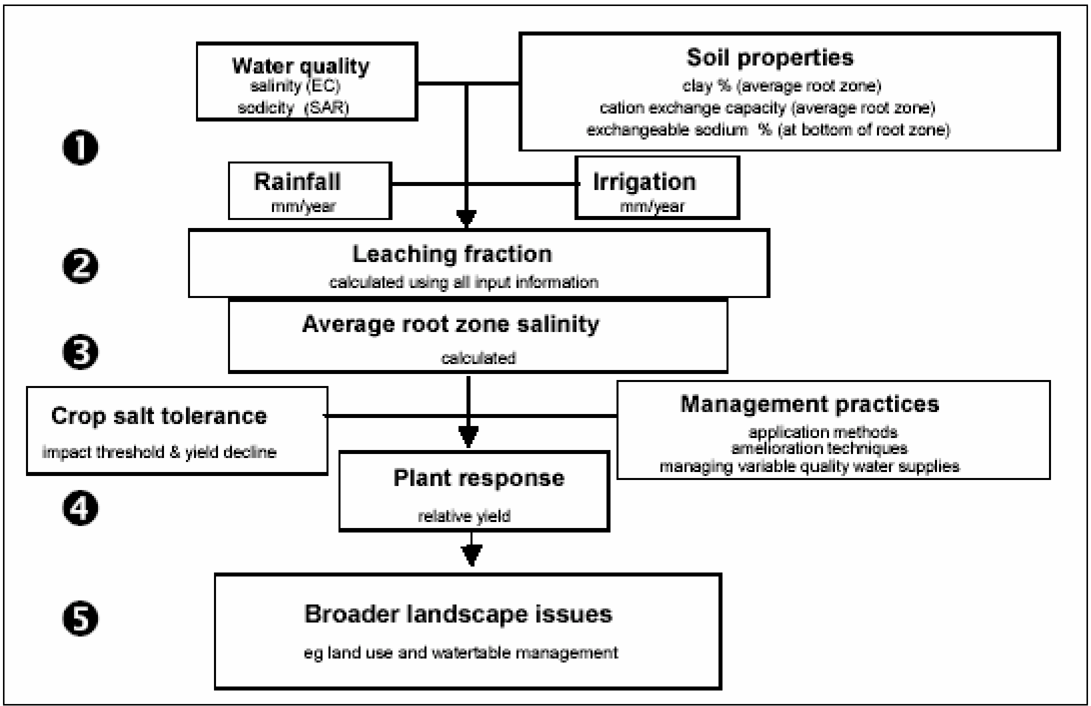


Figure 7.6: Flow diagram for evaluating salinity and sodicity impacts of irrigation water quality

The key factors to assess are:

- water quality of irrigation water;
- the salt tolerance of plants that will be irrigated; and
- the influence of the dissolved salts on soils

Water quality of irrigation water

To assess the potential application of CSG product water for irrigation, water quality with respect to salinity, the salt content or electrical conductivity of the water must be known. Electrical conductivity (EC) measures the ability of water to conduct an electric current, which is carried by various ions in solution such as chloride, sodium, sulfate, nitrate, carbonate, bicarbonate, calcium and magnesium.

As outlined in the ANZECC (2000) Water Quality Guidelines, a preliminary water salinity rating can be assigned to irrigation waters based on EC. Table 7.3 presents these ratings, however are given in TDS, rather than EC, for ease of comparison. These ratings provide only a general guide and are not intended to be used on their own to define the suitability of irrigation water. Other factors such as soil characteristics, climate, plant species and irrigation management must be considered.

Table 7.3: Irrigation water salinity ratings based on electrical conductivity

TDS (mg/L) [1]	Water salinity rating	Plant suitability	Example of Potential crop[2]
<390	Very low	Sensitive crops	Flowers/shrubs/fruits
390-780	Low	Moderately sensitive crops	
780-1740	Medium	Moderately tolerant crops	Clover[3]
174043120	High	Tolerant crops	Corn, soy bean, lucerne, sorghum, sunflower[3]
312044860	Very high	Very tolerant crops	Barley, cereals (wheat)[3], cotton
>4860	Extreme	Generally too saline	

1 Approximate conversion applied/EC units X 0.6 = mg/L
2 Department for Water Resources, SA
3 relative yields for salinity figures is approximately 75%

The primary purpose of measuring the EC of irrigation water (ECiw) is to calculate the average root zone salinity (ECse), one of the critical measurements used in salinity assessment and the evaluation of plant salt tolerance.

From the information applied for this study, water quality values of CSG product water would fall into the high to extreme water salinity rating and not be appropriate for long-term direct use in irrigation.

Plant salt tolerance

Relatively high salt content can be irrigated provided that the soils are well drained. Plants use or take up some of the dissolved ions but reject others so salts accumulate in the soil at or below the root zone. If soils are well drained (e.g. sandy soils) the salts can be flushed out and don’t affect plant growth.

In poorly drained soils the rejected salts accumulate to a level where, in spite of sufficient water volume, plants can experience water stress due to the osmotic influence of high salinity.

Plants have different tolerances to dissolved salts, some salts are toxic on their own such as:

- chloride
- boron
- sodium

The salt content of the water is indicated by the electrical conductivity. For specific ion toxicity, a more detailed water analysis that includes toxic trace elements is required.

Broad categories of salinity influence are summarised in Table 7.4 (From ANZECC 2000).

Table 7.4: Irrigation water salinity ratings based on electrical conductivity

EC (dS/m)	Water salinity rating	Plant suitability
<0.65	Very low	Sensitive crops
0.65 - 1.3	Low	Moderately sensitive crops
1.3 - 2.9	Medium	Moderately tolerant crops
2.9 - 5.2	High	Tolerant crops
5.2 - 8.1	Very high	Very tolerant crops
>8.1	Extreme	Generally too saline

1dS/m = 1000 µS/cm

Influence of dissolved salts on soils

Salinity influences the aggregation of soil particles most ions cause particles to adhere and so salinity contributes to soil structure. Sodium however causes soil particles to disperse particularly if the soils contain montmorillonite clays.

Dispersion causes:

- surface crusting preventing water infiltration; and
- soil structure breakdown, this lowers soil hydraulic conductivity.

Lower infiltration means:

- more runoff and associated increased erosion;
- lower plant water availability; and
- decreased flushing by rainwater thus preventing reversal of the damage.

The influence of dissolved sodium on soils is commonly assessed using the sodium adsorption ratio (SAR). This is also sometimes referred to as the sodicity of the soil water. SAR is calculated from the milliequivalent concentration of Na^{+}, Ca^{2+} and Mg^{2+} ions in the water using the following expression:

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}}$$

Depending on the soil and water types precipitation of calcium carbonate (CaCO3) can increase the concentration of sodium in the water thus increasing the SAR. This potential is measured as the residual alkali (RA) content of the water. RA is expressed in milliequavalents of NaHCO3[3]. Table 7.5 outlines the sodicity classes for irrigation water.

Table 7.5: Sodicity classes for irrigation water (After Mills 2001)

Sodium absorption ratio (SAR)	Residual alkali (RA)	Sodicity class
Less than 3	Less than 1.25	No sodium problem
3 to 6	Less than 1.25	Low sodium, few problems except with sodium sensitive crops.
6 to 8	Less than 2.5	Medium sodium, increasing problems; use gypsum and not sodium sensitive crops.
8 to 14	Less than 2.5	High sodium - not generally recommended.
Greater than 14	Disregard	Very high sodium – unsuitable.
Less than 6	1.25 - 2.5	Medium R.A. – as for class 2.
Less than 14	2.5 – 5	High R.A. – as for class 3.
Less than 14	Greater than 5	Very high R.A. – unsuitable.

7.9.4.3 Potential constraints

Constraints on direct use of product water for irrigation is limited by the generally poor salinity value of the CSG groundwater. The product water may require treatment and therefore increase cost to the development.

It is important to note that temporary storage of water piror to land application can alter the water chemistry, due to the abundance (and instability) of bicarbonate in the water. Produced water from coal seams that has been under pressure is generally oversaturated with bicarbonate (ALL Consulting, 2003). Therefore, it will be important to collect water quality data from stored water prior to application.

7.9.4.4 Economics

The costs associated with irrigation of produced waters will be dependant on the quality of produced water and the treatment level required and the distance to the irrigation demand.

If produced water quality is such that water can be directly irrigated the costs of the scheme may be limited to transfer of produced water to the irrigation area. Infrastructure will include pump and pipeline. Storage of water on the landholders site will be the responsibility of the landholder.

[3] $NaHCO_3$ must be determined by speciation and requires a complete major ion water analysis. Speciation is best achieved using an equilibrium chemistry model such as MINTEQ2 or PHREEQC.

Current water quality results indicated that if irrigation was to be a viable option some treatment would be required. This treatment would likely be desalination to reduce TDS which will add significant costs to the disposal option.

7.10 Industrial use

7.10.1 Introduction

This option involves the provision of water to other industries for use in operational activities. Industries that have been identified as potential users of produced water include coal mining, intensive animal feed operations, cooling tower water, aquaculture, enhanced oil recovery and fire protection. Other industries that are not included in this report in detail may include breweries, ethanol fuel plants, abattoirs and other industrial activities currently drawing water from rural town centre supplies.

Initial identification of industrial users would focus on large individual demand operations such as those discussed below, however, if a number of medium industrial users were identified in a single area such as on the outskirt of a rural town centre then is may be possible to supply this area with a supplementary supply to relieve pressure on municipal supplies.

Required water quality will vary significantly depending on the industrial activity and activities within one industry. In most cases some form of treatment will be required to increase the quality of produced water. Treatment will significantly increase the cost associated with the provision of water to industry however, these costs will be offset by the perceived value of water in industry. If alternative sources of water are not available to that industry a higher value and thus higher payment for that water is likely. Industry will generally value water at a higher rate if it is important for continued operation.

7.10.2 Alternative 1 — Coal mine use

7.10.2.1 Applicability

The coal industry has been identified in the Surat Basin as a potential user of CSG produced water. A number of active and proposed open cut coal mines operate in the basin.

Coal mining, particularly open cut coal mining, generally requires water for applications such as extraction operations, dust suppression on roads and in operational pits, product preparation and handling, general mine operations such as truck washing, and for rehabilitation.

