SENATE RURAL AFFAIRS AND TRANSPORT REFERENCES COMMITTEE

Inquiry into the management of the Murray-Darling Basin

Public Hearing Tuesday, 9 August 2011

Questions Taken on Notice – AGL

7. HANSARD, PG 33

Senator EDWARDS: I am interested in aspects of your well and your interaction with landowners. In other submissions—and I am sure you have the same situation—annual payments per well vary between $750 and $5,500. That is another company's example. Then there are additional amounts paid, between $1,000 and $10,000 per well. We are trying to find out why all these things are kept confidential. That is the first part of the question. Also, do you as a company have any problem in no longer seeking confidentiality agreements with landowners to try and get a bit of sunlight in and having a market place for having a well on your property? With the number of wells that you have out there in Australia, what is the payment for an average well for the exploration licence and then for the production licence?

Mr Moraza: I do not have that detail with me today. In order for me to represent a factual response to your question, if you do not mind I will take that question on notice and I will put a submission through to the committee within 14 days.

8. HANSARD, PG 34

Senator WATERS: Now, I will go to the same questions that I have asked of the other companies. In terms of when you make claims about coal seam gas being cleaner than coal, are you coming to those figures on the basis of a life cycle analysis and by that I mean are you including to the liquefaction energy inputs and reversals, energy inputs and any leaking wells or pipes?

Mr Moraza: In the case of AGL, none of our activities involve liquefaction.

Senator WATERS: You are not exporting?

Mr Moraza: We are not exporting. In short, the answer to your question is, yes, I can confirm that the industry figures are for life cycle figures.

Senator WATERS: What are you basing that on?

Mr Moraza: The emission intensity of natural gas.

Senator WATERS: Have you done independent reports? What are you relying on to come to those figures?

Mr Moraza: Yes we have an internal report and I am happy to table that.

Senator WATERS: Yes, thank you, I would be very appreciative.

9. HANSARD, PG 34

Senator WATERS: Yes, thank you, I would be very appreciative. Do you know what proportion of your wells leak?

Mr Moraza: None of our wells leak and I can confirm that because of the fact that at least once every year each and every well is tested with a gas-testing device.

Senator WATERS: Just once a year?

Mr Moraza: No, I think it is done more frequently but I do not have the detail of the actual frequency. I can confirm that if you wish.

Senator WATERS: Yes, thank you, I am interested in that well-checking process.

10. HANSARD, PGs 34–35

Senator WATERS: Yes, thank you, I am interested in that well-checking process. Likewise pipes, do you know if your pipes are leaking and what is the process for checking?

Mr Moraza: Yes, we do. We have gas detection devices around the plant and each of our gas-gathering wells has a survey done where we traverse the ground with gas-detecting devices.

Senator WATERS: The whole length of the pipeline?

Mr Moraza: We do. There are some areas which are not readily able to be accessed. I will give you an example: we have a gas-gathering system that runs under the Hume Highway out of Sydney, so it is impossible to get access to the surface there, but we are able to get access to either end of the location.

Senator WATERS: Okay, so you can confirm that there are no leaking pipes.

Mr Moraza: Based on the testing I can confirm that there are no leaking pipes.

Senator WATERS: If you would not mind tabling those processes that you undertake in terms of the rigour of your testing that would be good.

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Energy in action.®

Committee Secretary
Senate Standing Committee on Rural Affairs and Transport
PO Box 6100
Parliament House
CANBERRA ACT 2600

09 September 2011

Dear Committee,

Inquiry into management of the Murray Darling Basin – impact of mining coal seam gas: AGL Energy Ltd response to questions on notice:

Please find attached AGL Energy Ltd ("AGL") responses to the Committee's questions on notice in Attachment A. In addition, please find attached AGL's response to the Committee's supplementary questions of 29 August 2011 in Attachment B.

Should the Committee require further clarification, please contact Sarah McNamara, Head of Government & Community Engagement on 02 9921 2050.

Yours sincerely,

Mike Moraza
Group General Manager Upstream Gas

ATTACHMENT A

Question 1

Senator EDWARDS:

I am interested in aspects of your well and your interaction with landowners. In other submissions—and I am sure you have the same situation—annual payments per well vary between $750 and $5,500. That is another company's example. Then there are additional amounts paid, between $1,000 and $10,000 per well.

We are trying to find out why all these things are kept confidential. That is the first part of the question. Also, do you as a company have any problem in no longer seeking confidentiality agreements with landowners to try and get a bit of sunlight in and having a market place for having a well on your property?

With the number of wells that you have out there in Australia, what is the payment for an average well for the exploration licence and then for the production licence?

AGL Response

AGL does not insist upon individual confidentiality agreements with landowners, although the standard form Access and Compensation ("A/C") agreement which is presented to the landowner does contain a confidentiality clause. As part of the process, this clause, along with all others, can be negotiated as to its existence, or content. It is not uncommon however for landowners to actually request confidentiality in the agreements.

AGL encourages each landowner to seek independent legal advice in regards to the A/C agreement, and AGL has a policy to pay the landowner's reasonable legal fees. AGL normally only requires commercially sensitive information to be kept confidential (unless requested by a Government or regulatory body).

AGL's current methodology for compensation consists of:

- A land valuation to provide the basis for negotiation and achieving an appropriate rate per square metre, or otherwise agreed for any land required as part of a proposed A/C Agreement. The rate per square meter is then generally applied for land which is used during the construction, commissioning and work over periods. The valuation takes into consideration existing land use.
- Adopting the rate per metre for upgraded or new access roads.
- Adopting the rate per metre for gathering lines.
- Option of leaving gathering lines on properties for farmers to use for irrigation.
- Works in kind e.g. installing new gates/fencing/cattle grids etc.
- Flexible planning of access roads to benefit the land owner.
- Flexible planning of gathering lines. We have agreed to move gathering lines to fit in with future land development if required.

(Where activities occur on Council land, AGL adopts the Council's set rate of fees, which they have adopted for standard leasing of Council land to other utilities.)

- AGL currently pays on average $3,000 to $5000 one off payment for short term exploration wells.
- For Production wells, total average annual compensation paid to June 2011 was $2,382 per well.

Where activities occur on land where land values are low, an alternative approach is usually to base the compensation assessment on the impact on land use and the business, rather than land value. The amount will depend upon the disturbance or impact to the farming operation.

In summary there are many variables in establishing an appropriate compensation sum, as each individual case will be unique. The broad measures outlined above are designed to ensure a level of consistency of approach in arriving at a negotiated outcome to the satisfaction of both parties.

Question 2

Mr Moraza:

We are not exporting. In short, the answer to your question is, yes, I can confirm that the industry figures are for life cycle figures.

Senator WATERS: *What are you basing that on?*

Mr Moraza: *The emission intensity of natural gas.*

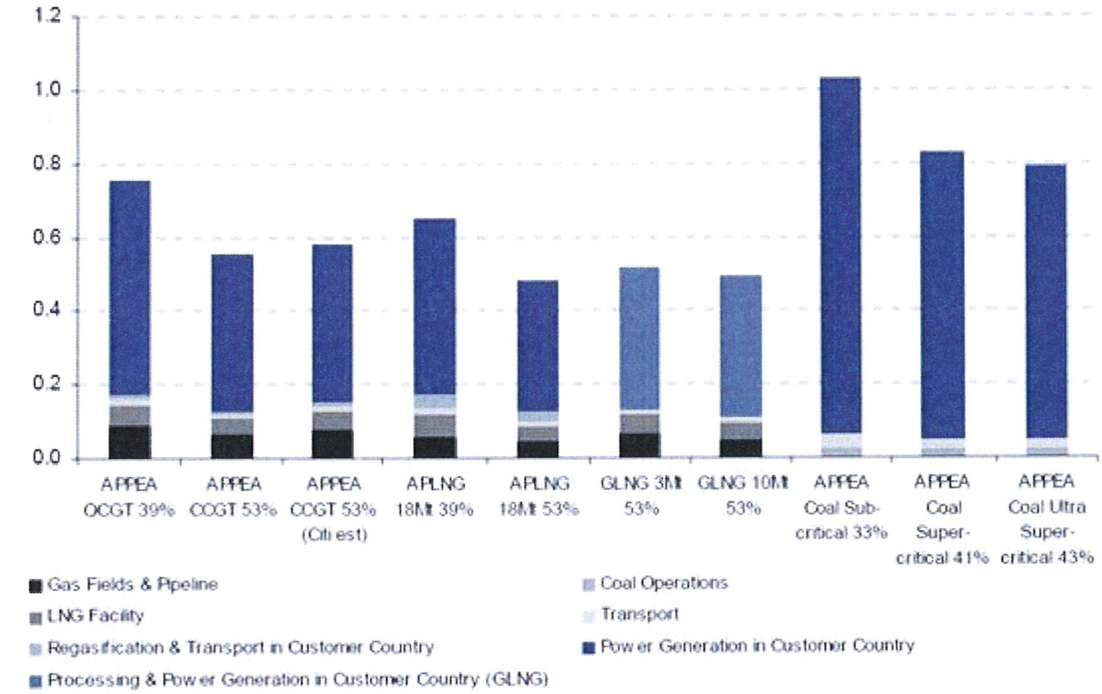
Senator WATERS: *Have you done independent reports? What are you relying on to come to those figures?*

Mr Moraza: *Yes we have an internal report and I'm happy to table that.*

AGL Response

AGL relies on external analysis from a range of sources which remain commercial in confidence. The below figure is an excerpt from a Citi Investment Research report, produced in the ordinary course for Citi's institutional clients. The paper is authored by Elaine Prior/Dale Koenders and entitled *Coal Seam Gas & Greenhouse Emissions Comparing Life Cycle Emissions for CSG / LNG vs Coal.*

Figure 1. Life Cycle GHG Emissions Comparison For Various CSG/LNG and Coal Scenarios (t CO2e/MWh)



Source: Citi Investment Research and Analysis

Question 3

Senator WATERS: *Yes, thank you, I would be very appreciative. Do you know what proportion of your wells leak?*

Mr Moraza: *None of our wells leak and I can confirm that because of the fact that at least once every year each and every well is tested with a gas-testing device.*

Senator WATERS: *Just once a year?*

Mr Moraza: *No, I think it is done more frequently but I do not have the detail of the actual frequency. I can confirm that if you wish.*

AGL Response

All AGL well site facilities are visited and inspected as part of a weekly well check by field operators. AGL commenced wellhead leak *detection* in 2010 following the introduction of the Queensland Code of Practice (CoP) annual inspection.

AGL can confirm that no wellhead leaks were detected as per our internal **Document (Reference Number DCS_GN_FO_PR_014) Gas Leak Detection & Response procedure** which states that a reportable leak is 10% Lower Flammable Limit (LFL) at 300 mm. This equates to 0.5% of methane gas in air. This is a very rigid standard which has recently been adopted by all CSG operators in Queensland and AGL has also adopted this high standard for its NSW operations.

The procedure also specifies 20% of the total number of operated CSG well site facilities to be inspected; however AGL inspects 100% of its operated CSG well site facilities.

Question 4

Senator WATERS: *Yes, thank you, I am interested in that well-checking process. Likewise pipes, do you know if your pipes are leaking and what is the process for checking?*

Mr Moraza: *Yes, we do. We have gas detection devices around the plant and each of our gas-gathering wells has a survey done where we traverse the ground with gas-detecting devices.*

Senator WATERS: *The whole length of the pipeline?*

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Mr Moraza: *Based on the testing I can confirm that there are no leaking pipes.*

Senator WATERS: *If you would not mind tabling those processes that you undertake in terms of the rigour of your testing that would be good.*

AGL Response

AGL conducts inspection annually for 100% of its gas lines. AGL reported a gas leak at a low point water trap on a low pressure polyethylene gas lines on 20 August 2010. This leak, caused by a failure in the connection fitting, was detected by the annual inspection and was immediately repaired. This was the first reportable leak found in AGL's 100 km's of gas gathering lines over the past 5 years of inspections.

This leak was reported to the New South Wales Department of Industry and Investment on the same day, 20 August 2010. The landowner was informed and the repair was completed safely.
AGL Document Reference **Number: DCS_GN_FO_PR_002 Facility Maintenance, HSE Auditing & Ongoing Compliance** is the procedure that requires AGL to conduct leak detection annually. All leak detection is undertaken by 3rd party.