The water quality required for these operations is generally divided into “dirty” and “clean” water for site water management purposes. “Clean” water is generally high quality water sources from surface water supplies external to the site and from the collection of runoff from undisturbed catchments within the site. This water is used for applications such as in the coal preparation plant and for truck washing and product dust suppression were degradation of equipment is a primary concern.

“Dirty” water, consisting of runoff from disturbed areas and groundwater entering the pits, is generally higher in TDS and is used for applications such as haul and pit road watering where quality of water is not of high priority.

The reliability of supply to coal mine operations is of high importance. Without a reliable supply of water there is a risk that operations will have to be suspended causing enormous financial penalty. Due to the climate of the area reliance on surface water often poses a large risk to supply. If produced waters could be used to supplement supply particularly during dry periods risk to production could be significantly reduced.

7.10.2.2 Constraints

A major constraint to the option is the cost of transporting the water from CSG production areas to active or proposed coal operations. Depending on the need for the water supply at the mine site the mining company will likely contribute to the cost of transportation. It may only be necessary for a CSG company to provide adequate funds to make the option viable for the mining company. This negotiation would be case dependant.

Treatment of the water would also be an issue for resolution. Again treatment will be dependant on end use of the water. Negotiations would need to be undertaken to determine if the water was required to be treated by CSG producer or by the mine prior to use.

Finally the timing of supply may be a significant constraint. A mining operation will require a reliable supply over the life of the mine. If the produced water supply is to be used as a primary water source and a constant rate of supply cannot be guaranteed, mines may need to provide significant storages to contain water produced at high rates early in CSG production.

7.10.2.3 Data needs

Identification of potential mine will be required and determination of the need for additional water supply sources.

Characterisation of produced water will be required prior to negotiations including quality and quantity of supply over the life of the operations.

7.10.2.4 Economics

The costs associated with this option will be highly dependant on the transportation distance between operations and the level of treatment required. Costs to CSG producers may be minimised by contributions from mining companies however, this would be a matter of negotiation.

7.10.3 Alternative 2 — Animal feeding operations

7.10.3.1 Applicability

Produced waters may be provided to animal feeding operations and intensive feed lots for stock watering and waste management.

The quality required for livestock watering and the potential constraints will be similar to those described above in agricultural use. It appears that the quality of produced water to data would be appropriate for livestock watering with the exception of fluoride levels. Further assessment of site specific produced water quality would be required to assess the applicability of this option.

The alternative option is to use produced water of waste management in animal feeding operations. The quality of the produced water is likely to be appropriate for this purpose, however, animal feeding operations would need to be mindful of the treatment and disposal of the waste produced from cleaning operations. Any discharge of waste from these operations should be controlled by the EPA and will not be investigated in this report.

It may be possible for animal feeding operations to use produced water to meet discharge requirements by providing a dilution of the concentration of nutrients in wastes prior to discharge.

It is possible that produced waters could reduce the demand for higher quality water currently being used for such purposes.

7.10.3.2 Constraints

Constraints associated with livestock watering have been included in the agricultural section above.

Constraints on use of produced water for waste management would include identification of potential users in close proximity to the production area and regulatory requirements on use and discharge of resulting wastes. The identification of potential users would also be constrained to a certain respect by the quality of the produced waters. If produced water is of such poor quality that it could not be used to improve waste quality from a feedlot it will be of limited use.

7.10.3.3 Data needs

Identification of potential users in close proximity to production areas will be required including determination of the potential for waste improvement by use of produced waters.

7.10.4 Alternative 3 — Cooling tower water

7.10.4.1 Applicability

A number of industries require water as a means of cooling plant components. Cold water is passed through a thermal exchanger which causes waste heat from the plant to transfer to the water cooling the system. The water can then be cooled and recycled through the system.

Generally high quality water is required for this application. However, this requirement means that even sources of relatively high quality such as surface water is treated prior to use.

Conversion of infrastructure within a plant to receive water of the quality observed to date in produced water of the Surat Basin may require significant capital expenditure. However, if current sources of water have similar qualities such as groundwater sources then modifications may be limited.

The volume of produced waters and the reliability of these flows would need to be negotiated with the end users. Additional storage may be required to provide assurance of a buffer supply during low CSG water production periods.

7.10.4.2 Constraints

The identification of potential users within relatively close proximity will be a large constraint for this option. Transfer costs will increase the cost of water and may in addition to treatment cost make this source of water uneconomic for the industry.

The quality of produced water will dictate the costs associated with treatment prior to use.

7.10.4.3 Data needs

Produced water quality and required water quality will be required to determine treatment requirements.

7.10.5 Alternative 4 — Enhanced oil recovery

7.10.5.1 Applicability

Significant oil recovery operations exist in the Surat Basin. There is potential that produced water may be used for enhanced oil production.

The *Handbook on Coal Bed Methane Produced Water* (ALL Consulting, 2003) describes the stages of oil production and the potential use of produced waters:

> ‘Primary recovery of oil is driven by the natural energy of the reservoir and can be supplemented by pumping. When primary recovery ends, secondary recovery begins and may be followed by enhanced recovery. Secondary and enhanced recovery is the process of injecting a fluid into a reservoir creating a waterflood that displaces the oil causing it to flow to the producing well (Collins and Carroll, 1987). Water is the fluid most commonly used in secondary and enhanced recovery of oil in non-CBM fields; CBM produced water could, therefore, be of beneficial use in secondary and enhanced oil recovery.’ (ALL Consulting 2003 p 5-143)

7.10.5.2 Constraints

The identification of an oil production area that is moving to secondary oil recovery may be one constraint of this option. Transportation costs could be a significant influence in the decision to utilise this water source or a closer option. The volumes required for enhanced oil recovery are relatively small compared to the volumes generally produced through CSG production. Therefore if adequate water can be sourced closer than CSG production areas this option is unlikely to be viable.

Water quality should not be a limitation in the option.

7.10.5.3 Data needs

The identification of prospective oil production areas moving into enhanced stages of oil recovery will be required.

7.10.6 Alternative 5 — Aquaculture

7.10.6.1 Applicability

"Queensland should be a major player in the world aquaculture industry. Just about everything is right in Queensland. Aquaculture is a new industry for the 21st century. It produces a wonderful product, there is a huge demand for what we produce, and we produce it to world best environmental standards. The industry needs to work closely with government on the research and standards necessary to allow the industry to reach its full potential. With wild caught fisheries under great stress right around the world, the farmed seafood industry in Queensland will need to grow six fold over the next decade to keep up with demand". Extract from Aquaculture News, September 2003.

The *Fisheries Act 1994* defines aquaculture as 'the cultivation of live fisheries resources for sale' (DPI, 2004). In particular, aquaculture that is conducted in purpose built land based ponds which use salt or brackish water is referred to as marine aquaculture on non-tidal lands (DPI, 2004).

Many inland commercial fisheries exist in Australia cultivating a variety of marine finfish, crustacea and shellfish. Recent interest has been shown in the study area in developing aquaculture as a secondary industry on existing cotton farms. A method to convert traditional ring tanks to aquaculture ponds has been developed and is being manufactured near Dalby. (Nicol, 2004). The development of this technology may make aquaculture more attractive to adjacent landholders as a secondary industry on their properties.

Environmental considerations play a major role in the selection of a suitable site and the operation of these farms. The salinity level of the source waters for an aquaculture operation will determine the species that can be grown (DPI, 2004).

Water produced to date in the Surat basin appears to be suitable for use in large scale brackish water operations. 'Species suitable for aquaculture in brackish water culture include estuarine fish such as barramundi, crustaceans such as black tiger, brown tiger and banana prawns' (DPI, 2004).

Production water may require concentration by evaporation to suit pond fattening of salt water species such as mud crabs. Available calcium may be a limiting factor for crustaceans.

7.10.6.2 Constraints

The applicability of this option will be dependant on the location of existing aquaculture operations or the identification of parties interested in starting a commercial operation.

An aquaculture operation in close proximity would reduce the constraints associated with the cost of transportation of water.

There is some potential that the produced water quality may be a constraint if levels of individual constituents such as fluoride are found to be an issue with respect to fish production and toxicity. In these cases some treatment may be required prior to use.

7.10.6.3 Data needs

The data need associated with the supplementation of water supply to an existing aquaculture operation will be limited to the location of an appropriate operation, investigation of transportation options and water quality analysis and treatment options.

If a new aquaculture operation is planned then considerations consistent with those discussed in constructed storage options will apply. These may include:

- soil types — to ensure the minimisation of loss through infiltration and engineering adequacy of soils;
- topography — to determine pond layout and design; and
- environmental considerations — including potential areas for release of wastes and risk of inundation from flooding.

In addition the proximity to agricultural and horticultural activities may constrain the development of an aquaculture operation. The DPI advises that ‘developments near agricultural or horticultural areas may need buffers over 1000 m to minimise the risk from spray drift. Buffer widths adjacent to residential estates should be a minimum of 150 m. (DPI, 2004)

Previous land use may also constrain the development of an aquaculture operation as chemicals in soils from old cattle dips, for example, may affect pond quality.

Recent interest and development in aquaculture in Queensland may place a significant role in the viability of this alternative in the future.

7.10.7 Alternative 6 — Fire protection

7.10.7.1 Applicability

It may be possible to store produced waters for use in the case of a fire. Where production areas are located close to rural communities and/or industrial areas it may be possible to supply this water to the area for fire protection. The applicability of this option will be limited by infrastructure requirements. The majority of Australian towns are supplied with fire fighting water through the traditional centralised reticulation system. The quality of produced water would not be suitable for use in this system without treatment.

However, if produced water was stored in a reservoir it may be possible for rural fire brigades and air tankers to utilise this water for large scale industrial and bush fires.

This is likely to be seen a secondary benefit of a constructed storage rather than a primary beneficial use.

7.10.7.2 Constraints

The major constraint is likely to be proximity to an area requiring fire protection. The location of major bushfires is relatively difficult to predict. Storage could be located near rural centres however the costs associated with transportation of water could make this option unattractive.

In terms of storage construction constraints will be similar to those described above in the section on constructed storages.

7.10.7.3 Data needs

It may be useful to obtain historic bush fire records and population distributions in the vicinity of the production area.

In terms of data needs for construction of the storage see the section above on needs for constructed storages.

7.10.8 Alternative 7 — Other industrial uses

As described above there are a number of other industrial activities which may benefit from a supplementary supply of water from CSG operations.

These industries may include breweries, ethanol fuel plants, abattoirs and other industrial activities currently drawing water from rural town centre supplies. Often a number of medium industrial users will be located on the outskirt of a rural town centre. In this case it may be possible to co-ordinate a number of industries to contribute to treatment and supply costs and relieve pressure on municipal supplies.

7.11 Municipal water use

7.11.1 Introduction

A salinity of 1000 mg/L TDS is generally palatable to most tastes, but up to 1500 mg/L TDS can be acceptable in areas where better quality water is not available. Salinities above 1500 mg/L TDS, generally render the water unacceptable for human consumption. The *Australian Drinking Water Guidelines* from the National Health and Medical Research Council and Agriculture and Resource Management Council of Australia and New Zealand (NHMRC, 1996) recommend a maximum TDS level for drinking water of 500 mg/L TDS.

Traditional raw water sources utilised by rural communities in the Surat Basin, such as the township of Dalby, have been declining in available volume and quality over the past decade. In order to meet municipal demands many communities have needed to identify additional sources of water and increase treatment abilities in order to use poor quality groundwater supplies.

The provision of produced water to these communities could provide a short to medium term solution to municipal water requirements.

An alterative would be to provide untreated water to a large water utility such as SunWater for blending and treatment prior to on-sale to customers. A large utility is likely to have the additional water sources to blend the produced water and treat under existing infrastructure. While this alterative would provide beneficial use it is unlikely to benefit rural communities in the vicinity of extraction sites.

7.11.2 General applicability

Use of produced water for municipal use may include use for potable or non-potable purposes.

Use for potable purposes will require a higher level of treatment than for non-potable uses such as irrigation and maintenance of community facilities.

If an appropriate agreement could be made between a local council and a CSG company the economic costs of treating the extracted groundwater by desalination may be offset, providing large benefits to rural communities. The agreement would be required to include details of the quality and quantity of water to be supplied, the monitoring requirements, ownership and costs of the supply of the water and any other legal implications of the agreement.

The longevity of the supply, being limited to 15 or 20 years, may detract from the appeal of the supply for local councils and reduce the cost/benefit of the investment in the required infrastructure.

7.11.3 Regulatory requirements

This beneficial use option will required the agreement between a private company and utility provider for a municipal area, be it a local council or a large utility such as SunWater. The scheme would require approval by the EPA and ministerial consent under the Petroleum Act 1923.

7.11.4 Constraints

The major constraints on use of produced water to supplement municipal supplies will be water quality, treatment and transport costs.

The treatment level required for potable water would require large capital expenditure to install treatment facilities to reduce TDS to 500 mg/L unless the utility has facilities to treat this level of water quality.

Following treatment there are few constraints on the supply of water for potable use as Local Councils and customers of large utilities would utilise existing delivery infrastructure and control systems.

The major restrictions on using the treated produced water for irrigation are the quality of the water, the vegetation characteristics, public health and environmental concerns. Environmental contamination of groundwater and runoff into surface waters are key concerns.

Issues requiring resolution prior to re-use for irrigation of community facilities will be similar to the issues discussed above for agricultural re-use. In addition issues of public health would require addressing.

Another constraint may be the variability in supply volumes from produced waters. This variation in volume may create issues in the design and sizing of a suitable desalination plant. It may be necessary to construct a buffer storage to maintain constant supply to a small municipal treatment plant.

7.11.5 Data needs

The identification of a rural community or a large utility in the vicinity of the production area will be necessary to minimise costs.

Produced water quality will require characterisation and treatment options will need to be investigated.

A cost/benefit analysis is likely to be required to determine the suitability of the option for a local municipal council.

7.12 Summary of water management options

For this overview study a significant range of water management options has been presented. For each option, the applicability, recognised constraints and data requirements have been briefly assessed where possible. For all options of use of CSG product water, two key factors must be known, the quality and quantity of supply. While some of the options presented may not be applicable in the short term, the aim is to present as many water use options as possible.

A summary of the advantages, disadvantages and suitability of the water management options presented in this section to the Surat Basin CSG industry is provided in Table 7.6.

Cost estimates have not been included due to the variability in costs due to site specific conditions.

Table 7.6: Summary of water management options for the Surat Basin

Option	Applicability	Advantages	Disadvantages	Constraints/ data needs
Surface Discharge				
Direct Discharge to Surface Water	Limited due to sensitive nature of surface water systems in the area	May provide increased environmental/base flows in systems with depleting flow regimes	Quality of produced water may impact on surface water health unless managed appropriately. Provision of additional water to a predominantly dry system may impact natural processes/ecosystems	Impacts of produced water quality on selected waters will need to be established on an individual basis
Underground Injection				
Alternative 1 – Injection into a non-coal aquifer	Not seen as applicable due to the high water quality and utilisation of surrounding aquifers	If water quality appropriate may provide an avenue for recharge of depleted groundwater resources	Where produced water is of poor quality contamination of aquifers may occur	Comparison of water quality of produced water and receiving aquifer will determine the viability
Alternative 2 – Injection into a coal seam aquifer	Possibly applicable either for re-injection into producing seam or into previously developed seam	Provides containment of produced water and minimises impacts on surrounding environment	Technical feasibility of both options unknown and will be dependant on the characteristics of the coal seam	Technical investigations will need completion to determine to feasibility of the option. Investigations should include possibility of movement of injected waters to surrounding aquifers
Constructed storages				
Storage design and construction considerations	Generally strongly applicable to this area	Provides containment of produced waters to only one location. Secondary benefits are provided by many constructed storage options	A relatively large area of land is required for storage construction. Costs associated with storage construction are comparatively larger than options of surface discharge.	Site suitability is the major constraint on construction of storages. An assessment of suitability will be required for each proposed location and storage use.

Option	Applicability	Advantages	Disadvantages	Constraints/ data needs
Alternative 1 – Wildlife and livestock watering	May be applicable depending on produced water quality and characteristics of the existing ecosystem	Provides a beneficial use for produced water	The longevity of supply may create an issue with regard to the sustainability of wildlife populations established due to supplementation by produced waters. Provision of additional water to a predominantly dry system may impact natural processes/ecosystems	Viability will depend strongly on produced water quality
Alternative 2 – Fisheries	May be applicable depending on produced water quality and identified need	Provides adjacent land holders with a beneficial use of produced water	Depending on the number of possible locations identified may not provide disposal of significantly large volumes of produced water	Identification of possible locations for private recreational ponds may be limited. This limits the volume of water that could be disposed by this option.
Alternative 3 – Recharge Ponds	Not seen as applicable in this region	If water quality appropriate may provide an avenue for recharge of depleted groundwater resources	Where produced water is of poor quality contamination of aquifers may occur	Comparison of water quality of produced water and receiving aquifer will determine the viability
Alternative 4 – Recreation	May be applicable depending on identified need and location	Provides widespread community benefit from produced water	Remote location of production areas may result in a limited population that would benefit from the construction of recreational facilities. Longevity of supply raises issues of sustainability	Identification of possible locations and target populations likely to benefit from facilities may limit viability
Alternative 5 – Evaporation Ponds	Highly applicable although no associated beneficial use	Climatic conditions make disposal option highly efficient. Waste contained to limited area	No beneficial use of produced water	Limited to site suitability

Option	Applicability	Advantages	Disadvantages	Constraints/ data needs
Alternative 6 – Constructed Wetlands	Limited applicability. In reality provides a combination of a wildlife watering pond and an evaporation pond	Some beneficial use associated with habitat creation	Longevity of supply raises question of sustainability of wildlife habitat created	Investigation of sustainability of wildlife habitat created by produced water supplementation would require resolution. Water quality may reduce applicability
Secondary Impoundment Uses	May be some applicable secondary uses	Additional benefits could be drawn from construction of storages		Data would be required to support secondary use of a constructed storage. Requirements for storage design for secondary use may need to be included in primary design
Agricultural use of produced water				
Alternative 1 – Stock Watering	Appears applicable based on current water quality	Provides benefit to landholders in vicinity of production areas. Reduced pressure on existing water resources	May cause production or health effects if water quality not suitable	Analysis of produced water quality at site will determine viability. Analysis should include Fluoride
Alternative 2 – Irrigation	Does not appear viable based on current water quality without treatment	Would provide benefit to landholders in vicinity of production areas. Reduced pressure on existing water resources	May affect crop yield and soil structure	Analysis of produced water quality at site will determine viability. Investigations into treatment may increase viability
Industrial Use				
Alternative 1 – Coal Mine Use	Applicable depending on economics	Provides beneficial use of produced water	Minimal	Identification of possible users and the proximity to production areas will determine viability
Alternative 2 – Animal Feeding Operations	May be applicable depending on water quality	Provides beneficial use of produced water	If water requires treatment costs may be excessive. Also discharge quality from feed lots may be decreased if water quality is poor	Identification of possible users and the proximity to production areas will determine viability

Option	Applicability	Advantages	Disadvantages	Constraints/ data needs
Alternative 3 – Cooling Tower Water	Applicable depending on economics	Provides beneficial use of produced water	Minimal	Identification of possible users and the proximity to production areas will determine viability
Alternative 4 – Enhanced Oil Recovery	Applicable depending on economics and identified need	Provides beneficial use of produced water	Minimal although likely that only small volumes of water would be required for this option	Identification of possible users and the proximity to production areas will determine viability
Alternative 5 – Aquaculture	Applicable depending on identified need	Provides beneficial use of produced water	Minimal	Identification of possible users and the proximity to production areas will determine viability
Alternative 6 – Fire Protection	Applicable depending on identified need	Provides beneficial use of produced water	Beneficial use limited as only used if required	Identification of possible users and the proximity to production areas will determine viability
Alternative 7 – Other Industrial Uses	Applicable depending on economics and identified need	Provides beneficial use of produced water and may reduce pressure on municipal supplies	Minimal	Identification of possible users and the proximity to production areas will determine viability
Municipal Water Use				
Potable	May be applicable depending on water quality and identified need	Provides large benefit to rural communities	Treatment required may be expensive and the longevity of supply may reduce attractiveness	Identification and agreement with potential users will be paramount. Costing of treatment and transfer works will determine viability
Irrigation	Unlikely to be applicable without treatment	Provides beneficial use for rural communities and reduces pressure on municipal supples	Water may require treatment prior to use making the economics unfavourable	Produced water quality and transport costs will determine if the option is economically viable

8. Treatment technologies

The water quality of the produced water and the re-use option chosen will dictate the level of treatment, if any, that is required. There are three main treatment levels which may be required for produced water: desalination, filtration and sterilisation.