ATTACHMENT B

Please find attached AGL's response to the Committee's supplementary questions of 29 August 2011. The Committee wrote

The various bans on using BTEX chemicals in fracking don't extend to banning the BTEX contained in the mechanical lubricants needed for the operation of the CSG wells. Following the reports in the media with regard to the presence of BTEX chemicals in bores at Arrow energy sites in Queensland, it would assist the committee if you could provide answers to the following questions:

1. *Are you able to advise what quantities of lubricants/operation-related BTEX is being used per well, and what is currently done to ensure these chemicals are isolated from the soil/ groundwater?*

AGL does not use BTEX additives as part of its drilling based mud or lubricants. The drilling fluids that AGL uses for its various CSG drilling operations are simplistic in nature due to the relative shallow nature of these wells. Typically, water based drill mud is used to drill CSG wells due to the compatibility of the water base with the reservoir/formation. The properties of drilling mud are designed with the following main criteria:

- Ability to maintain well control (that is, the pressure exerted by the mud on the formation is greater than the pressure within that formation to avoid any reservoir fluids flowing into the wellbore during drilling).
- Ability to effectively bring the drill cuttings to surface to avoid any drilling components becoming stuck if the cuttings build up around the equipment.
- Ability to cool and lubricate the bit.
- Ability to ensure that the hole maintains integrity throughout the drilling operation and avoid any swelling of any clays' within formations that are being drilled.

Various lubricants are used onsite to maintain all the surface equipment used to undertake the drilling of the wells. Please refer to the list of lubricants in the table below (Table 1) commonly used by the current drilling contractor to maintain their equipment. Pipe lubricant (commonly referred to as 'dope') is used to lubricate drill pipe treads, the material used is BTEX free (refer to attached MSDS and confirmation documentation from the manufacturer "BestoLife"). It is brushed onto the threads prior to making them up and running into the hole.

The quantities used are extremely low, to the point of insignificance. Any amount of pipe lubricant on the surface of any pipe is residual. The only lubricant that may be exposed to the wellbore during drilling or maintenance operations (workovers or completions) is the pipe lubricant ('dope'). This however is BTEX free and only minimal amounts are used (brushed onto the threads for protection as they are made up to run the drill pipe into the wellbore). Other lubricants are not exposed to the wellbore to present a risk of contamination.

Measures that are in place to prevent soil or groundwater contamination include;

- Lined and bunded area for storage of all oil/lubricant and additives.
- Clearly labelled containers/storage.
- MSDS onsite for handling the additives/chemicals.
- Spill kits located throughout the site.
- Double skinned tanks for fuel storage.
- Additives/chemicals are blended in a controlled environment into enclosed tanks.

- Appropriate location for storage (that is, no near any sensitive areas identified during Environmental planning).
- The shallow surface formations and aquifers (typically <120m on most CSG wells) are protected during drilling down to the coals by rated casing and specifically designed cement (see more detailed description below).
- Drill fluid volumes are monitored at all times throughout the operation, allowing fast reaction times to any fluid loss into any formations that may be observed.

Table 1: Lubricants currently in use on AGL Drilling Rig (Ensign Rig 67)

Ensign Rig 67 Chemicals / Lubricants		
Trade Name	**Supplier**	**Basic Function**
Mobil Delvac 1240 oil	Mobil	Rig powerplant and worktrain lubricants
Mobil DTE 26 oil	Mobil	
CRC Tac 2 chain lubricant	CRC	
Dow Corning 111 valve lubricant & sealant	Dow Corning	
Mobilfluid 424	Mobil	
Mobilgrease XHP222	Mobil	
Mobilube XHP 75w-90	Mobil	
Mobilube HD 85w-140	Mobil	
Mobil Delvac X 15w-40	Mobil	
Mobil Rarus SHC 1025	Mobil	
Mobilgear 600 XP 220	Mobil	
Mobil ATF	Mobil	
Bestolife Copper supreme special blend plus	Bestolife	drill pipe thread lubricant
Prizmaz Meg95 Long life engine coolant/antifreeze concentrate	Primaz	Radiator coolant additive
Septone Speedy truck wash	Septone	general equipment cleaning product
CO Contact cleaner	CRC	
Brakleen	CRC	
CRC 2-26	CRC	
Lanotec lubricant	Lanotec	wire rope lubricant
WD40	WD40	lubricant
Shellite 16225 solvent	Recochem	Hydraulic fitting cleaning agent

2. *Particularly, is the amount involved comparable/ miniscule compared to the quantities that would be used in fracking? What quantity of concentration in groundwater would you need from a leakage of these chemicals for it to be a health or environmental risk.*

As BTEX products are not used during the drilling of a well or in the fracturing of a well, any leakage which may occur does not present a health or environmental risk arising from exposure to any BTEX components. During the drilling of shallow water aquifers (referred to as the surface hole) lost circulation is typically not experienced or observed. That is, drilling fluid is typically not lost or seeping into the formation. Lost circulation would indicate that a feed rate into a potential aquifer has been established. As most aquifers drilled through have low permeability, there are typically no fluid losses seen during the drilling process.

These shallow formations and aquifers are then isolated by surface casing and cement (described below). In principle, the volume of lubricants used for drilling or maintenance operations compared to fracture fluid volumes is minute.

The concentrations of the chemicals used in the drilling mud, do not pose an environmental or health risk if they are handled, stored and disposed of correctly as per the instructions and MSDS. There is minimal chance of prolonged exposure to these chemicals/additives during the drilling process, as there is minimal handling and all fluids are correctly stored and disposed of.

3. *What mechanisms (and additional redundancies) are currently taken to protect against contamination risks?*

The drill mud can be quickly altered to address technical drilling issues including mud losses. During the drilling process if a loss of the drill mud were experienced, bentonite (organic clay) may be added to the mud which would create a filter cake and seal the area where the drilling fluid may be seeping into the aquifer. Other organic materials may also be used to plug up any higher permeability zones that the loss may be occurring in. These additives are easily and quickly added, resulting in fast response times to any situation of loss contamination However, for CSG operations, regardless of the additives used to react to various drilling scenarios, the base of the mud remains as water.

As the drilling through any beneficial aquifers occurs relatively quickly, there is minimal time for contamination. When the surface hole total depth has been completed, the hole is lined with API (American Petroleum Institute) steel casing. This casing has specific properties and is pressure rated. This steel casing is then pressure cemented in place back to surface or ground level. This forms the first two barriers to the surface formations and protects them from any potential communication between the wellbore and the formation.

As the drilling continues down to the coal seams, any shallow (beneficial or not) aquifers remain protected. Once the well is drilled to the total depth planned another steel casing (known as the production casing, also rated and manufactured to API specification in the same way surface casing has been) is pressure cemented in place. Similar to the surface hole, the cement column extends from the total depth of the well back to the surface. In effect, this means that the shallow aquifers are in fact protected by 4 barriers.

Regarding any lubricants, the only lubricant that may be exposed to the wellbore during drilling is the pipe lubricant ('dope'), this however is BTEX free and only minimal amounts are used (brushed onto the threads for protection as they are made up to run the drill pipe into the wellbore). Other lubricants are not exposed to the wellbore to present a risk of contamination.

4. *Do you have any data on the naturally-occurring levels of these chemicals in your area of operation?*

AGL is monitoring the natural water quality variations of CSG water and shallow groundwater across each of its production (Camden) and exploration areas (Gloucester, Hunter, and Galilee). These comprehensive analyses include TPH/BTEX analyses of both produced water and shallow groundwater that is sometimes used for stock/domestic/limited irrigation uses.

AGL has commissioned a CSIRO literature review study to examine the known extent of natural TPH/BTEX across Permian coal basins in Australia. Although there is little published data available, low natural concentrations do not appear unusual - the CSIRO study concludes that "*Water soluble organic compounds such as phenols and BTEX have been encountered in Australian basins, but in many cases the origin of these organic components is unclear. Some of the detected compounds such as halogenated phenols clearly have no natural origin from coal. Others such as BTEX and PAH may be derived from coal.*"

Regarding our own results to date, re BTEX compounds:

- at Camden - no BTEX compounds have been detected in CSG produced waters
- at Hunter - no BTEX compounds have been detected in CSG produced waters, however T has been detected in shallower groundwater in fractured rock (1-20 ug/L concentrations)

- at Gloucester - no BTEX compounds have been detected in CSG produced waters, however BT has been detected in shallower groundwater in fractured rock (1-40 ug/L concentrations)

- at Galilee - no BTEX compounds have been detected in CSG produced waters or in shallower groundwater in sandstone aquifers

B detections are rare and are always very low concentrations - T is more common and concentrations are higher. In AGL's experience low (natural) concentrations are mostly present in shallow aquifers sometimes used for agricultural water supplies.

Facility Maintenance, HSE Auditing & Ongoing Compliance

Document Ref Number:	DCS_GN_FO_PR_002
Revision Number:	1
Issue Date:	1 January 2011
Revision Due By:	1 January 2013
Prepared By:	Production Mgr- Gloucester
Checked By:	Gas Operations Management
Approved By:	Head of Gas Operations
Team:	All Production and Pilots

ANY DEVIATION FROM THIS PROCEDURE SHALL HAVE A RISK ASSESSMENT COMPLETED (JSEA) AND WORK CONDUCTED UNDER THE PERMIT TO WORK SYSTEM. CHANGES TO THIS PROCEDURE CAN ONLY BE APPROVED BY THE SITE MANAGER

1.0 PURPOSE

The purpose of this procedure is to provide instruction on the method of ongoing activities post commissioning to ensure a proper preventative maintenance program, HSE auditing and other statutory compliances are carried out.

2.0 SCOPE

This procedure applies to the Camden, Hunter, Gloucester, Galilee and any other future coal seam methane production pilot operations.

3.0 HEALTH, SAFETY & ENVIRONMENT

3.1 HSE RESPONSIBILITIES

- Site Manager is responsible for ensuring that systems, procedures, training and equipment are available to the employees for the following of this procedure.
- Field Supervisors are responsible for ensuring appropriate job planning is carried out and that employees are trained in this procedure and this procedure is reviewed in toolbox meetings.
- Senior Operators will assist with training and are responsible for ensuring that field staff follows this procedure and all relevant documentation has been completed.

3.2 PREJOB PLANNING

- Ensure appropriate recording keeping in place to have an effective preventative maintenance program

3.3 TOOLBOX MEETING

In toolbox meeting discuss tasks to be carried out & assign personnel to specific tasks noting the following points:

- All personnel are aware of their duties and roles and that all JSEAs are discussed, revised where required for site conditions, re-approved by job supervisor and signed off by work party

- Ensure that the general hazards associated with working outdoors are identified and control methods implemented to reduce risk scores to as low as possible
- Use of the Permit to Work System when there is substantial deviations from this Standard Operating Procedure
- Ensure correct PPE is selected and worn/used.
- Golden Rules are followed

4.0 DEFINITIONS

P&ID: Piping & Instrumentation Diagram

5.0 OVERVIEW OF ACTIVITIES

This procedure is split into the following sections

- Preventative maintenance
- Auditing
- Ongoing compliance

5.1 PREVENTATIVE MAINTENANCE

1. All control loops to go through critical function test on commissioning and in **6 monthly** intervals thereafter. The schedule of these function tests include as a minimum for recording on pilot monitoring sheet
   a. LSHH703 & LSLL703 effecting PSD1+2
   b. PI705 effecting PSHH705 & PSLL704 → PSD1+2
   c. OI731 (for PCP/ESP) effecting OAHH731 →PSD2
   d. Removal of fusible loop to effect fail close function of SDV709.
2. All control loops to go through process alarm function test on commissioning and in **6 monthly** intervals thereafter. The schedule of these function tests include as a minimum for recording on pilot monitoring sheet
   a. PT712 effecting PAH712
   b. PT714 effecting PAH714 & PAL714
   c. FI705 effecting FAH705 & FAL705
   d. OI731 (for PCP/ESP) effecting OAH731
3. All pressure & flow transmitters to be calibrated annually.
4. All pressure safety valves are to be reset to 500kPag (72.5psig) every 4 years by qualified personnel).
5. Wellhead separator is to be internally inspected every 4 years by qualified personnel (All Areas Inspections or AXS etc.)
6. All valves to be stroked/actuated every 2 months or more often if seizing up of valve is detected during routine well checks.

5.2 AUDITING POST COMMISSIONING

1. The well head production facility shall be audited within the first 6 months post commissioning
2. Ongoing audits shall be at the discretion of the Field Supervisor however no longer than 12 months between audits
3. Auditing of well head production facility shall use the same form as commissioning (Production Pilot Commissioning & Audit Form) and other AGL HSE auditing forms as required.
4. Audits are an extension of routine Well Monitoring activities and should be done by 2 or more people, one which does not operate the facility on a frequent basis.
5. Audits to review the following aspects (list below to be used as a guide but as a minimum)
   a. Site signage, security & housekeeping
   b. Emergency egress & fire fighting equipment
   c. Detection of any gas leaks from wellhead or other surface equipment (use gas detector within well compound controlled workspace and soapy water where required)
   d. Condition of wellhead facility equipment with particular note to UV radiation damage , housekeeping & vibration damage
   e. Adherence to the relative P&ID
   f. Commissioning action list items are complete

5.3 ONGOING COMPLIANCE

1. Any changes to the mechanical or instrumentation as per approved P&ID to be covered under the Process Management of Change procedure
2. Ensure that all open connections are positively isolated with hex plugs or blind flanges after testing activities.
3. Ensure well compound access is maintained and combustible materials (weeds) are not present.
4. Internal gas leak detection on all wellheads facilities with the following requirements
   a. Annual internal leak detection with gas detector held maximum 300mm from all wellhead and pipework equipment
   b. 3rd Party inspection of 100% of gathering systems and 10% of project wellhead facilities; minimum 1 wellhead per field

6.0 ASSOCIATED DOCUMENTS

Project Emergency Response plan

DCS_GN_MOC_PR_001_Management of Change (process changes)

DCS_GN_FO_FM_001_Production Pilot Well Monitoring Sheet

DCS_GN_FO_FM_003_Pilot Facility Commissioning & Audit Form

**** END OF PROCEDURE ****

7.0 COMPETENCY SIGNOFF

This procedure has been read and understood

Operator Name	Date	Supervisor Name	Date

SENATE RURAL AFFAIRS AND TRANSPORT REFERENCES COMMITTEE

Inquiry into the management of the Murray-Darling Basin

Public Hearing Tuesday, 9 August 2011

Questions Taken on Notice – Arrow Energy

11. HANSARD, PG 40

Senator EDWARDS: You heard me ask these other companies what their average payments are per well, both in the exploration and the ongoing production. Are you as a company prepared to table to this inquiry your average payment across all your wells?