Where water is being disposed to the environment, be it to a waterway or via re-injection it may be necessary to provide some level of sterilisation prior to release. In the US, water that has been exposed at the surface is required to be sterilised prior to reinjection into an aquifer (ALL Consulting, 2003). Also if water is being used for a purpose where human contact or ingestion may occur sterilisation may also be required.

If water is to be used for purposes requiring a higher quality of water than when extracted, it is likely that some reduction in chemical and biological constituents will be required. Filtration will provide a means of removing undissolved solids and desalination will also remove a proportion of dissolved solids.

8.1 Sterilisation

8.1.1 Ultraviolet light

Treatment with ultraviolet light is one method of sterilisation, removing free floating constituents. When exposed to UV energy bacteria, viruses, fungi, algae and protozoa are prevented from multiplying due to damage cause to the cell's nuclei. The concentrations of germs, bacteria, suspended solids, soluble molecules and mineral concentrations will effect the performance of UV treatment (ALL Consulting, 2003).

In comparison to chemical treatment UV is generally a more expensive option. ALL Consulting (2003) states that 'the (US) EPA researched UV light versus chlorination for small scale (waste) water treatment plants and discovered unfavourable results due to higher cost, (and) lower reliability'.

8.1.2 Chemical treatment

The most popular chemical treatment used for sterilisation is chlorination. 'Chlorination effectively removes disease-causing bacteria, viruses, protozoa, and other organisms, and can be used to oxidise iron, manganese and hydrogen sulphide so these materials can be filtered from the water' (ALL Consulting, 2003).

An advantage of chlorination over other disinfection treatments is the residual disinfection provided. Chorine will continue to provide disinfection protection after it leaves the treatment facility. Chlorination will also help to prevent algae and slime growth in pipes and storages (ALL Consulting, 2003).

8.2 Desalination

8.2.1 Reverse osmosis

Reverse osmosis (RO) is a proven process for the removal of dissolved solids from brackish or saline feed water. This process uses pressure to ‘force’ water through a semi permeable membrane, leaving the ions behind. A clean water stream and a concentrated brine solution result.

‘Reverse osmosis is capable of rejecting bacteria, salts, sugars, proteins, particles, dyes, and other constituents that have a molecular weight of greater than 150-250 daltons’ (GE Water Technologies, 2004a).

A typical RO plant operates at pressures of between 1000 and 2000 kPa for feed water with a TDS of between 500 and 3500 mg/L.

The pre-treatment of feed water is important in the RO process to ‘insure stable, long-term RO system performance and membrane life’ (ALL Consulting, 2003, p.5-5). RO membranes are particularly susceptible to fouling by chemical and biological species. ‘Pre-treatment may include clarification, filtration, ultrafiltration, pH adjustment, and removal of free chlorine’ (ALL Consulting, 2003, p.5-5). The type of pre-treatment and the number of pre-treatment steps required are dependent on the quality of the feed water, the required recovery ratio and the required quality of the product water.

The potential for use of water treated by RO is extensive due to the ability to treat the water to very high levels. RO has the ability to treat the product water to near 0 mg/L TDS, however, this reduction in TDS comes at a cost both financial and in terms of recovery ratio. As a general rule the larger the required reduction in TDS the more expensive an RO plant is in terms of capital and operating expenditure. Generally, a recovery ratio of between 80% and 94% of the feedwater stream can be achieved leaving a waste stream of between 20% and 6% of the volume.

Waste streams often cause a problem for disposal due to the concentration of chemical constituents and the addition of chemical cleaning agents. Options for disposal of wastes are similar to the options presented above for disposal of CSG produced water. Due to the concentrated nature of the stream it is unlikely that any release to the environment either through surface discharge, injection or recharge will be approved by regulatory authorities. Typically inland plants dispose of waste streams via evaporation in constructed storages.

8.2.2 Ion exchange

There are two common applications of ion exchange; water ‘softening’ where hardness ions (Ca^{++}, Mg^{++}) are replaced with Na^{+} and Cl^{-} ions and deionisation where conductive salts are replaced with H^{+} and OH^{-} (GE Water Technologies, 2004b).

‘The ion exchange process works by charging resins with replacement ions, e.g., Na^{+}, Cl^{-}, H^{+} or OH^{-}. Ions in the water are then attracted to the resin and attach themselves to the resin, replacing the ions that are already attached. Once the replacement ions are exhausted, the resin is regenerated with a concentrated solution of the replacement ions’ (All Consulting, 2003). There are two solutions that are used to regenerate a deionizer. One is a concentrated acid, and the other is a concentrated base (GE Water Technologies, 2004b).

This process is considered 'non-polluting and requires low energy' (ALL Consulting, 2003 p. 5-8).

Ion exchange is often coupled with other treatment technologies such as RO and is reported to reduce waste streams to as little as 5% of the feedwater volumes. This waste stream will require disposal generally by use of an evaporation pond in inland areas.

Since this process removes divalent ions preferentially to sodium, SAR adjustments are required after treatment (ALL Consulting, 2003).

8.2.3 Capacitive desalination (CDI) or deionization

Capacitive desalination is a new technology developed out of a material developed for the aerospace industry to prevent 'toasting astronauts on re-entry' (Bender 2003). Carbon aerogel is an extremely porous material with an extremely high surface area and an extremely low electrical resistance (Bender, 2003).

'In operation, the salty water flows between paired sheets of aerogel. Electrodes embedded in the aerogel apply a small direct current; positively charged ions attach to the sheet with the negative electrodes, and negatively charged ions cling to the sheet with the positive electrodes. After a suitable number of hours or days, the current is reversed, rinsing the ions off into a concentrate stream' (Bender, 2003). The process does not require the use of acids or bases for regeneration like conventional ion exchange therefore, secondary waste is eliminated (ALL Consulting, 2003).

While this technology has not been extensively tested on a commercial scale, the technology shows promise in the treatment of brackish water with a solids concentration of 8000 ppm or less. 'These include brackish aquifers as well as the water produced by coal bed methane extraction or other petroleum operations' (Bender, 2003).

The largest hurdle for this technology appears to be the unknown cost of manufacture. Capacitive Deionisation Technology Systems Inc. licensed CDI and aerogel technology in 1997 from the original developers, Lawrence Livermore National Laboratory, and has been refining the technology for desalination since. This company has recently entered into a joint venture with a large Japanese company to undertake assembly and marketing of the technology for the Japanese water market (Bender, 2003).

While this technology remains promising the cost effectiveness and suitability for the treatment of produced water from CSG remains to be seen.

8.2.4 Electrodialysis reversal (EDR)

EDR passes water through anode and cathode plates that surround charged membranes. Ions in the water are concentrated and attracted to the waste line while demineralised water is obtained in a separate line. The reversal side of the process refers to the reversal of the polarity of plates and membranes that provides a self cleaning capability by changing the flow directions through the membranes. (PB, 2002) The process is shown schematically in Figure 8.1. The reversal of flow 'aids in the prevention of slime and other build-up and lowers the amount of pre-treatment chemicals necessary to produce predetermined water quality objectives' (ALL Consulting, 2003).

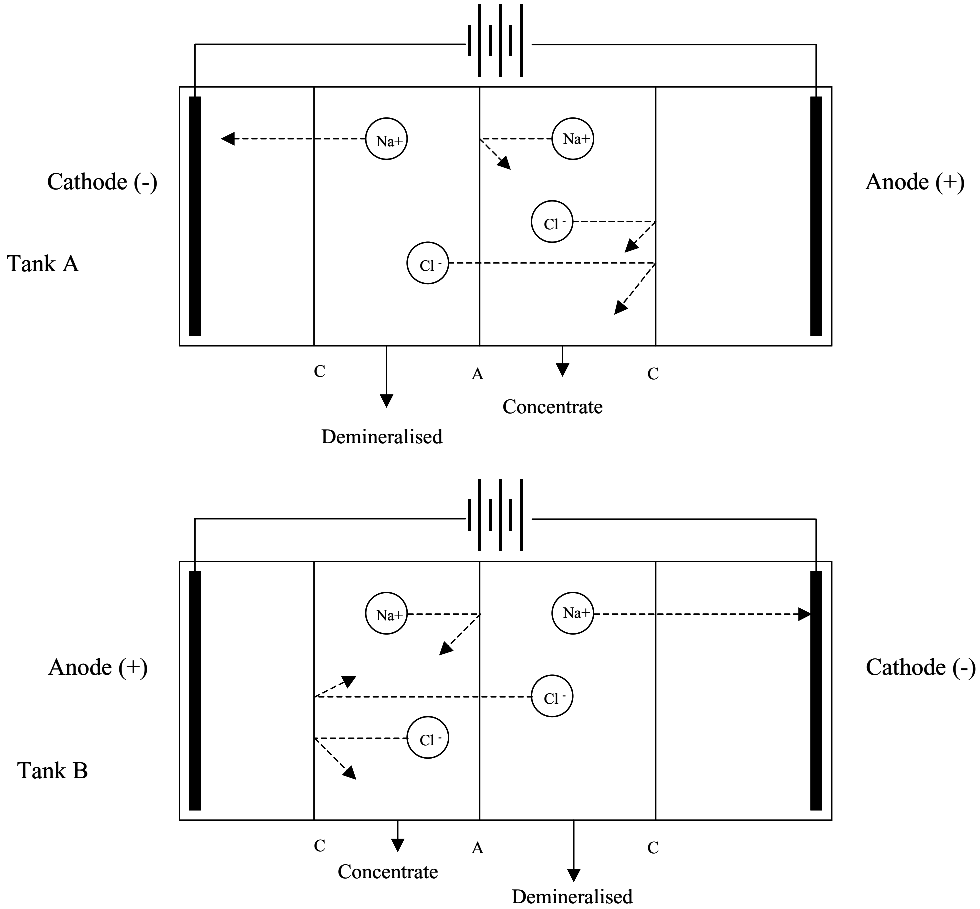


Figure 8.1: Electrodialysis reversal (EDR) process (AWWA, 1990)

EDR generally has a higher capital cost than a similar sized RO plant or nanofiltration, however it generally requires less pre-treatment than RO and thus may have lower operating costs in terms of chemical dosing (PB, 2002). The self cleaning nature of the process means that it has the potential to operate 'more efficiently for longer periods of time' (ALL Consulting, 2003).

It must be noted that EDR will only remove ionic species and thus if the feed water is high in organic compounds or non ionic species some form of filtration prior to the EDR unit will be required (PB 2002). It is claimed that when combined with other treatment technologies the volume of the waste stream can be reduced to 12% of the feedwater volume (Hodgson, 2001 from ALL Consulting, 2003).

Disposal of this waste stream is generally via evaporation in inland areas.

8.2.5 Distillation

Distillation is highly effective in the removal of impurities with up to 99.5% of impurities in raw water (ALL Consulting, 2003). The distillation process involves heating the raw water to boiling producing stream. The stream is then passed through a cooling chamber and is subsequently condensed to near pure water. 'Constituents having similar boiling points of water are not effectively removed during the distillation process. Such impurities may include volatile organic contaminants, certain pesticides, and volatile solvents' (ALL Consulting, 2003). If the presence of these constituents is suspected testing should be completed prior to use.

Various variations of distillation exist including flash distillation and mechanical distillation. These treatment methods generally required significant energy inputs.

8.2.6 Freeze-Thaw/Evaporation process

This process has been developed for areas that reach sub freezing climatic conditions and thus is not applicable in Australia, and particularly Queensland.

Freeze/Thaw Evaporation (FTE) 'couples conventional evaporation and freeze–thaw for treatment and disposal of wastewater. During warm months, the FTE system is operated as a conventional evaporation facility. However, during months with subfreezing (<32°F) temperatures, a large ice pile is created by spraying the water to be treated in a shallow pit, and the natural freeze/thaw process takes over. FTE has the potential to enhance the economic and environmental viability of oil and gas production by providing water for beneficial use and obtaining a substantial reduction in wastewater volume' (EERC, 2004).

8.3 Filtration

8.3.1 Physical filtration

Physical filtration is a traditional water treatment technology and involves the passage of water through a filtration media such as sand or activated carbon. While physical filtration methods can effectively reduce suspended solids and when coupled with chemical addition and traditional water treatment process can effectively reduce Fe and Mn levels.

This method of treatment will have limited effect on TDS level in produced waters and thus limited application in this case.

8.3.2 Artificial wetlands

The use of artificial wetland to treat CSG produced water has been discussed in the water management options above. A study of the use of artificial wetland to treat CSG produced water in America concluded that the system could possibly treat iron and possibly barium although further testing of the wetland system at higher loading rates as required. The system was not effective in altering SAR of produced waters over the 12 month study period (ALL Consulting, 2003).

The primary use of artificial wetland for this application would be to settle out suspended solids and for secondary use benefits.

8.4 Cost estimate for treatment options

It is difficult to compare the cost of treatment when the water quality and the volume to be treated are unknown.

Desalination technologies were compared in a report to the Department of Natural Resources and Mining Desalination in Queensland (GHD, 2003). The following comparison of desalination treatment technology costs was reported (Table 8.1).

Table 8.1: Desalination capital, operating and Maintenance Costs

Technology	Capital costs $/(KL/d)	Operating Costs $/(kL/d)
Multistage Flash Distillation	2000 – 3800	Dependant on Energy costs
Multi effect Distillation	2500 – 3900	1.8 – 2.8 (no waste heat available) 0.055 – 0.95 (waste heat available)
Vapour Compression Distillation	1600 – 1700	Dependant on Energy costs
Reverse Osmosis (RO)	700 – 1000 (brackish water) 1700 – 2400 (seawater)	0.65 – 1.5 (brackish waters) 1.89 – 2.2 (seawater)
Electrodialysis Reversal (EDR)	570 – 3250	1.00 – 2.80

Source: GHD 2003 Desalination in Queensland

The operating costs of distillation are generally highly dependant on energy costs. The availability of waste heat from a source such as a power station can significantly reduce the operating costs of distillation technologies.

While EDR can be less expensive in terms of capital costs for brackish water it is generally more expensive in terms of operating costs. RO can be prone to fouling and without pilot testing with specific water qualities costs of membrane replacement may become an issue for consideration in selection of a technology.

Ion exchange and capacitive deionisation have not been cost due to a lack of information. Freeze/thaw evaporation is not applicable and thus have not been cost.

The costs associated with sterilisation and filtration is best compared based on comparison of costs form water treatment facilities.

The capital costs of a water treatment plant will be dependant on scale. As a budget estimate from the NSW Reference Rates (DLWC, 1999) and incremented to 2004 costs indicates a conventional water treatment plant with a capacity of 2 ML/d will be in the order of $2.2 million ($1100/kL). However if this treatment plant was increased to a capacity of 10 ML/d costs would fall to approximately $630/kL.

A survey of ‘Australian non major urban water utilities’ completed by AWA for 2000–2001 (AWA, 2002) indicates that operating costs of existing water treatment plants with a range of treatment from disinfection only to disinfection and filtration range from 5c/kL to 30c/kL.

Overall conventional water treatment including sterilisation and filtration will be significantly cheaper than desalination technologies.

8.5 Summary

A summary of available treatment option for CSG produced waters and their applicability to management options for waters produced in the Surat basin is provided in Table 8.2.

Table 8.2: Summary of treatment options for CSG produced water

Option	Applicability	Advantages	Disadvantages	Constraints/ data needs
Sterilisation				
Ultraviolet Light	Applicable where sterilisation only is required and no improvement in water quality is required	Provides assurance that there is no risk to public health in terms of pathogens	Provides limited improvement in water quality with respect suspended solids and TDS	No increase in water quality other than sterilisation
Chemical Treatment	Applicable where sterilisation only is required and no improvement in water quality is required	Provides assurance that there is no risk to public health in terms of pathogens	Provides limited improvement in water quality with respect suspended solids and TDS	No increase in water quality other than sterilisation
Desalination				
Reverse Osmosis	Applicable for improvements in water quality	Provides effective removal of bacteria, salts, sugars, proteins, particles, dyes, and other constituents that have a molecular weight of greater than 150-250 daltons	Significant pre-treatment may be required High concerns with fouling and cleaning of membranes A concentrated waste stream requires disposal	Relatively expensive with significant operating and maintenance costs
Ion Exchange	Applicable for improvements in water quality	Provides softening of water or removal of salts Limited pre treatment Less waste stream than RO	Does not provide removal of constituent other than charged ions Preferential removal of divalent ions therefore SAR adjustment required on treated water	Relatively expensive with significant operating and maintenance costs
Capacitive Desalination (CDI) or Deionization	Applicable for improvements in water quality	Provides the removal of charged ions No use of cleaning chemicals therefore reduced waste stream	New technology with no commercial record Does not provide removal of constituents other than charged ions	Application, effectiveness and costs unknown

Option	Applicability	Advantages	Disadvantages	Constraints/ data needs
Electrodialysis Reversal (EDR)	Applicable for improvements in water quality	Requires a lower level of pre-treatment than RO and thus lower associated capital costs Less concern with fouling of membranes	Higher capital cost of EDR plant than RO Does not provide removal of constituents other than charged ions	Relatively expensive with significant operating and maintenance costs
Distillation	Applicable for improvements in water quality	Provides removal of all but constituents with similar boiling points to water such as some organics, pesticides and volatile solvents Limited pre treatment	High energy requirements	Relatively expensive with significant operating and maintenance costs
Freeze-Thaw/Evaporation Process	Not applicable			
Filtration				
Physical filtration	Limited applicability	Traditional water treatment method providing removal of suspended particles	Does not provide significant reductions in TDS or SAR or nutrient loadings	Limited effectiveness in reduction of constituents relevant to CSG water re-use
Artificial Wetlands	Limited applicability	Provides settlement of suspended particle and some reduction in nutrient concentration May provide some reduction in iron and barium	Does not provide significant reductions in TDS or SAR	Limited effectiveness in reduction of constituents relevant to CSG water re-use

9. Beneficial use case studies

A number of beneficial use case studies are included below to demonstrate to applicability of options described in Section 7 and 8. The case studies include:

- supply to a coal mine;
- supply to a municipal council; and
- supply to an intensive feed lot.

As mentioned in previous sections, the end use of the product water will depend on the water quality, level of treatment required and the percentage of water that may be allocated to an adjacent industry or end user. The cost of water treatment, transportation, construction and operation of supply to the proposed end use scheme, needs to also be assessed. In addition, the commitment of supply to a beneficial use will only be allowed for the life of the CSG development.

9.1 Supply to coal mine

As part of this study brief, it was requested that the option to supply CSG product water to the proposed Wandoan Coal Project be assessed. As a separate project, on behalf on XStrata (*Preliminary Assessment of Water Supply Options for Wandoan Coal Project* 2132093A – PR001Cjb) PB carried out a water supply option study for the Wandoan Mine, assessing all potential options for supply. While the 2002 report did not recommend CSG product water as a supply, PB has developed the option further based on this project's requirements.

9.1.1 Executive summary and study background

The Preliminary Assessment of Water Supply Options for the Wandoan Coal Project report (PB, 2002b) summarises the prefeasibility assessment of the mine water supply options for the Wandoan Coal Project. The original "fatal flaw study" for the Wandoan Coal reserve identified insufficient water as one of two issues with the development of the mine. The purpose of this study was to identify sufficient potential water sources for the mine (to a level appropriate for a pre-feasibility study) and to determine order of magnitude costs of supplying this water.

Water is used in four main areas of mine operations:

- coal handling and preparation plant make-up water and dust suppression sprays:
- haul road watering;
- service water requirements in the mine industrial area; and
- potable water.

A total water demand from these sources of 3000 ML/year has been adopted for the purpose of this study. The range of options for water supply was considered. Some example of surface water options are as follows.

- Capture runoff (clean and dirty) from within the mine area using the mine water management system.
- Construct new dams or weirs.
- Construct dams to capture overland flow on or near MDL's.
- Purchase existing watercourse licences.
- Utilise treated sewage effluent from Wandoan and/or Roma.
- Reduce losses from existing irrigational channels and obtain an allocation based on the volume of water saved.
- Purchase pit water from Moura Mine.
- Develop a high yield catchment within or adjacent to the mine.