Mr Faulkner: Yes, I am prepared to table that, as per the earlier request.

12. HANSARD, PG 40

Senator EDWARDS: Are you also, to be consistent, prepared to table the summary information—without identifying any of your landowners—as to the commercial arrangements that you have in dollars and cents across the number of farmers and regions?

Mr Faulkner: If your question is: am I prepared to table or share with you in an anonymous fashion what our typical ranges of settlements are for the existing production and the exploration agreements that we have in place, then the answer is yes, I am prepared to do that.

13. HANSARD, PG 41

Senator EDWARDS: Do you know how many megalitres of water storage in total that you have above ground in your operations?

Mr Gossman: No, we do not have those technical details with us today. We do know the answer to that and will be happy to provide the exact number on notice.

14. HANSARD, PG 42

Senator WATERS: Thank you very much for your evidence today. I am really looking forward to seeing your submission. As you would appreciate, it does make it a bit more difficult for us to have sufficient detail to question you appropriately. I foreshadow that we may need to call you back if there is some detail in your submission that we need to examine further. Pardon my long list of questions. I need to get across this. You mention that you have got five major gas projects or gas fields. Can you quickly give me the details of those, the locations?

Mr Knight: We have in the Bowen Basin the Moranbah gas project. The other four are clustered in the Surat Basin.

Senator WATERS: What areas are they in?

Mr Knight: They are west and south-west of Dalby. There are Kogan, Daandine, Stratheden and Tipton.

Senator WATERS: Do they all have their Queensland approvals?

Mr Knight: Their environmental authority, do you mean? Yes.

Senator WATERS: And their EPBC approvals, the Commonwealth ones? Are they issued yet?

Mr Gossman: We would have to take that on notice.

Senator WATERS: You are not sure if you have got federal approval yet? Surely you would know that.

Miss Elder: I do not think they are subject to federal approval.

Senator WATERS: So you referred and they were found not to be controlled actions?

Mr Faulkner: We will have to come back on that one, Senator.

15. HANSARD, PG 42

Senator WATERS: That is a pretty big point. I would appreciate the detail on that. Moving on to the questions I have put to the other companies, like the other players in the industry you say—not in your submission because we do not have one but on your website—that coal seam gas is one of the world's cleanest burning fuels. Obviously the reference there is to burning. Have you considered the emissions from the full life cycle of the fuel: the reverse osmosis, the liquefaction process if you are exporting and the leaking wells and pipes?

Mr Faulkner: We would say exactly the same as those before us, that the analysis has captured all potential emissions and activities that would result in emission.

Senator WATERS: And what analyses are they?

Mr Faulkner: There are industry analyses available as well as Shell based analyses, because Shell has done this sort of analysis worldwide.

Senator WATERS: So industry-based analyses. Can you be a little more specific?

Mr Faulkner: Certainly Shell has utilised independent consultants to do analyses of the emissions associated with the LNG industry.

Senator WATERS: Are you able to table that for us, please?

Mr Faulkner: Happy to.

Senator WATERS: Are there any other reports you are relying on to justify the claim about cleanliness?

Mr Faulkner: I think there are a substantial amount; I am more than happy to table.

Senator WATERS: If you could table any of those that you think go to that point, I would be most grateful.

Mr Faulkner: I will be pleased to do so.

11. HANSARD, PG 40

Senator EDWARDS: You heard me ask these other companies what their average payments are per well, both in the exploration and the ongoing production. Are you as a company prepared to table to this inquiry your average payment across all your wells?

Mr **Faulkner:** Yes, I am prepared to table that, as per the earlier request.

12. HANSARD, PG 40

Senator EDWARDS: Are you also, to be consistent, prepared to table the summary information—without identifying any of your landowners—as to the commercial arrangements that you have in dollars and cents across the number of farmers and regions?

Mr Faulkner: If your question is: am I prepared to table or share with you in an anonymous fashion what our typical ranges of settlements are for the existing production and the exploration agreements that we have in place, then the answer is yes, I am prepared to do that.

RESPONSE TO 11 AND 12:

Production

Upfront payments
Per production well $1000 - $5700 per well
Dams $170 - $5,000/ha
Management time $500 (one off payment)
Approximately $3000 for professional fees (one off payment)

Ongoing payment
Wells $500 - $2500 per well per year
Dams $150 - $330 per ha per year

Exploration
Upfront payments
Per exploration well $3,250 to $7,250
Approximately $3000 for professional fees (one off payment)

13. HANSARD, PG 41

Senator EDWARDS: Do you know how many megalitres of water storage in total that you have above ground in your operations?

Mr Gossman: No, we do not have those technical details with us today. We do know the answer o that and will be happy to provide the exact number on notice.

RESPONSE TO 13:

In our operations in the Surat Basin, which falls into boundaries of the Murray Darling Basin area, we have total surface storage of approximately 6.9GL

14. HANSARD, PG 42

Senator WATERS: Thank you very much for your evidence today. I am really looking forward to seeing your submission. As you would appreciate, it does make it a bit more difficult for us to have sufficient detail to question you appropriately. I foreshadow that we may need to call you back if there is some detail in your submission that we need to examine further. Pardon my long list of questions. I need to get across this. You mention that you have got five major gas projects or gas fields. Can you quickly give me the details of those, the locations?

Mr Knight: We have in the Bowen Basin the Moranbah gas project. The other four are clustered in the Surat Basin.

Senator WATERS: What areas are they in?

Mr Knight: They are west and south-west of Dalby. There are Kogan, Daandine, Stratheden and Tipton.

Senator WATERS: Do they all have their Queensland approval

Mr Knight: Their environmental authority, do you mean? Yes.

Senator WATERS: And their EPBC approvals, the Commonwealth ones? Are they issued yet?

Mr Gossman: We would have to take that on notice.

Senator WATERS: You are not sure if you have got federal approval yet? Surely you would know that.

Miss Elder: I do not think they are subject to federal approval.

Senator WATERS: So you referred and they were found not to be controlled actions?

Mr Faulkner: We will have to come back on that one, Senator.

RESPONSE TO 14

As advised by the Federal Department of Sustainability, Environment, Water, Population and Communities to the committee during the hearings on 9 August, our domestic gas producing projects did not trigger the EPBC, however we have obtained the necessary EPBC approvals for the Arrow Energy Dalby Expansion Project.

15. HANSARD, PG 42

Senator WATERS: That is a pretty big point. I would appreciate the detail on that. Moving on to the questions I have put to the other companies, like the other players in the industry you say—not in your submission because we do not have one but on your website—that coal seam gas is one of the world's cleanest burning fuels. Obviously the reference there is to burning. Have you considered the emissions from the full life cycle of the fuel: the reverse osmosis, the liquefaction process if you are exporting and the leaking wells and pipes?

Mr Faulkner: We would say exactly the same as those before us, that the analysis has captured all potential emissions and activities that would result in emission.

Senator WATERS: And what analyses are they?

Mr Faulkner: There are industry analyses available as well as Shell based analyses, because Shell has done this sort of analysis worldwide.

Senator WATERS: So industry-based analyses. Can you be a little more specific?

Mr Faulkner: Certainly Shell has utilised independent consultants to do analyses of the emissions associated with the LNG industry.

Senator WATERS: Are you able to table that for us, please?

Mr Faulkner: Happy to.

Senator WATERS: Are there any other reports you are relying on to justify the claim about cleanliness?

Mr Faulkner: I think there are a substantial amount; I am more than happy to table.

Senator WATERS: If you could table any of those that you think go to that point, I would be most grateful.

Mr Faulkner: I will be pleased to do so.

RESPONSE TO 15:

For a given energy source, the Well to Wheels (WtW) analysis results in the evaluation of the total environmental footprint, from primary energy extraction up to the final use by the consumer.("From the well to the wheels of a vehicle").

Following are a cross section of studies and reports which outline WtW greenhouse gas emission (GHG) analyses between gas technology and coal:

> There is up to 70% WtW GHG emissions reduction[4, 5] when new gas power generation technology is compared to older existing coal power generation. When comparing new gas technology to new coal power generation technology, there is a 50% WtW GHG emissions reduction. [1,2,3]

[1] The European Commission has published the document below

This document (see table 2.1 at page 4 [1]) depicts: ~ 50% WtW emissions reduction if modern gas and coal technology is compared (w/o CCS). ~ 60% WtW emission reduction if compared modern gas to older existing coal plants

- *http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SEC:2008:2872:FIN:EN:PDF*

[2] The figure of 40 – 50% is supported by an National Energy Technology Laboratory study for the US for comparison newest gas and coal technology. A ~60% WtW emission reduction is shown for gas compared to older coal plant (NETL is the US Department of Energy's National Energy Technology Laboratory).

- *http://www.netl.doe.gov/energy-analyses/pubs/PowerLCA_Comp_Rep.pdf*

[3] An updated slidepack on NETL study provides an additional external source for the US confirming our estimates of the CO_2 advantages of gas over coal for comparing newest technologies.

- *http://www.netl.doe.gov/energy-analyses/pubs/NG_LC_GHG_PRES_12MAY11.pdf (slide 34; May 2011 update [2])*

[4]. There is a respected 2007 paper by Pauline Jaramillo of Carnegie Mellon University, which shows ranges for U.S. gas and coal power generation. If the best gas is compared to the worst coal then the GHG emissions of gas are almost 70% lower than coal (795 vs 2518 lbCO2e/MWh).

"Comparative Life-Cycle Air Emissions of Coal, Domestic Natural Gas, LNG, and SNG for Electricity Generation", Pauline Jaramillo, 2007, *http://pubs.acs.org/doi/suppl/10.1021/es063031o* .

[5] The German Federal Environment Agency published the below graph (see link) in June 2011 which confirms 70% for old coal vs new gas.

- Old brown coal (far left) has an average efficiency of 32% and emits 1,26 kg/kWhe
- Modern CCGT plant (far right) has a 60% efficiency and emits 0,34 kg/kWhe

http://www.umweltbundesamt-daten-zur-umwelt.de/umweltdaten/public/theme.do?nodeIdent=3438

http://www.umweltbundesamt-daten-zur-umwelt.de/umweltdaten/public/document/downloadImage.do;jsessionid=B08ACC0C4B16D665B0E221AABD5479A9?ident=20764

16. HANSARD, PG 41

(Additional Question on Notice identified by Arrow Energy)

Senator EDWARDS: And what you extract. It is not about how you wordsmith your way around this issue. Your people on the ground, who are very professional and highly qualified, were not able to answer where the waste goes. If you are going to truck it out in B-doubles—6½ million tonnes was one example of the waste that is going to be produced over the next 20 years—at 34 tonnes for every B-double, that is a lot of transporting out to an approved government-regulated waste facility, which, I suspect, does not exist right now. Is that right?

Mr Gossman: On the specifics of whether such a waste facility exists or not, I would need to obtain those technical details and come back to you.

RESPONSE TO 16

There are two large government regulated (privately managed) waste facilities in SE Qld both with capacity to accept Salt waste.

The industry preference is for reuse of the salt products in industrial chemicals manufacture (such as Soda Ash and Salt).

The Waste Management industry is investigating innovative options (with CSIRO and CRC's) for storage and management of CSG waste.

SENATE RURAL AFFAIRS AND TRANSPORT REFERENCES COMMITTEE

Inquiry into the management of the Murray-Darling Basin

Public Hearing Tuesday, 9 August 2011

Questions Taken on Notice – SEWPAC

16. HANSARD, PGs 49–50

CHAIR: Right, let us get to facts. How much money have we spent on the capping and piping of the Great Artesian Basin, the savings and the re-pressurisation?

Mr Slatyer: We do not have that number with us, but we could probably get it to you before this hearing finishes.

CHAIR: Could you take that on notice.

17. HANSARD, PG 50

CHAIR: I see, but you can take that on notice as well. The CSIRO informs us, the agreement for the extraction from the Great Artesian Basin in Queensland could be between 300 and 400 gigs. I want to put that into context with what we are looking to save through the re-pressurisation of the Great Artesian Basin given, Mr Slatyer, that you understand that we really have not completed the science on the recharge of the Great Artesian Basin. Do you know when we will know what the recharge of the Great Artesian Basin is?

Mr Baker: Extensive work was done and completed in 2003 by Kellett et al for Queensland. That is considered to contain the recharge numbers for that part of the GAB. Some work was done by Habermehl which was released three years ago, I think, and does need some further work for parts of New South Wales.

CHAIR: What is the annual recharge of the Great Artesian Basin in Queensland? We will start there.

Mr Baker: I do not know the number off the top of my head.

CHAIR: What is your designation in the department?

Mr Baker: Principal Science Advisor.

CHAIR: And you do not know that?

Mr Baker: The specific recharge number, no.

CHAIR: Does anyone on the panel know? For God's sake, it is a baseline question.

Mr Baker: The recharge changes per year. It is not one number.

CHAIR: You know what I am aiming for—give me an average.

Mr Baker: I know there is one. I cannot recall what that number is off the top of my head.

CHAIR: That is embarrassing. Could you take that on notice.

Mr Baker: Certainly.

18. HANSARD, PGs 50–51

Mr Slatyer: A provision of the Water Act relevant here is section 255A, which is a provision requiring that an independent inquiry be conducted before any licensing of mining activity that could impact on the basin and the specifics of that provision describe—

CHAIR: Could you provide us with that inquiry material? They have already ticked off a lot of this stuff so there must be some material around where there has been an inquiry.

Mr Slatyer: There has been an inquiry.

CHAIR: So could you provide that inquiry outcome to this committee?

Mr Slatyer: All the inquiry material that was undertaken prior to the licensing of the Queensland operations is on the public record.

CHAIR: No, I am asking you to provide it to this committee, not for us to go and look for it somewhere.

Mr Slatyer: We can provide the URL or the document.

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Mr Slatyer: We do not have that number with us, but we could probably get it to you before this hearing finishes.

CHAIR: Could you take that on notice.

Answer: The amount of Commonwealth funding expended on/committed to the Great Artesian Basin Sustainability Initiative (1999-2000 to 2010-11) is $68 million.

17. HANSARD, PG 50

CHAIR: I see, but you can take that on notice as well. The CSIRO informs us, the agreement for the extraction from the Great Artesian Basin in Queensland could be between 300 and 400 gigs. I want to put that into context with what we are looking to save through the re-pressurisation of the Great Artesian Basin given, Mr Slatyer, that you understand that we really have not completed the science on the recharge of the Great Artesian Basin. Do you know when we will know what the recharge of the Great Artesian Basin is?

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Mr Baker: I know there is one. I cannot recall what that number is off the top of my head

CHAIR: That is embarrassing. Could you take that on notice.

Mr Baker: certainly.

Answer: The latest available estimate (published in the 2010 Great Artesian Basin Resource Study Update) is that the average recharge for the Queensland portion of the Great Artesian Basin is 823,281 ML/year.

18. HANSARD, PGs 50–51

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CHAIR: No, I am asking you to provide it to this committee, not for us to go and look for it somewhere.

Mr Slatyer: We can provide the URL or the document.

Answer: A copy of the report "Assessment of impacts of the proposed coal seam gas operations on surface and groundwater systems in the Murray-Darling Basin" can be found at http://www.environment.gov.au/epbc/notices/assessments/pubs/coal-seam-gas-operations-impacts.pdf.

Assessment of impacts of the proposed coal seam gas operations on surface and groundwater systems in the Murray-Darling Basin.

Prepared by: Professor Chris Moran, Dr Sue Vink
Centre for Water in the Minerals Industry
Sustainable Minerals Institute
The University of Queensland

Commenced: 14 October 2010
Final report: 29 November 2010

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1 Executive Summary

Context and Scope

This report was commissioned by Department of Sustainability, Environment, Water, Population and Communities on advice in a report by Geoscience Australia and Habermehl (2010) that the location and nature of current and proposed CSG activities in Queensland may trigger Section 255AA - Mitigation of unintended diversions - of the *Commonwealth Water Act 2007.* The scope of this study was to undertake a desktop study to determine the impacts of the proposed CSG operations on the connectivity of groundwater systems, surface water and groundwater flows and water quality in the Murray-Darling Basin.

Underlying the MDB, the primary target of CSG development are the seams of the Walloon Coal Measures located in the Surat/Clarence Morton Basins. In order to extract gas, the hydrostatic pressure must be reduced by pumping water from cleats in the coal seams so that gas is desorbed from the coal pores. This dewatering has been predicted to result in drawdown of water levels in overlying and underlying aquifers in the region during CSG production.

The scope of this study included rivers, streams and associated alluvial aquifers in the MDB. The spatial coverage defined as alluvium was supplied by the government and covers an area of 172,898 km^2. Assessment was restricted to CSG activities on this area. Although the Great Artesian Basin aquifers are not part of the MDB surface water management area, the impacts of dewatering of the Walloon Coal Measures on these aquifers may also impact alluvial aquifers, in particular the Condamine Alluvium. Given the spatial extent of CSG activities the primary focus of the report was the Condamine-Balonne River system and Central Condamine Alluvium. The Condamine River and the alluvium have been extensively used as water resource for agriculture. No data have been made available to examine the possible implications of hydrocarbons, eg, BTEX, in associated water. Engineering solutions for surface water storage, water treatment facilities and consequential brine management were not examined.

As of November 2010, there were 105 tenements in the MDB with a total area of 18,903 km^2. The area of alluvial extent within these tenements is 4,130 km^2. Arrow Energy and QGC have the highest proportion of alluvium in their tenements.

Assessment of impacts on MDB surface and groundwater systems

A conceptual diagram of flows and processes driving flows in the system was constructed. Imports, exports and hydraulic interactions between the system components were reviewed. Changes to the processes controlling water flows and interactions as a result of CSG activity were categorised according to the relative significance of change and/or local risk. Four interactions are identified as creating significant changes and/or local impacts. Three interactions are categorised as intermediate, six as minor and eight with no changes.

		To				
		Surface water	Groundwater			Mixed S/G
		Rivers	Alluvium	WCM	GAB	Other uses
From	Rivers		14. recharge from losing streams	15. recharge from losing streams into outcrop intake beds	16. recharge from losing streams into outcrop intake bed	12. crops, forestry, municipal
	Alluvium	17. discharge (gaining streams)	3. redistribution potentially with water quality change	7. redistribution potentially with water quality change	10. redistribution potentially with water quality change	12. crops, forestry, municipal
	WCM	1. discharge of associated water (with treatment if required)	2. reinjection of co-produced water via surface bores 5. redistribution potentially with water quality change	8. reinjection of co-produced water via surface bores	6. reinjection of co-produced water via surface bores	13. crops, forestry, municipal
	GAB	11. discharge (gaining streams)	9. redistribution potentially with water quality change	4. redistribution potentially with water quality change	redistribution potentially with water quality change	12. crops, forestry, municipal
	Other Uses	Discharge (Municipal effluent)	recharge (Drainage below root zone)		recharge (Drainage below root zone)	

Blue= significant and/or local risk; Green = intermediate changes; Yellow = minor changes; White = no change.

MDB Surface waters

The Upper Condamine River is a losing stream (water moves from the stream to recharge aquifers) under which groundwater is already significantly depleted and currently not connected to the stream. Flow is therefore unlikely to be changed by further drawdown of water level in the alluvium as a result of CSG extraction. Below the Chinchilla Weir, flow in the Condamine River may be increased by discharge of treated associated water (permeate). Modelling of stream flow by one proponent (APLNG, 2010) suggested that permeate discharge could be managed to meet environmental flow requirements and not significantly affect water quality. Permeate discharge proposed by APLNG could return on the order of 2-17 % of pre-development flows to the River. QGC and Santos have investigated disposal of treated associated water to streams as an option, currently this is not the preferred option for Santos (QGC, 2010, Vol 3 Ch. 11; Santos, 2010, Appendix Q). If more than one proponent discharges to the Condamine River, an assessment will required to determine the cumulative impact of discharges from multiple proponents. This assessment will need to consider the physical and ecological implications of changes to water quantity and quality and account for the timing of discharge.

Mitigation strategies proposed by the proponents should minimise the risk of water quality compromise to surface waters due principally to potential sediment production from construction activities (APLNG, 2010, Vol 5 Att. 22; QGC, 2010, Vol. 3 Ch.9; Santos, 2010, Section 6.5).

Alluvial Aquifer

Hydraulic connectivity between the Central Condamine Alluvium and both the Walloon Coal Measures and some GAB aquifers has been demonstrated by analysis of bore water levels and water quality data (KCB, draft in review; Hillier, 2010). Current hydraulic relationships between the alluvium and the underlying units may be altered by dewatering of the coal measures. Loss of water availability from the Central Condamine Alluvium due to direct or indirect induced leakage caused by dewatering of the coal seams could not be separately assessed due to lack of sufficiently detailed numerical model outputs and measurements from current operations. Drawdown of the water table was predicted to be ~2 m on average by one of the proponents (APLNG, 2010, Vol. 5 Att. 21). The predicted drawdown area was not expected to extend appreciably beyond the current tenement boundaries. Thus only a small area of the Central Condamine Alluvium was predicted by proponents to be affected by CSG activities.

The area of maximum drawdown of the water table (5-7m) is restricted to a small area around Miles and immediately downstream of the Chinchilla Weir (APLNG, 2010, Vol. 5 Att. 21). One water bore user was identified as likely to be affected by water table drawdown in these areas (APLNG, 2010, Vol. 5 Att. 21).

Water quality in the Central Condamine Alluvium is most likely to be affected by redistribution of water within the alluvium in response to aquifer drawdown because net movement of water is into the coal measures as a result of dewatering. Water quality in the alluvium is heterogeneous and in some areas varies considerably between bores. While the movement of water within the alluvium will not likely change water quality over a wide spatial extent it may impact individual bore holders

Reinjection of treated associated water into aquifers may lessen the impact of drawdown created by dewatering of the coal seams. A significant amount of further technical work is required to determine appropriate reinjection targets, timing and water quality/treatment needs.

Subsidence effects due to aquifer compaction were predicted by all proponents to be minor (APLNG, 2010, Vol. 5 Att. 21; QGC, 2010, Vol 3 Ch. 10; Santos, 2010, Appendix P1). However, even small changes to the land surface due to subsidence may alter overland flow paths initiating new erosion features in susceptible areas. Additionally, subsidence may also change or cause fracturing in aquifers which may alter the hydraulic connectivity.

Current predicted drawdown of the Condamine Alluvium by CSG proponents suggest that the drawdown of the alluvial aquifer due to CSG activity is likely to be considerably smaller than the drawdown that has occurred over recent decades due to water extraction for agricultural purposes. None-the-less there are significant gaps in knowledge of the system and the numerical models currently being used to assess likely impacts.

Gaps

Localised drawdown effects are likely to be significantly different to the predicted regional average drawdown owing to the spatial variability in hydraulic connectivity between the coal measures and aquifers, rates of water movement, depth of the coal seam and the thickness confining layers. No proponents have considered the effect of faulting or fractures in their models. These preferential flow features can alter local drawdown. Data on hydraulic properties is scarce. More spatially explicit hydraulic data should be collected and incorporated into models on an on-going basis.

Targeted areas for monitoring and additional data on hydraulic properties should be prioritised. Ongoing validation of model predictions of drawdown and water production will provide insights into areas requiring better characterisation and/or additional monitoring. Water production data should also include water produced during exploration because this extraction will contribute to the water deficit of the system. It is not clear whether this is currently included in water production estimates and, if so, how.

Water quality analyses, including isotope tracers and dating of waters may aid in identification of changes to local hydraulic conditions. Changes in water types and salinity in the Central Condamine Alluvium in combination with analysis of water levels have been interpreted to be indicative of hydraulic exchange between the alluvium and underlying Walloon Coal Measures and sandstone aquifers. Incorporation of geochemical analysis into a monitoring program with water level monitoring may improve understanding of changes to aquifer interactions.

An adaptive management regime, supported by significant monitoring at the individual well level, with specific management actions stated upfront to cope with predictable localised effects should provide an acceptable mechanism for ongoing system control. Transparency of information and impact reporting provides a strong adjunct to adaptive management to assist community, government and industry to maximally benefit from the full range of resource uses available in the region.

2 Purpose

Professor C. J. Moran, on behalf of the Centre for Water in the Minerals Industry, was contracted by the Department of Sustainability, Environment, Water, Population and Communities (DSEWPAC) to conduct an independent expert study in relation to development of coal seam gas (CSG) industry in Queensland and potential for impacts on the Murray Darling Basin water flows. The need for this study was based on advice in a report by Geoscience Australia and Habermehl (2010) that the location and nature of current and proposed CSG activities in Queensland may trigger Section 255AA - Mitigation of unintended diversions - of the *Commonwealth Water Act 2007.*

Section 255AA of the Water Act 2007 states that:

"Prior to licences being granted for subsidence mining operations on floodplains that have underlying groundwater systems forming part of the Murray-Darling system inflows, an independent expert study must be undertaken to determine the impacts of the proposed mining operations on the connectivity of groundwater systems, surface water and groundwater flows and water quality".