Examples of groundwater supply options were:

- source water from existing groundwater allocations (e.g. town water bores);
- drilling of new bores into Hutton aquifer or Precipice Sandstone aquifer;
- groundwater inflow to the mine pit; and
- coal bed methane surplus water.

There appears to be sufficient potential sources of water that a supply of 3000 ML/year can be guaranteed to 95% reliability. The issue is whether total supply can come from one source, and whether the cost of supplying water will be a limiting factor. In addition, the most potentially reliable surface water supply options have not yet been built, and groundwater supply, while technically feasible, has a number of allocation issues to overcome before a supply can be guaranteed.

9.1.2 Scheme description

A number of cases will be presented for this case study, as the location of an appropriate CSG produced water supply is uncertain in terms of both distance from the Wandoan mine and the available quantity of water.

The two assumed cases for the location of the CSG production area are:

1. 100 km from the Wandoan mine near the town of Miles; and
2. 10 km from the Wandoan mine.

It was assumed that the 100 km pipeline would follow the railway alignment and the 10 km pipeline would be constructed on relatively flat terrain. Figure 9.1 shows the assumed alignments.

Two supply cases have been included:

1. 1500 ML/a; and
2. 3000 ML/a.

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Figure 9.1
Coal mine supply case study
Locality plan

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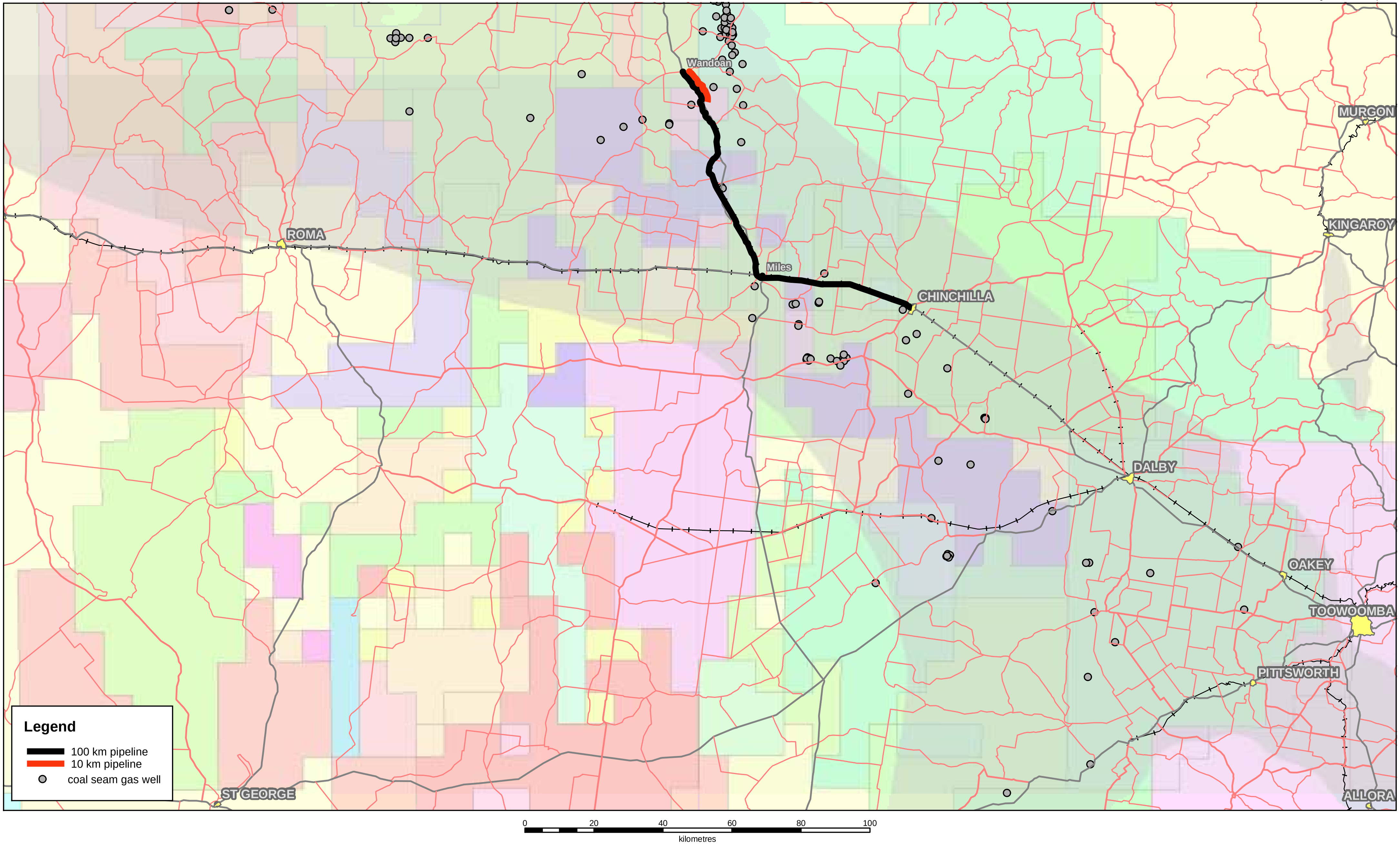
Sources
Coal seam gas wells, ATP expl titles: DNRME Qld 2003
Base map: Geoscience Australia 2002



The systems are summarised in Table 9.1.

Table 9.1: Wandoan Mine supply case summary

Case	Pipeline length (km)	Pipeline diameter (mm)	Supply volume (ML/a)
A	100	375	3000
B	10	375	3000
C	100	300	1500
D	10	300	1500

9.1.3 Viability

The viability of supplying CSG produced water to the Wandoan mine will depend on the generic constraints noted in Section 7.10.2 including:

- the costs transportation of water;
- the need for an additional reliable supply of water of the quality of the CSG produced water; and
- the timing of supply being in line with coal mine demands.

The acceptable costs associated with the transfer of water to the mine will in part be dependant on the other sources of water supply to the mine. If the mine cannot meet the required 3000 ML/a demand with a 95% reliability from the other identified water sources then the mining company will be willing to contribute a higher cost to the construction of a pipeline.

The preliminary assessment of water supply options included estimates of the capital cost of supply per mega litre per annum supplied to the mine from the various principal supplies. These cost ranged between $1700/ML and $28,500/ML for options proposing use of groundwater bores on the site and construction of new dams, respectively (PB, 2002b). These costs did not include operational or maintenance costs and the capital cost were not distributed over the life of the mine.

Agreement will need to be made as to which company contributes to the transfer costs and the operation and maintenance of the pipeline.

9.1.4 Costs

Costs have been calculated for comparison purposes only based on the assumptions stated in this report and should not be used for budget purposes.

The cost of transport for the four cases to the proposed Wandoan Coal Mine are summarised in Table 9.2.

Table 9.2: Summary of costs for each pipeline case

Case	Pipeline length (km)	Pipeline diameter (mm)	Supply volume (ML/a)	Capital Cost	Capital Cost/ML supplied
A	100	375	3000	$40.26 M	$13,420
B	10	375	3000	$4.49 M	$1500
C	100	300	1500	$33.4 M	$22,000
D	10	300	1500	$4.37 M	$2900

If a CSG supply can be identified within 10 km of the Wandoan Coal Mine with the capacity to supply either 1500 ML or 3000 ML with a relatively high level of reliability then the cost per mega litre of this supply would be attractive in comparison with the other options investigated within the preliminary planning study.

If the CSG supply is 100 km south of the mine near Miles the cost of transport is significantly increased. However, it may still be more attractive than the construction of a new dam costing up to $28,500/ML.

9.2 Supply to a Municipal Council

A number rural centres are located in the Surat basin in the vicinity of proposed CSG production areas including Dalby, Miles, Chinchilla, and Wandoan. This case study presents an example of the supply of produced water to a municipal council for supplementation of their water supply.

9.2.1 Scheme description

The supply of produced water to a nearby community would require:

- construction of a transfer pipeline from the production area to the existing town water treatment plant;
- construction of a buffer storage at the treatment plant to enable regulation of supply;
- augmentation of the existing plant to include a desalination unit such as an RO unit; and
- construction of an evaporative pond to receive concentrated waste from the RO unit.

The case study will assume that the existing town treatment facilities are designed to receive water from a number of sources including surface water and high quality groundwater. Water is blended, treated by conventional means including clarification and disinfection prior to distribution of customers. It is assumed that the existing treatment facilities include adequate capacity to receive water treated by RO and blend with additional water sources prior to disinfection.

The addition of the desalination unit would be on the grounds of the current water treatment plant and a location suitable for the construction of a concentrate disposal pond exists approximately 5 km for the water treatment plant.

Conservatively, a desalination plant to treat brackish water of the quality of produced water to date can achieve a recovery ratio of 80%, meaning that 20% of the flow for the produced water will become waste.

If it is assumed that the desalination plant is designed with a capacity of 20 L/s treated water, the rate of supply of produced water will be required to be at least an average of 25 L/s (756 ML/a assuming the plant operated 350 days/year).

Preliminary sizing of a pond to contain and evaporate a 5 L/s waste stream would be 20 ha at a depth of 1.5 m. It would be recommended that this pond be designed in a number of cells and thus construction could be staged.

For the case study it is assumed that the CSG production area is approximately 40 km from the rural centre.

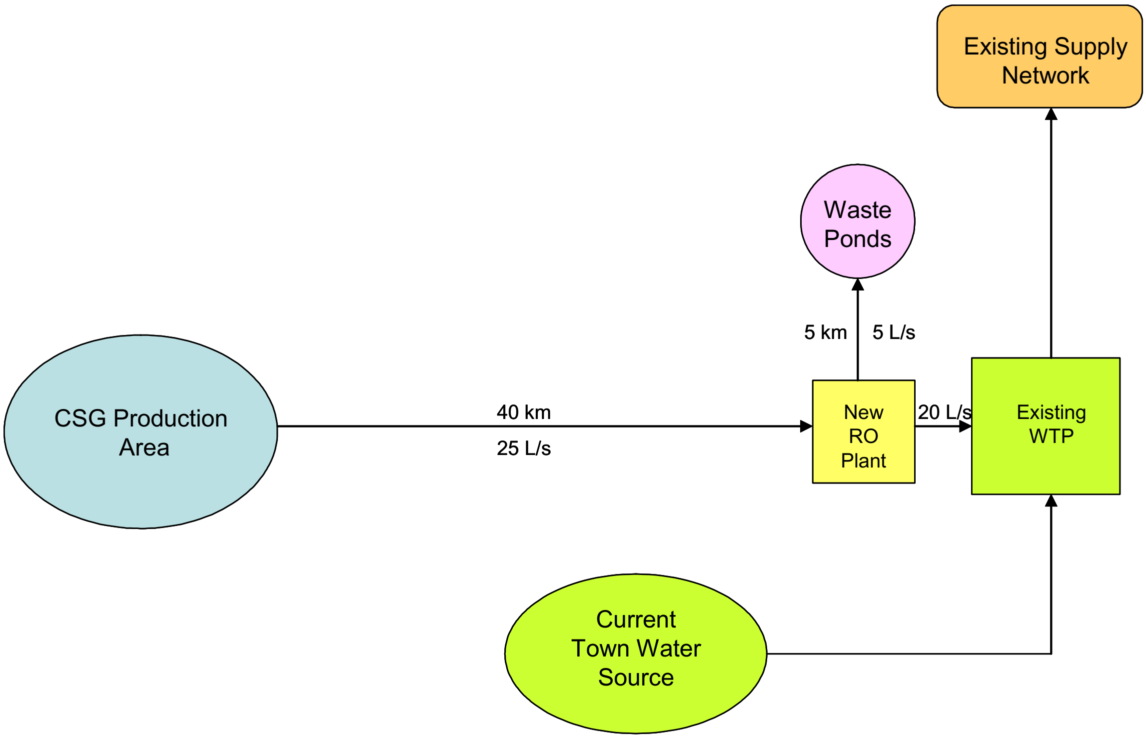


Figure 9.2: Schematic representation of supply to a Municipal Council

9.2.2 Viability

As discussed in the general description of this option the viability of this option will be dependant on the cost/benefit analysis of the proposed option.

If water supplies available to a rural town are sufficient in quantity and quality to sustain the growth of a rural centre it is unlikely that the expense of transport and treatment will make this option viable. However, if it is apparent that in the short to medium term the town centre will require additional supplies currently unavailable then the costs associated with use of the produced water may be justified. This may be the case where an industry such as a coal mine is proposed near a town and the population of the town is likely to increase substantially for the life of the mining operation.

9.2.3 Costs

Costs have been calculated for comparison purposes only based on the assumptions stated in this report and should not be used for budget purposes.

Transfer to Desalination Plant

A preliminary estimate for the transfer of 25 L/s along a 40 km pipeline is provided in Appendix A. This estimate assumes relatively flat terrain.

Desalination Plant

Based on the costs indicated above for desalination treatment technologies (Section 8.4) the budget costs have been calculated for the proposed plant.

Waste Disposal

The sizing of the disposal basin has been calculated based on climatic conditions near Dalby. The CSIRO produced a report in 1999 detailing costs for construction of evaporation basins (CSIRO 1999). Disposal costs for the brine produced in this case study have been calculated based on the findings of this report and increased in line with CPI increases. A budget cost estimate is provided in Appendix A.

Summary of costs

Table 9.3 presents an estimate of cost for supply to a Municipal Council

Table 9.3: Summary of costs associated with supply to a Municipal Council

Item	
Transfer to Plant	$11,190,000
Desalination Plant	$1,220,000
Disposal Ponds	$475,500
Total Costs	**$12,885,500**

9.3 Supply to intensive stock feeding

Feedlots require local access to cattle, grain and other roughage. Consequently feedlots are concentrated in the heartlands of Australia's mixed farming regions including southern Queensland.

Latest statistics show that there are currently 629 accredited feedlots in Australia representing a total capacity of approximately 894,000 cattle. Of these feedlots, 78 have a capacity of over 1000 head, or 12.4% of the feedlots hold 80.0% of the capacity. The largest feedlot has a capacity of more than 50,000 head. (ALFA, 2002)

For this case study it will be assumed that the water quality of produced waters is adequate for direct livestock watering.

9.3.1 Scheme description

The assumption is made in this example that an average sized beef cattle intensive feedlot contains 500 head of cattle.

The average daily water consumption for beef cattle taken from the Australian Water Quality Guidelines for Fresh and Marine Waters (ANZECC, 2000) is 45 L/head/day. The calculation of feed lot water demands is included in Table 9.4.

Table 9.4: Feedlot assumptions

Assumed head of Beef Cattle	500	Head
Daily Water Consumption	45	L/Head/day
Total Annual Consumption	8.2	ML/annum
Assumed Volume for waste clean up and other uses	16.8	ML/annum
Assumed site use	**25**	**ML/annum**

It is assumed that a feedlot is located approximately 5 km from the CSG production area and the terrain is relatively flat.

9.3.2 Viability

The location of feedlots with respect to possible CSG production sites is not known at this stage. It may be possible that an average sized beef cattle feedlot will be located within close proximity to the production areas.

The produced water demand calculated for the example is relatively small compared to the estimated volumes of water to be produced by the industry in the region. However, this option may be viable for small water production areas and may be used in conjunction with other water management alternatives.

9.3.3 Costs

An estimate of the cost associated with transporting 25 ML/a of untreated water a relatively short distance of 5 km has been calculated for comparison purposes only (Table 9.5).

Table 9.5: Transfer costs for supply to a feedlot

	Cost estimate
Transfer pipeline	$219,000.00

10. Communication of report findings

As an outcome of this study, both the regulator and CSG industry representatives must effectively disseminate relevant information to the community in relation to the emerging CSG industry.

Identification of key stakeholders in relation to where development will be targeted, beneficial re-use options and acknowledgement of groundwater user concerns, need to be undertaken.

Key legislation changes, as discussed in the *Petroleum and Gas (Production and Safety) Bill 2004 (P&G Bill)*, should be effectively communicated to existing groundwater users that may be concerned about this new industry. In particular the implimentation of water managemnet practices that the P&G Bill enforces should be communicated to stakeholders.

Key messages sent to relevant stakeholders should be:

- awareness of the CSG industry development for Queensland and how each development may relate to the local community;
- acknowledgement of potential groundwater impacts due to the CSG water extraction process and what legislation requirements and industry practices are occurring to ensure protection of groundwater resources; and
- identification of CSG water re-use options for adjacent industry benefit.

Both regulator and the CSG industry representatives must present to the identified stakeholders a consistent and effective means of communication to ensure concerns regarding protection of existing water rights are addressed.

11. Conclusions

Water use and water quality are key elements of understanding the relation of CSG development and production to water resources. The type and magnitude of potential impacts due to the CSG development vary greatly throughout the CSG development area. Within the Surat Basin, the Walloon Coal Measures form the main target units for CSG development.

Limited groundwater information is available on the coal seams that directly correlates hydrogeological response to CSG development. However, based on existing geological information and information from the NRM&E groundwater database, it was assumed that:

- no exploration is undertaken in the vicinity (i.e. 20 to 50 km distance) of outcrop zones of the WCM, predominantly due to the shallow seams being unprospective for CSG development;
- the nature of the Surat Basin coal seam units that contain the methane gas (i.e., layers of coal interbedded with confining layers having low vertical hydraulic conductivity) should minimise impacts to aquifers above these seams. Confining layers above the coal seam units should provide a degree of protection from drawdown associated with CSG production from the coal seams;
- the coal cleats do not provide a continuous porous medium that has been simulated by low hydraulic conductivity (approximately 0.12 to 0.0113 m/day) (PB, 2002); and
- leakage from overlying or underlying aquifers is also considered negligible due to the presence of fine-grained sediments (siltstone, mudstones and shale) below the coal measures and over or underlying formations.

Existing groundwater bores with in the WCM predominantly use the water supply for stock only due to the typically poor quality of groundwater. Of the 13,000 registered groundwater users with the study area, only approximately 300 are registered from the WCM. The majority of existing WCM registered users also access only the shallower seams (i.e. less than 300 m below ground level) within the full unit, whereas CSG industry development typically targets the coal seams at depths from 500 m to 700 m below ground surface level.

Water management options

For this overview study a significant range of water management options has been presented. For each option, the applicability, constraints and data requirements have been briefly assessed where possible. For all options of use of CSG product water, two key factors must be known, the quality and quantity of supply. While some of the options presented may not be applicable in the short term, the aim is to present as many water use options as possible.

The key water management options available for management of produced water include (but not limited to):

- surface discharge;
- underground injection;
- impoundment with no re-use (evaporation, recharge); and
- beneficial uses.

It is likely that a production area will require a combination of management options for produced water. It may be that a portion of the produced water is used on site, a portion is used for a beneficial use and part is disposed. Water management options will be site specific and will be influenced by some or all of the following factors:

- location of production area and proximity to communities, industries, agricultural lands;
- confidence of water extraction rates that can be guaranteed for beneficial use;
- water quality of produced waters;
- environmental sensitivity of surrounds;
- responsibility of capital costs for beneficial use scheme; and
- philosophy of the CSG producing company in accordance with Government policy/ legislative framework.

Due to the water quality characteristic of the coal seam water within the Surat Basin, it is assumed that all or some of the management options chosen by industry may require treatment of the produced water to meet the required water quality. If a treatment option it should be recognised that it is likely that the waste stream from the treatment will require disposal.

It should also be noted that while surface water discharge has been included in the discussion as a potential water management option, the complexity of regulatory approvals and the poor water quality of CSG product water against the water quality of the receiving environment, does not allow for this option to the directly viable, from both an environmental and social acceptance perspective.

Potential uses of water

If produced water was to be used for a beneficial use it may include but not be limited to:

- agriculture;
- aquaculture;
- niche/cottage industries — algae farming;
- industrial — coal mining, cooling water;
- municipal potable water supply;
- community water supply and recreational activities; and
- environmental — recharging streams/aquifers, minimum environmental flows, wildlife water supply and habitat creation.

Again the quality and quantity of CSG product water must be known in order to determine suitability of end use, reliability of supply to end use and level of treatment required.

Summary

Lessons learnt from CSG development in other countries can be applied to the assessment of potential groundwater impacts and water management options within the Surat Basin. The CSG industry will provide a new extractive energy industry for Queensland and in addition provide opportunities for beneficial re-use of a water resource that may otherwise not be readily accessible to adjacent industries.

Legislation changes will ensure that industry should manage both potential groundwater impacts and beneficial re-use of the product water to a level acceptable to both regulator and the community. Key conclusions made from this study are as follows.