2.1 Scope of work

The scope of this study was to determine the impacts of the proposed CSG operations on the connectivity of groundwater systems, surface water and groundwater flows and water quality in the Murray-Darling Basin. Terms of References for the study are given in Appendix 1.

The study scope did not include analysis of engineering structures or solutions such as storage pond design, well completion techniques or brine management strategies.

2.2 This report

This report is the final deliverable for the project. The information assessed in this report was predominantly obtained from the Environmental Impact Statement (EIS) documents of three CSG proponents (APLNG, Santos and QGC), as well as a report prepared by Geoscience Australia (GA) (GA and Habermehl, 2010). Published literature and reports obtained from Queensland Department of Environment and Resource Management (DERM) were also reviewed. Technical data and information was requested from the CSG proponents and science and data agencies within the Queensland and Commonwealth governments. To date, only data downloaded from the Queensland Government website (QPED) has been obtained. No information has been obtained from Arrow Energy Ltd.

Discussion of water quality is largely restricted in this report to consider salinity and major anion/cation composition. While there is a small amount of dissolved heavy metal and nutrient data reported in the proponent EIS documents it was not considered sufficiently spatially or temporally detailed to form an assessment. Analytical results for dissolved organic compounds (including BTEX) were not available for this report.

3 Background and Context

The preconditions for triggering the provisions of Section 255AA of the *Commonwealth Water Act (2007)* are that the activity must be:

- a subsidence mining operation;
- occur on a floodplain; and
- have potential to impact on Murray-Darling Basin (MDB) system inflows.

Based on advice in a report by Geoscience Australia (GA and Habermehl 2010), the location and nature of current proposed coal seam gas (CSG) developments in Queensland mean that the above preconditions may potentially be met and it is therefore prudent to commission an independent expert study in accordance with s255AA of the Water Act 2007 in order to inform government decision makers prior to approvals being granted. The independent expert sought advice from the Joint Liaison Committee for definition of the floodplain. A map of the extent of alluvial sediment in the Queensland Murray Darling Basin was supplied for this purpose.

Under the *Commonwealth Water ACT 2007* this study is restricted to analysis and evaluation of CSG activities that are physically occurring on the floodplain and therefore does not consider activities in CSG tenements that are not overlying alluvium. Figure 1 shows the extent of alluvium in the Murray Darling Basin and location of CSG tenements. The total area of alluvium shown in Figure 1 is 172,898 km^2. Production schedules, proposed well locations during development of the fields, estimates of water production for individual wells and detailed hydrological modelling were not available for this report. Consequently the smallest spatial unit available for the assessment presented in this report is the tenement. Thus if a tenement intersected the alluvial extent shown in Figure 1, it was considered to be part of this assessment.

Within the study region, there are 13 companies undertaking CSG activities (including exploration, extraction and processing activities). The majority of tenements are to be developed by four proponents: Santos, BG/QGC, APLNG and Arrow Energy. Both Santos and QGC have had their developments approved with a significant number of conditions imposed by both State and Commonwealth Governments. The APLNG Environmental Impact Statement is currently under review by the Queensland State Government. The number and area of tenements intersecting alluvium are summarised in Table 1. As of November 2010, there were 105 tenements in the MDB with a total area of 18,903 km^2. The area of alluvial extent within these tenements is 4,130 km^2. Arrow Energy and QGC have the highest proportion of alluvium in their tenements. There is 1,646 km^2 of the Condamine Alluvium under CSG tenement.

Within the study region, there are currently 1,272 CSG wells. Figure 2 shows the current distribution of CSG production wells in the study area (QPED, October 2010). It can be clearly seen that current production is concentrated in well defined areas. Each proponent is proposing that ~10,000 wells will be staged in operations over the lifetime of their projects (~ 40 years). Most CSG activity is occurring on the Northwestern – Western margin of the Condamine Alluvium (Figure 2).

The primary areas under consideration are: Santos tenements in the vicinity of Roma, the central and south-east development areas under development by QGC, all APLNG tenements and all Arrow Energy tenements. It should be noted that no information was available regarding Arrow Energy CSG developments.

In addition, only considering activities that occur on alluvium may represent a significant gap in this analysis. CSG activities located outside of the alluvium may indirectly impact on MDB alluvium and surface water flows by changing hydraulic conditions in surrounding aquifers which may change aquifer connectivity.

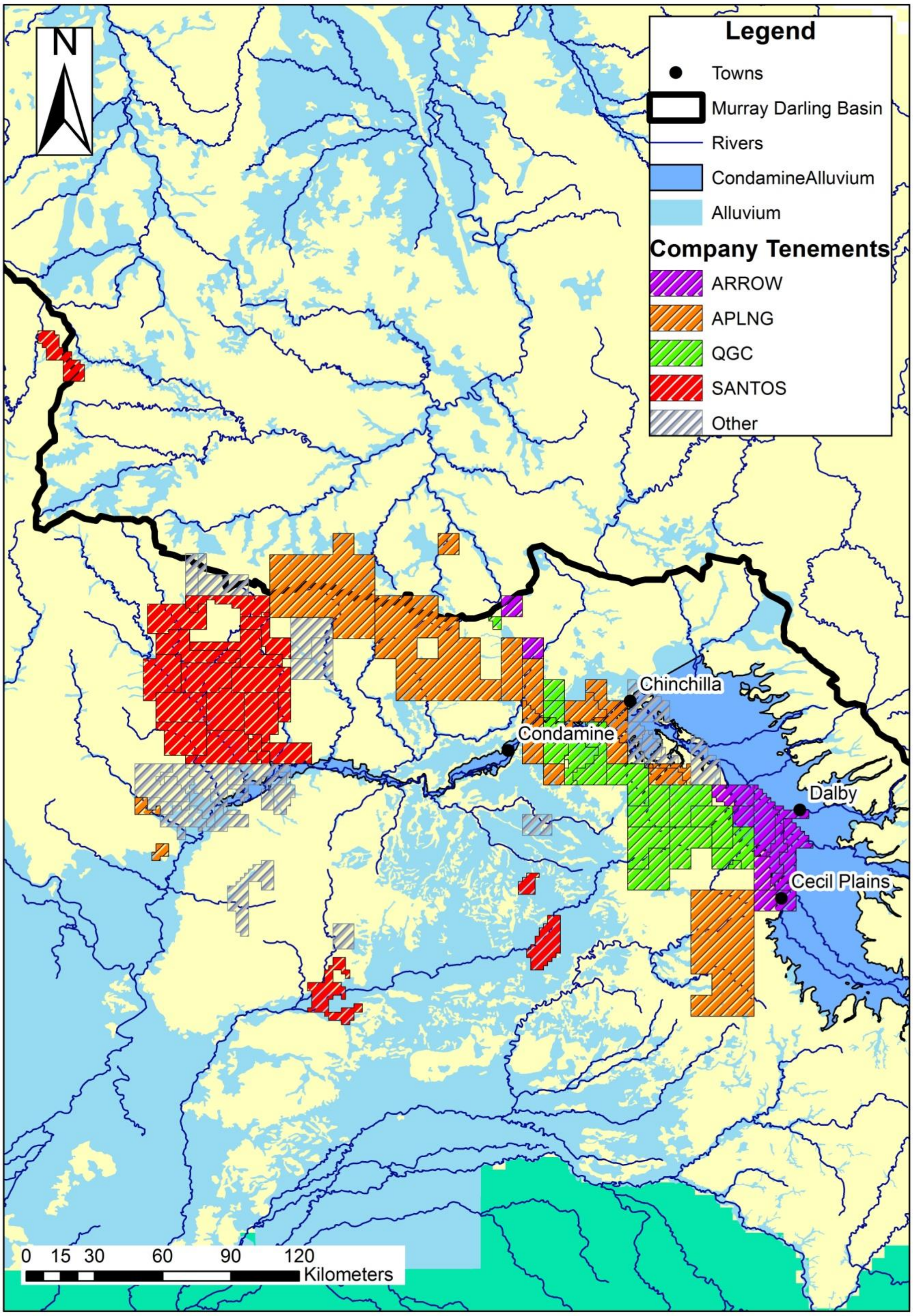

Figure 1. Alluvial extent and CSG tenements.

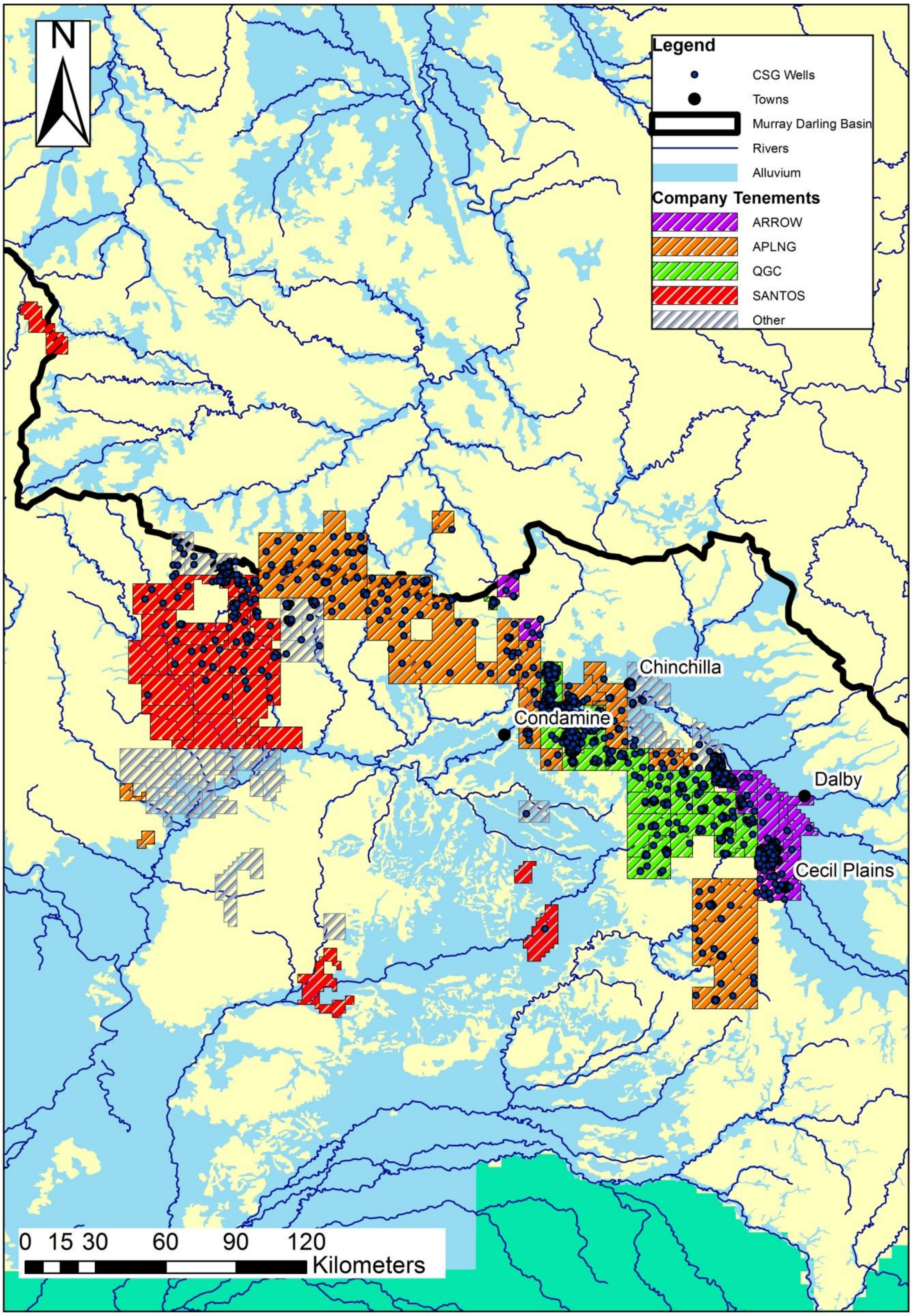

Figure 2. Location of CSG wells in the study area.

Table 1. Summary of CSG tenements within the boundary of the MBD and area of alluvium in the tenements.