- Target unit for CSG development and therefore water extraction within the Surat Basin is the Walloon Coal Measures.
- Information provided by industry representatives indicates that the coal seam may vary in thickness from 2 to 10 m, and be separated by up to 30 to 80 m of predominantly silts and tight sands that may restrict any vertical leakage between seams and overlying and underlying units. It should be noted that this may refer to an individual seam, and that multiple seams may be encountered in a single CSG well, each separated by 30 to 80 m of predominantly silts and tight sands. Therefore, regionally, the coal seams are considered an aquitard (non water conducting) more than an aquifer unit.
- Based on geological information and inferred groundwater information from the NRM&E database, the WCM are not considered to be hydraulically connected to the Great Artesian Basin aquifers within proposed regions of CSG development. This assumption may alter depending on site specific hydrogeological data. It should be noted, that no detailed, site specific groundwater assessment has been undertaken as part of this study.
- Current legislation changes will ensure adequate monitoring and predictive modelling of effects from water extraction will be addressed by the CSG industry.
- Within regions of CSG development sites, all existing water users within the Walloon Coal Measures should be identified.
- Typical water management practices currently applied by CSG producers are to re-use water on-site and application of evaporation ponds. This is an acceptable method for industry based on existing water extraction rates however identification of alternative beneficial uses need to be addressed when full production is achieved. As potential beneficial use options are site-specific, data capture for quality and quantity of CSG product water is critical and confident application of this data, for future supply volumes, is important. The CSG Industry is being proactive in addressing future site water management practices and working at applying beneficial use of water.
- Direct application of CSG product water is fairly constrained and unlikely due to the water quality characteristics of the CSG product water that typically exceed guidelines for irrigation and livestock. In addition, direct discharge of CSG product water to surface water bodies is unlikely due to impact on receiving environment and legislation requirements. Treatment of CSG product water is required for most water management options presented in this report. The beneficial use options are site specific.
- Baseline groundwater data should be established at CSG pilot sites. The quality and quantity of the CSG product water should be confidently known.

- Potential groundwater impacts will be mitigated through current legislation changes for the CSG industry which will ensure responsible water management by the CSG producer.
- Project planning for CSG development will include protection of adjacent water rights and CSG rights through emerging legislation requirements.
- The choice of beneficial product water end use will depend on economics, regulatory requirements, produced water quality, and local hydrogeologic conditions.
- The beneficial use of product water should be outlined before extraction commences for the project.
- The responsibilities for meeting the costs of treatment, transportation, construction and operation of end use applications need to be established before development begins.

12. Recommendations

The following recommendations promote the sustainable development of CSG within the Surat Basin while conserving ecological and agricultural values.

- The role of both Industry and Government in this emerging industry should be communicated to the community. In particular, in regions where development will be targeted and potential water re-use options may be viable.
- The mitigation measures (such as monitoring etc) that will be a requirement of emerging legislation and the role and responsibility of the CSG producer should be communicated to the community.
- Baseline information should be gathered for any well within the general location of CSG development so that the effects of groundwater drawdown can be monitored.
- The end-use of the product water should be outlined in the planning phase of the development.
- A more detailed assessment of the economic viability of beneficial use of CSG product water from each project should be undertaken, once there is confidence in long-term extraction volumes and reliability of supply.
- Commence collating suggested baseline datasets at CSG pilot sites (in accordance with legislation requirements).
- Prepare best practice guidelines for industry specific to the Surat Basin but drawing on experiences from local, national and international CSG developments.

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Appendix A

Cost estimation for case studies

Case Study 1 — Wandoan Mine Water Supply

Cost estimation

Table A1: Cost estimation for Wandoan Mine water supply

No.	Item	Quantity	Unit	Rate	Amount
	Case A – 100 km, 3000 ML/a				
1.0	Preliminaries	5%	Item	—	$148,716
2.0	Pipeline (DN375 DICL)	100,000	m	$262	$26,158,037
3.0	Pump Stations (PS)				
3.1	*Duty and standby PS (Total pumping head 120m/2*179kW)*	2	Item	$508,683	$1,017,365
3.2	*Duty and standby PS (Total pumping head 60m/2*89kW)*	1	Item	$113,879	$113,879
3.3	*Break Pressure Tank and Control*	2	Item	$304,163	$608,326
3.4	*Power Supply (assumes HV power within 5km)*	3	Item	$175,000	$525,000
4.0	Terminal Storage Tank and Control Building	1	Item	$397,752	$397,752
5.0	Telemetry and Control	1	Item	$312,000	$312,000
	Sub-Total				$29,281,076
	Investigation and Design			7.5%	$2,196,081
	Construction Supervision			10.0%	$2,928,108
	Contingency			20.0%	$5,856,215
	TOTAL				**$40,261,479**
	Case B – 10 km, 3000 ML/a				
1.0	Preliminaries	5%	Item	-	$56,952
2.0	Pipeline (DN375 DICL)	10,000	m	$207	$2,068,310
3.0	Pump Stations (PS)				
3.1	*Duty and standby PS (Total pumping head 40m/2*60kW)*	1	Item	$254,280	$254,280
3.4	*Power Supply (assumes HV power within 5km)*	1	Item	$175,000	$175,000
7.0	Terminal Storage Tank and Control Building	1	Item	$397,752	$397,752
8.0	Telemetry and Control	1	Item	$312,000	$312,000
	Sub-Total				$3,264,294
	Investigation and Design			7.5%	$244,822
	Construction Supervision			10.0%	$326,429
	Contingency			20.0%	$652,859
	TOTAL				**$4,488,404**

No.	Item	Quantity	Unit	Rate	Amount
	Case C – 100 km, 1500 ML/a				
1.0	Preliminaries	5%	Item	-	$172,624
2.0	Pipeline (DN300 DICL)	100,000	m	$207	$20,683,099
3.0	Pump Stations (PS)				
3.1	*Duty and standby PS (Total pumping head 120m/2*89kW)*	3	Item	$339,276	$1,017,827
3.2	*Duty and standby PS (Total pumping head 30m/2*22kW)*	1	Item	$112,419	$112,419
3.3	*Break Pressure Tank and Control*	3	Item	$304,163	$912,490
3.4	*Power Supply (assumes HV power within 5km)*	4	Item	$175,000	$700,000
7.0	Terminal Storage Tank and Control Building	1	Item	$397,752	$397,752
8.0	Telemetry and Control	1	Item	$312,000	$312,000
	Sub-Total				$24,308,212
	Investigation and Design			7.5%	$1,823,116
	Construction Supervision			10.0%	$2,430,821
	Contingency			20.0%	$4,861,642
	TOTAL				**$33,423,791**
	Case D – 10 km, 1500 ML/a				
1.0	Preliminaries	5%	Item	-	$52,961
2.0	Pipeline (DN300 DICL)	10,000	m	$207	$2,068,310
3.0	Pump Stations (PS)				
3.1	*Duty and standby PS (Total pumping head 50m/2*37kW)*	1	Item	$174,468	$174,468
3.4	*Power Supply (assumes HV power within 5km)*	1	Item	$175,000	$175,000
7.0	Terminal Storage Tank and Control Building	1	Item	$397,752	$397,752
8.0	Telemetry and Control	1	Item	$312,000	$312,000
	Sub-Total				$3,180,491
	Investigation and Design			7.5%	$238,537
	Construction Supervision			10.0%	$318,049
	Contingency			20.0%	$636,098
	TOTAL				**$4,373,175**

Costs have been calculated for comparison purposes only based on the assumptions stated in this report and should not be used for budget purposes.

Case Study 2 — Municipal Supply

Cost estimation

Table A2: Transfer costs to desalination plant

No.	Item	Quantity	Unit	Rate	Amount
1.0	Preliminaries	5%	Item	-	$109,574
2.0	40 km Pipeline (DN200)	40,000	m	$146	$5,839,934
3.0	Pump Stations (PS)				
3.1	*Duty and standby PS (Total pumping head 100m/2*37kW)*	3	Item	$174,468	$523,404
3.2	*Break Pressure Tank and Control*	2	Item	$304,163	$608,326
3.3	*Power Supply (assumes HV power within 5km)*	2	Item	$175,000	$350,000
4.0	Terminal Storage Tank and Control Building	1	Item	$397,752	$397,752
5.0	Telemetry and Control	1	Item	$312,000	$312,000
	Sub-Total				**$8,140,990**
	Investigation and Design			7.5%	$610,574
	Construction Supervision			10.0%	$814,099
	Contingency			20.0%	$1,628,198
	TOTAL				**$11,193,862**

Costs have been calculated for comparison purposes only based on the assumptions stated in this report and should not be used for budget purposes.

Table A3: Desalination plant costs

Item	Desalination Plant
Plant Capacity (product water)	20 L/s (1440 kL/d)
Cost per kL/d	$850/kL/d
Capital Costs	**$1.22 million**
O&M cost per kL/d	70 c/kL/d
O&M Cost[1.]	**$353,000**

1. Assumes plant operates 20 hrs per day and 350 days per year.

Table A4: Estimates of capital and maintenance cost a 20 ha Evaporation Pond

Item	Evaporation Pond
Pond Size	20 Ha
Construction of Pond (2004 adjusted)#	$155,000
Pump and Pipeline	$140,000
Capital Costs	**$295,000**
Contingency (20%)	$59,000
Engineering design and management (20% of capital costs)	$59,000
Purchase of Land (25 ha @ $2,500/ha)	$62,500
Total Construction Costs	**$475,500**
Maintenance Cost/annum	**$7,310**

1999 costs are increased by 3%/annum to account for CPI increases (CSIRO 1999)

Case Study 3 — Water Supply To A Feedlot

Cost estimation

Table A5: Transfer costs for supply to a feedlot

No.	Item	Quantity	Unit	Rate	Amount
1.0	Preliminaries	5%	Item	—	$2500
2.0	Pipeline (PE80B PN12.5 63mm)	5000	m	$26.00	$130,000
3.0	Pump Station (PS)				
3.1	*Duty and standby PS (Total pumping head 30m/2*1.3kW)*	1	Item	$50,000	$50,000
	Sub-Total				**$182,500**
	Contingency			20.0%	$36,500
	TOTAL				**$219,000**

Costs have been calculated for comparison purposes only based on the assumptions stated in this report and should not be used for budget purposes.

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