Company	Number of Tenements	Area of Tenements (km^2)	Alluvium area in tenements (km^2)
ANGARI PTY LIMITED	2	153	16
ARROW ENERGY	8	1240	819
AUSTRALIA PACIFIC LNG PTY LTD	17	5802	863
AUSTRALIAN CBM PTY LTD	3	667	425
BNG (SURAT) PTY LTD	2	312	4
BRISBANE PETROLEUM LTD	3	357	0
BRONCO ENERGY PTY LIMITED	2	465	46
MOSAIC OIL NL	3	102	24
MOSAIC OIL QLD PTY LIMITED	8	874	30
OIL INVESTMENTS PTY LIMITED	9	1266	415
QGC PTY LIMITED	21	2786	651
SANTOS QNT PTY LTD	26	4771	752
SOUTHERN CROSS PETROLEUM & EXPLORATION PTY LTD	1	108	85
Total	105	18,903	4,130

3.1 Coal Seam Gas Development

Current approval of significant expansion of CSG development within the MDB has been given for two companies located in the Surat Basin. Further expansion is projected in order to supply gas to Liquefied Natural Gas (LNG) plants to be located in Gladstone. The primary target of CSG development are the seams of the Walloon Coal Measures located in the Surat/Clarence Morton Basins. The Walloon Coal Measures extend from surface outcrops to as deep as 1600 m below ground level, with the area being targeted for CSG primarily being where the coal is between 250m and 600m below ground level. The Walloon Coal Measures is composed of at least three coal seams (composed of 9 coal intervals) of variable thickness. In contrast to the relatively contiguous coal seams of the Bowen Basin, the seams of the Walloon Coal measures typically present as discontinuous relatively thin seams (Draper and Boreham, 2006). The coal seams are embedded in mudstone, siltstone and sandstones.

In order to extract gas, the hydrostatic pressure must be reduced by pumping water from cleats in the coal seams so that gas is desorbed from the coal pores. In the Surat Basin, CGS proponents typically reduce the hydraulic head to within 35 m of the upper coal seam. This groundwater drawdown has been predicted to result in drawdown from overlying and underlying aquifers in the region during CSG production. The spatial extent of the drawdown is expected to extend beyond the boundary of the gas field production area and recovery of the groundwater systems is expected to extend significantly beyond cessation of CSG operations.

Water quality in the Walloon Coal Measures is variable, reflecting the depositional environment, depth of burial and coal type. In general, waters are slightly brackish to brackish, although some bores in the Walloon Coal measures yield freshwater (i.e. Total Dissolved Solids (TDS) < 1000 mg/L). Salinity (measured as TDS) ranges between 950 -12,894 mg/L, with an average values across the Surat Basin of 4,494 mg/L. Average composition is compared to the only information available from the alluvium, specifically from the Central Condamine Alluvium, in Table 5.

Coal seam water from the Walloon Coal Measures is typically Na-Cl or Na-HCO3-Cl. Water type varies spatially. QGC state that saltier Na-Cl coal seam waters dominate in the north-west area of their tenements, while fresher Na-HCO3 waters occur in the Southeast area (QGC, 2010). Water samples from the Walloon Coal Measures in the area underlying the Central Condamine Alluvium also show spatial variation. KCB (draft in review) showed that Na-Cl type waters predominantly occur in the Walloon Coal Measures underlying the western margin of the alluvium, whereas Na-HCO3-Cl and to a lesser extent Na-Cl-HCO3 dominate to the east.

4 Murray Darling Basin

4.1 Setting

The MDB is the catchment for the Murray and Darling rivers and tributaries. The region has an approximate area of 1,060,000 km^2, occupying approximately 14% of Australia's total area, and spanning across the States of Queensland, New South Wales, Victoria, South Australia, and the Australian Capital Territory (Figure 5).

The region provides important economic, social and ecological values for the country. It is Australia's most important agricultural area, supporting 65% of Australia's irrigated agricultural land, it produces over one-third of Australia's food supply and generates 39% of the national income derived from agricultural production. The region is home to more than 2 million people and supports an additional 1.5 million people reliant on the MDB water resources. Important environmental assets of the region include wetlands of national significance (as listed under the Ramsar Convention) and other groundwater dependent ecosystems.

This scope of this study included rivers, streams and associated alluvial aquifers in the MDB. Although the Great Artesian Basin aquifers are not part of the MDB surface water management area, the impacts of dewatering of the Walloon Coal Measures on these aquifers may also impact surface waters and alluvial aquifers, in particular the Condamine River and Alluvium. The hydrogeology of the area, and particularly the Great Artesian Basin, has been described extensively and a simplified stratigraphic sequence is presented in Figure 3. In general the sandstone sequences are confined aquifers. The confining units (aquitards) are generally siltstone and mudstones and include the Walloon Coal Measures. The units considered at greatest risk from CSG development are the Hutton (the Hutton sandstone grades into the Marburg sandstone in the Clarence Moreton Basin) and Precipice Aquifers located below the Walloon Coal Measures and the Springbok and Gubberamunda Aquifers located above the coal measures. There is also considerable concern regarding possible impacts on the Condamine Alluvium.

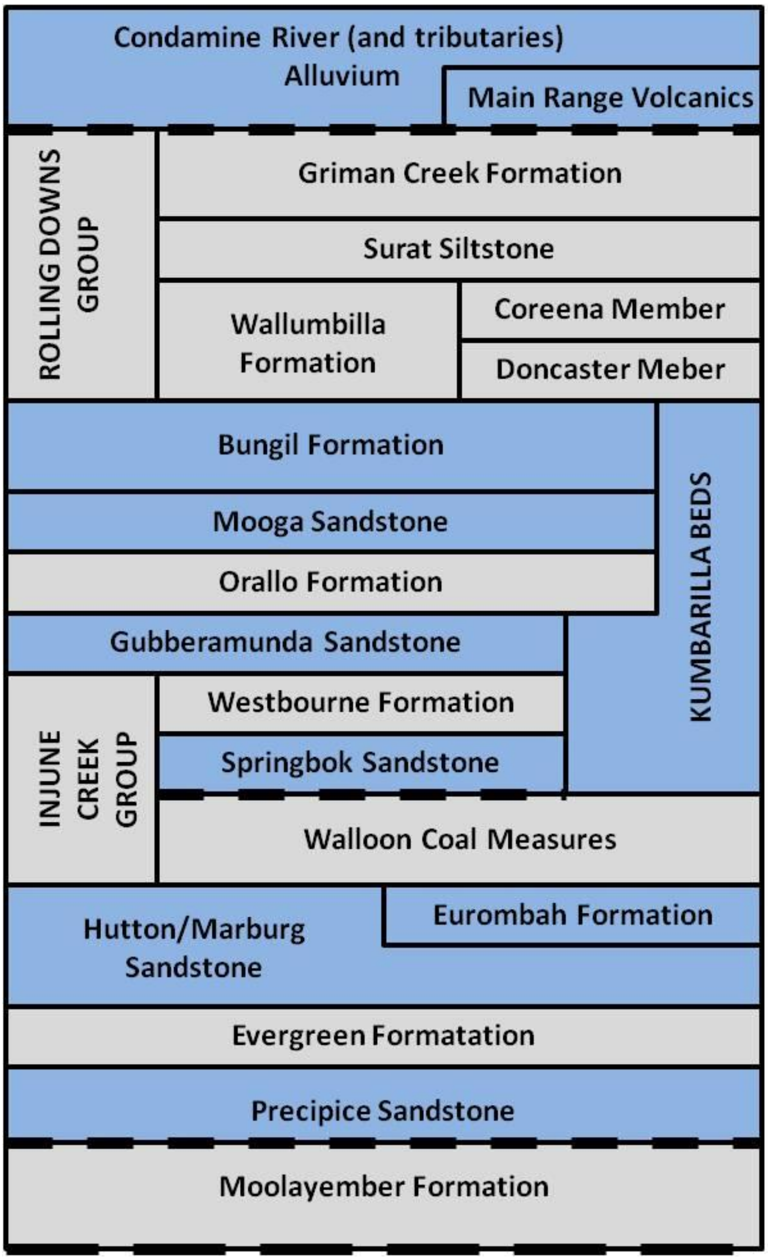

Figure 3. Simplified stratigraphic sequence and corresponding aquifers (blue) and confining units (grey) in the study area (after Radke et al., 2000; Draper and Boreham, 2006).

5 Conceptual model of flows and processes

Figure 4 is a conceptual model of the flows in the system. Exchanges between aquifers and surface waters are presented. At the top of the figure the pre-CSG flows are represented. Below, CSG direct drivers are shown. Water is extracted from the Walloons to reduce pressure to release gas from the coal. The water is drawn to the surface and then may be:

- Discharged to streams after treatment;
- Used in forestry, cropping, municipal and other beneficial purposes (with consequential redistribution of deep drainage and discharge of effluent); and
- Recharged into aquifers via reinjection bores.

Water can move between aquifers when a gradient of total potential (osmotic, pressure and capillary) exists. Pressure gradients exist where connected aquifers have different heads of water. This occurs because the water flows are more-or-less separate with respect to water sources into them. These pressures, and the hydraulic conductivity and juxtaposition of layers determines the actual water flows in space and time between strata. Water flows represented by the arrows may not be the same during dewatering and re-wetting. The term hysteresis[1] is used to describe this. Hysteresis is important in the design and optimisation of the relationship between water extraction and reinjection.

Water extracted outside the area of CSG extraction overlying the alluvium could be introduced to the alluvium by reinjection via bores and by regulated discharge to local waterways.

Figure 4 also indicates that each of the water system components has imports and exports. Exports from the Walloon coal measures resulting in additional beneficial use of water at the surface (with brine management) and potentially abstractions for licensed use are the only import/export fluxes affected by CSG. Table 2 is a tabulation of the conceptual model. Four categories of water movement process are used: Recharge, Discharge, Re-distribution and Other beneficial uses.

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[1] Hysteresis is the term used to describe the well known phenomenon that porous materials do not wet and dry in the same way. There is evidence that dewatering can alter the pore structure of aquifers and coal potentially increasing the magnitude of hysteresis. Surface subsidence is one expression of loss of void space in the system.

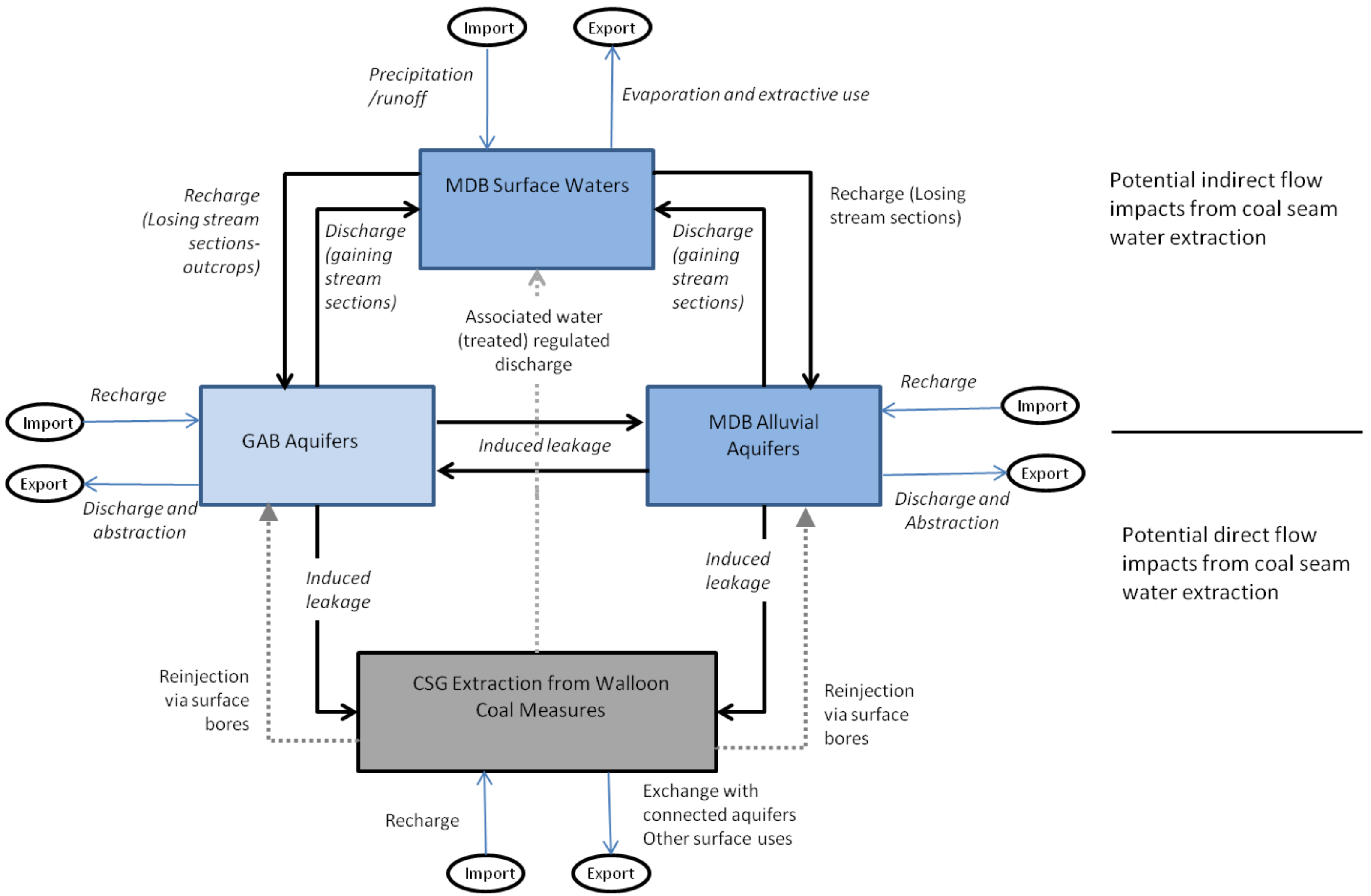

Figure 4. Conceptual diagram of the water balance for surface and groundwaters in the study. Arrows represent water fluxes. Dotted arrows represent input of treated coal seam water discharged to surface waters or re-injected into aquifers.

Table 2. Processes of water recharge, discharge and redistribution under pre- and post-CSG.

		To				
		Surface water	Groundwater			Mixed S/G
		Rivers	MDB Alluvium	WCM	GAB	Other Beneficial Uses
From	Rivers		recharge from losing streams	recharge from losing streams into outcrop intake beds	recharge from losing streams into outcrop intake beds	crops, forestry, municipal
	MDB Alluvium	discharge (gaining streams)	redistribution potentially with water quality change	redistribution potentially with water quality change	redistribution potentially with water quality change	crops, forestry, municipal
	WCM	discharge of associated water (with treatment if required)	reinjection of co-produced water via surface bores redistribution potentially with water quality change	reinjection of co-produced water via surface bores	reinjection of co-produced water via surface bores redistribution potentially with water quality change	crops, forestry, municipal
	GAB	discharge (gaining streams)	redistribution potentially with water quality change	redistribution potentially with water quality change	redistribution potentially with water quality change	crops, forestry, municipal
	Other Beneficial Uses	Discharge (Municipal effluent)	recharge (Drainage below root zone)		recharge (Drainage below root zone)	

5.1 MDB Surface waters

The major surface water systems of the Queensland MDB are the Condamine - Balonne River system and the Border Rivers (Figure 5). As can be seen in Figure 5, development of coal seam gas industry is predominantly occurring in the Condamine-Balonne Catchment with tenements distributed across the catchment. Six tenements intersect the headwaters of streams in the Border Rivers catchment.

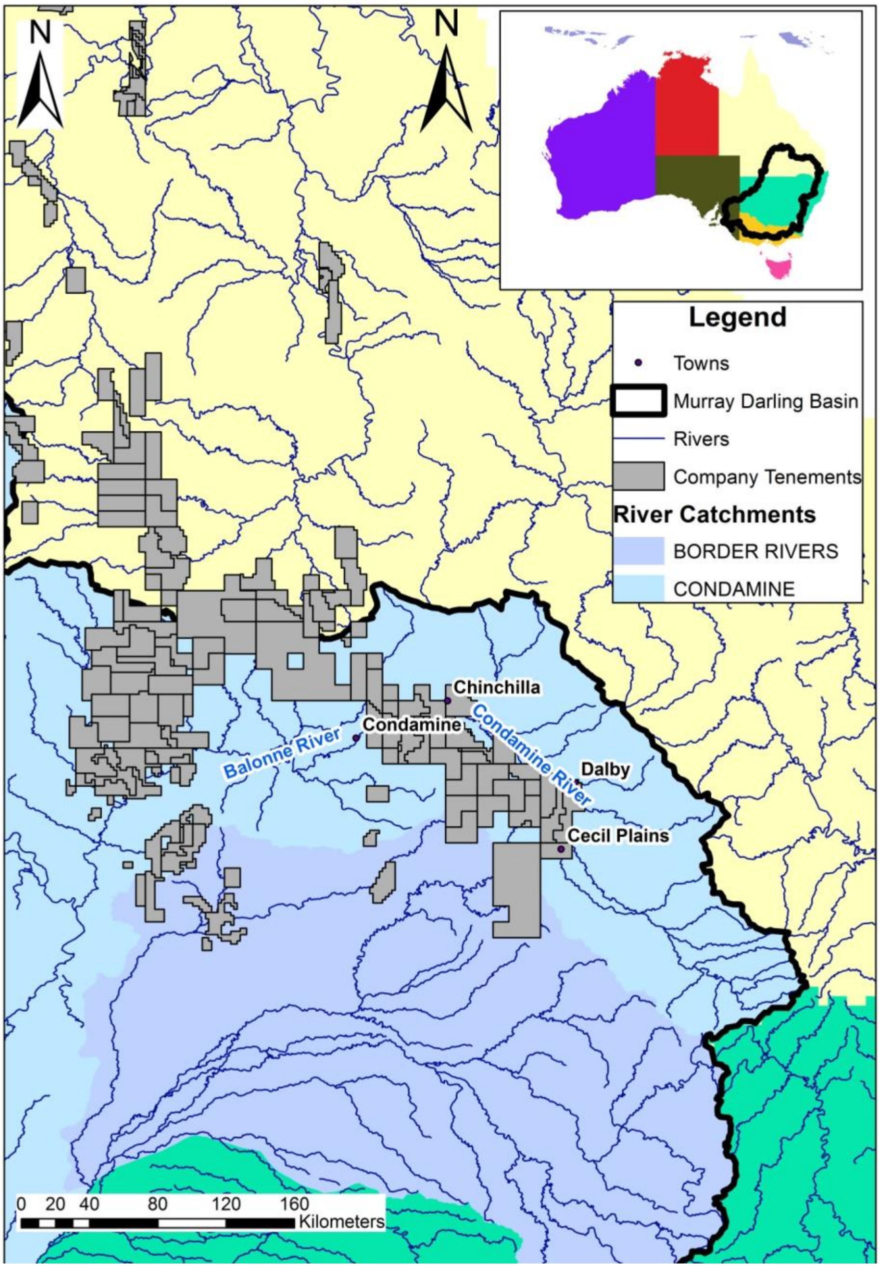

Figure 5. Location of the Murray Darling Basin (inset), major catchments and coal seam gas tenements.

All proponents have rivers or streams flowing through some tenements. APLNG, QGC and Arrow Energy all have tenements that intersect the Condamine River. Bungil Creek, Wallumbilla Creek and Yuleba Creek, within the Condamine-Balonne Catchment, flow across Santos tenements located near Roma.

5.1.1 Imports

Streams in the Condamine -Balonne catchment are ephemeral, with flow generally occurring during summer between December – February. Streamflow is rainfall/runoff dependent. Average annual rainfall is 514 mm (CSIRO, 2008) for the region with average annual rainfall of 635 mm and 634 mm at Miles and Dalby respectively. Annual stream flow is highly variable due to long term variations in rainfall.

5.1.2 Exports

Average annual evaporation is 2.5 - 3 times greater than average rainfall. Average annual evaporation at Miles is 1740 mm and Dalby is 1992 mm.

Total water entitlements for the Condamine – Balonne system is 729,000 ML/y. Water entitlements from the Condamine River, primarily for agriculture, are on the order of 240,000 ML/y or ~ 54% of the pre-development flow measured at the Chinchilla Weir (DERM, pers comm.).

5.1.3 Hydraulic Interactions with Groundwater

Surface water-groundwater interactions are often complex and difficult to quantify, particularly in areas where stream flow is ephemeral or intermittent. Where stream baseflow is derived from groundwater the stream is classified as a gaining stream and conversely where stream flow is lost to the groundwater the stream is classified as a losing stream. Connectivity between streams of the Condamine-Balonne and the alluvial aquifers is spatially and temporally variable.

5.1.3.1 Interactions with Alluvial Aquifer

CSIRO (2008) classified the Condamine River to be a high to medium losing stream upstream of Chinchilla Weir and as low - medium gaining stream downstream of the weir. KCB (draft in review) recently reviewed the conceptualisation of the Central Condamine Alluvium and also concluded that the Condamine River upstream of the Chinchilla Weir was a losing stream. These authors suggested that "the zone of hydraulic disconnection between surface water and groundwater (maximum rate of conceptual stream loss) is considered to extend further downstream than indicated by CSIRO (2008), with possible connectivity being apparent only downstream of the Tipton (bore) Line" (KCB, draft in review p 33). The Tipton bore line is in the vicinity of current CSG leases operated by Arrow Energy. In this upstream reach, stream loss during flow periods will be governed by the hydraulic conductivity of the stream bed and unsaturated zone of the aquifer rather than the difference in hydraulic head between the stream and groundwater. However, KCB (draft in review) stress that the mechanisms governing stream loss to the alluvium are complex and at least five processes may be occurring depending on river flow conditions. Preliminary modelling by QGC estimated that at most 17 % of flow in the Condamine River downstream of Dalby may be baseflow contributed by groundwater. This baseflow was only apparent during periods of heavy rainfall (QGC, 2010, Vol. 3 Ch. 10) and may be reflecting short-term storage in stream banks during high flows returning to the river during flow recession (KCB, draft in review).

The Condamine River, immediately downstream of the Chinchilla Weir was classified as a low gaining stream by CSIRO (2008) (Figure 6). Advice from the Queensland Government provided for this report is that there is unlikely to be any measureable baseflow contributed from groundwater in this reach due to the limited extent of the alluvium and evidence from IQQM stream flow modelling.

5.1.3.2 Connectivity to GAB Aquifers

AGE (2005) using depth to water table mapping for GAB aquifers and results from Kellett et al. (2003) determined that some river reaches in the area under CSG development could potentially receive baseflow from GAB aquifers. Of particular interest are reaches of the Condamine River (near Condamine), Dogwood Creek, Wambo Creek, Moonie River which were identified by Kellett et al., (2003) as being fed from the Hooray Sandstone equivalents (Gubberamunda and Mooga sandstone in the Surat Basin). Also, a reach of both the Weir River and Western Creek could be fed from the Kumbarilla Beds (AGE, 2005). No estimates of the baseflow contribution to these streams from GAB aquifers has been made.

Advice from the Queensland Government provided for this study is that there is no evidence of connectivity between surface waters and GAB aquifers in the study area.

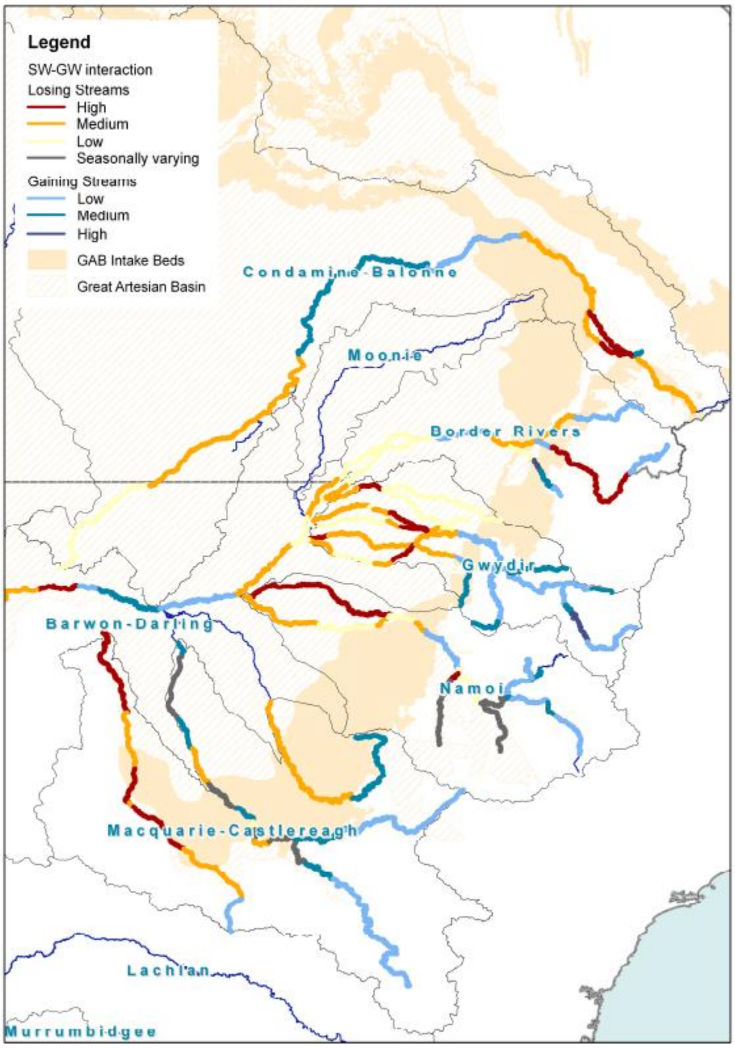

Figure 6. Gaining and losing stream reaches of the MDB. Taken from CSIRO (2008).

5.1.4 Water quality

Surface waters of the Condamine-Balonne system typically have low salinity, slightly alkaline pH and high turbidity. Statistics for stations on the upper Condamine River and four creeks in the Roma area are summarised in Table 3. The two Condamine River stations are located near Cecil Plains (station 422316A) and Dalby (Station 422333A) (ANRA, 2009; Santos, 2010; QGC, 2010; APLNG, 2010). Surface waters of the upper Condamine River have salinity between 200 – 1800 μS /cm. Median salinity is higher at the downstream station. Turbidity is highly variable. Surface waters downstream of Chinchilla are considered to be poor quality with high turbidity.

Water quality of surface water in the creeks near Roma are similarly variable although appear to have lower median salinities. Turbidity is also high and varies with rainfall and stream flow. Turbidity generally increases downstream (QMDC, 2010; Santos, 2010).

Table 3. Summary of water quality parameters for two stations located on the Condamine River and three stations in streams located in the Santos development near Roma (ANRA, 2010; QMDC, 2010; Santos, 2010; APLNG, 2010; QGC, 2010)

			Condamine River		Bungle Creek @Tabers	Yuleba Creek @Forestry	Balonne River@ Surat
			422316A	**422333A**			
Salinity	(µS/cm)	median	310	586	160	164	95
		min	188	226	66	72	74
		max	654	1350	1890	455	154
pH		median	7.72	7.78	7.5	7.4	6.9
		min	7.1	7.28	6.6	6.6	6.8
		max	8.6	9.2	8.5	7.9	7.2
Turbidity	(mg/L)	median	82.2	133	96.5	107	857
		min	0.9	0.5	5	10	148
		max	898	1390	1500	360	2810

5.2 MDB Alluvial Aquifers

The primary alluvial aquifer in the study area is the Central Condamine Alluvium and alluvium associated with tributaries of the Condamine-Balonne River system. The Central Condamine Alluvium extends across an area between Chinchilla, Dalby and Millmerran and is shown in Figure 1. The alluvium is heavily utilised as a water resource for agriculture and water abstraction has significantly impacted water levels in the alluvium. The conceptualisation and water balance of the Condamine alluvium was recently reviewed by KCB (draft in review). The alluvium is up to 100m thick in the thalweg located slightly to the east of the current river channel (KCB, draft in review). On average the alluvium is 20 - 30 m thick. Thick alluvial sediments are also associated with the Balonne River system. These alluvial sediments are Tertiary age and contain poor quality groundwater except in the area of the Maranoa and Balonne River junction.

The Central Condamine Alluvial basement sequences vary depending on how deeply the river channel eroded into the underlying sequences shown in Figure 3. In some areas the river cut through to the underlying Walloon Coal Measures providing opportunity for direct hydraulic connectivity between these units.

The water balance for the Central Condamine Alluvium presented in KCB (draft in review) is shown in Table 4.

5.2.1 Imports

Recharge of the alluvial aquifer is predominantly through rainfall and stream flow with smaller inflows to the Central Condamine Alluvium from bedrock and tributaries in the east (Table 4).

5.2.2 Exports

The largest outflow from the Alluvium is via groundwater abstraction. The current water deficit in the alluvium is estimated to be between 30,351 – 41,954 ML/y (KCB, draft in review). Groundwater flow in the alluvium is generally in the downstream direction (i.e. North-Westward). There has been significant drawdown of the watertable for agriculture in some areas (KCB draft in review). The area most affected by agricultural groundwater extraction is the area between Dalby and Macalister and to the east of Cecil Plains. Local internal groundwater flow developed in this area between 1990 – 2000 in response to groundwater abstraction resulting in drawdown of the aquifer water level by around 5-30 m (KCB, draft in review, p 40). This area lies adjacent to the current extent of CSG tenements located on the Western margin of the Central Condamine Alluvium.

5.2.3 Hydraulic interactions

5.2.3.1 Surface waters

Connectivity with surface waters was discussed above in Section 5.1.3.1. The alluvium is generally hydraulically disconnected from surface waters upstream of the Chinchilla Weir. Downstream of the weir there is not likely to be a measurable contribution of groundwater to Condamine River baseflow.

Table 4. Water balance for the Central Condamine Alluvium (from KCB, draft in review).

	Lane (1979)	Huxley (1982)	SKM (2002)	SKM (2008)	KCB (draft in review)
Area (km^2):	4910	7700	3953	3953	4463
	ML/annum				
Imports:					
Streambed Recharge	12170 - 20810	19085-32634	15500 - 20239	11539	11158 - 22761
Bedrock contributions from the East	3610 - 3760	1130	1140	1604	1500
Bedrock contributions from the West		520	267	249	500
Tributary Alluvium Contributions from the East	280 - 410	1470	250	250	705
Flux into Alluvium from Upstream	760	-			316
Rainfall Recharge	-	-	1%[1]	0.10%[1]	10265
Irrigation Deep Drainage	-	-	-	-	446.3
Flood Recharge	-	-	-	-	-
Meander Channels Seepage	-	2000	2100	-	-
Exports:					
Groundwater abstraction (unmetered)	-	-	-	-	20200
Groundwater Abstraction	58903	61403	50000	50000	46400
Basement (bedrock) Leakage	8050	-	1649	0	0
Flux Out of Alluvium at Downstream	645	-	16467	12568	244.5
Evapo-transpiration	-	-	-	-	-

[1] presented as % rainfall.

5.2.3.2 Walloon Coal Measures and GAB Aquifers

The basement of the alluvium includes Marburg (Hutton) Sandstone, Walloon Coal Measures and the Springbok Sandstone. Historically, the Condamine River has incised valleys into the Springbok Sandstone (Kumbarilla Beds) and the Walloon Coal Measures (Hillier, 2010; KCB, draft in review). These valleys have subsequently been in-filled with what is today termed the Condamine Alluvium. Therefore water can move into and out of the alluvium depending on the hydraulic gradient. The details of the hydraulic conductivity and bedding of the alluvium also determines the rates and quantities of water movement. Given that these historical processes are highly spatially variable and the beds being incised were not homogeneous a great deal of local variation exists in both the connectivity and the potential for water exchange between strata across the alluvium. This explains why different studies in different parts of the Central Condamine Alluvium have reached what appear to be conflicting conclusions regarding water exchange. A brief summary follows.

Generally, water levels in the alluvium reflect basement topography. Discrete areas of basement highs have been mapped by KCB (draft in review) and were also noted by Huxley (1982) (Figure 7). Huxley (1982) interpreted the areas of basement highs to be intersection with the Walloon Coal Measures.

Hydraulic connection of the alluvium with the Walloon Coal Measures and other aquifers has been inferred from analysis of groundwater level records by Hillier (2010) and more recently by KCB (draft in review). KCB (draft in review) concluded that there was a general slight gradient driving water from the alluvium to Walloon Coal Measures. The strength of the gradient was variable, in the upstream section of the alluvium (the Southern area) there is a negligible or only slightly pressure gradient driving water from the alluvium in to the Walloons. Further north, around Dalby, water levels in the Walloon Coal Measures were similar to water levels in the alluvium implying little net water movement. There is evidence of variation around this general picture. KCB (draft in review) provided an example where water levels in the Walloon Coal Measures were up to 25 m lower than the alluvium. CSG dewatering of the Walloon Coal Measures will increase this gradient. Implications for water movement will depend on the hydraulic properties at the interface between the alluvium and Walloon Coal Measures. On the other hand, Hillier (2010) found alluvium water levels to be on the order of 10-15 m below the water level of bores in the Walloon Coal Measures in the area just south of Dalby and east to Oakey. Dewatering of the Walloon Coal Measures may neutralise or reverse this gradient. This is a possible driver for local re-distribution of water within the alluvium. For example water quality may be observed to change in bores from local re-distribution within the alluvium (see section 6.2.2).

Connectivity of the Condamine Alluvium with the Marburg sequence is similarly variable but generally there appears to be neutral to moderately upward hydraulic gradient (KCB, draft in review).

A detailed assessment of the sequences underlying the alluvium is currently being undertaken for DERM (Healthy Headwaters Program), results were not available for this report. Adaptive management will require this information to respond to local effects. For example, with this information it will be easier to target priority areas for reinjection into the Walloon Coal Measures to minimise the impact of dewatering on flows from the alluvium. This may be particularly important if action is taken to reduce abstraction to restore water levels in the alluvium.

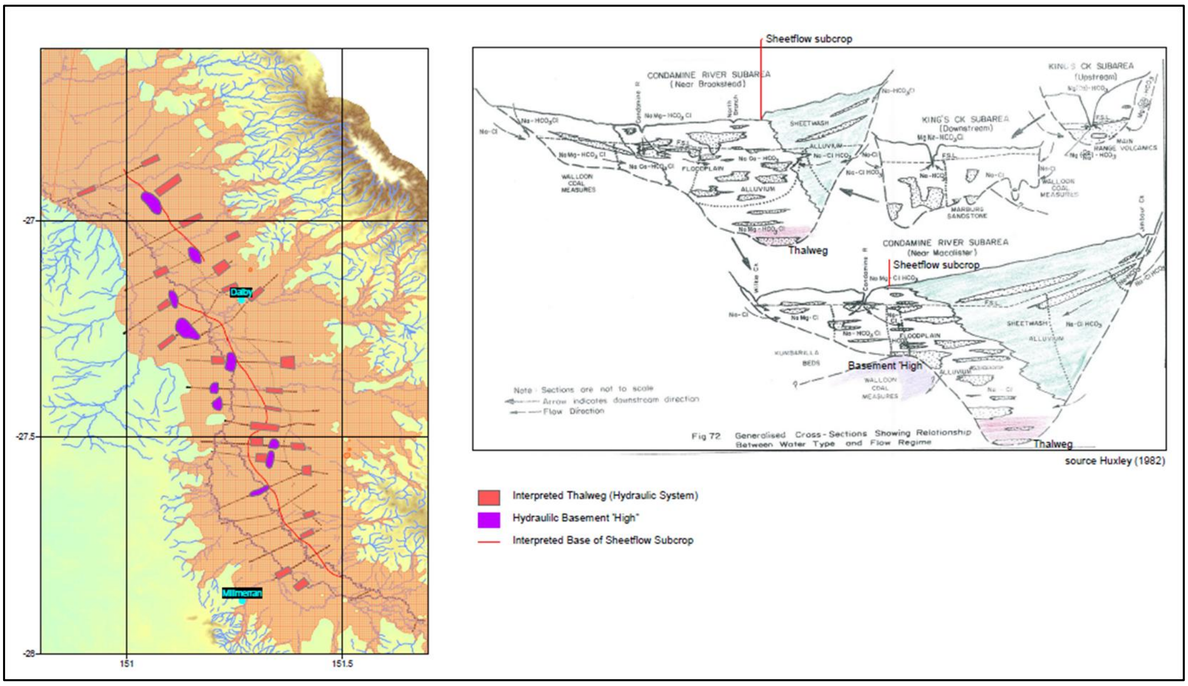

Figure 7. Location of thalweg and hydraulic basement highs in the Condamine Alluvium (from KCB, draft in review).

5.2.4 Water Quality

Water quality of the Condamine alluvium is spatially variable reflecting proximity to basin margins, tributary inflows and the Condamine River as well as variations in basement geology/water chemistry. Time-series of individual bore water quality data were not available for this report, consequently temporal changes in water type or water quality could not be determined. KCB (draft in review) reviewed groundwater chemistry and presented spatially contoured salinity maps. Their analysis suggested "that the spatial salinity distribution shows only minor variations over time, with changes in the continuity of individual sampling influencing these patterns. While minor changes occur, the overall trends in the dataset remain relatively constant" (KCB, draft in review, p 61). A summary of the findings of KCB (draft in review) water quality analysis is given below. It should be noted that the trends observed by KCB represent modal (most commonly occurring) or average changes in water chemistry throughout the alluvium. KCB (draft in review, p 64) note that for bores in proximity of Tipton, Westend, Oakey, Dalby, Yarrala and Pirrinuan "While broad trends associated with water chemistry and geology are inferred, the trend is not obvious, with different hydrochemical values often observed to occur in adjacent boreholes".

Salinity (as total dissolved solids) ranges between 103 – 24,473 mg/L. In general, salinity increases northward (i.e. downstream). Lower salinities are typically observed in the alluvium where bores are located close to the Condamine River and tributary inflows. Higher salinities are found in the northern area of the alluvium. Bores in this area tend to be drawing from deeper in the alluvium close to the basement contact. It is not clear whether these higher salinities are due to longer residence time (due to lower transmissivity), inflow from basement rocks or interaction with different parent material (KCB, draft in review). It is likely that all three processes may be influencing water quality.

Water type generally changes down the inferred groundwater gradient. The upper alluvial area waters are dominated by $Na\text{-}Cl\text{-}HCO_3$ as are waters from bores located close to the Condamine River. Deeper bores located in the upper Condamine located east of the river are $Na\text{-}Mg\text{-}Ca\text{-}HCO_3$. Margins of the alluvium are Na-Mg-Cl dominated which is thought to reflect the influence of Walloon Coal Measures and Main Range Volcanics, although there may also be some influence of lower recharge (KCB, draft in review). Downstream of Oakey

Creek alluvium water chemistry is Na-Cl-HCO_3 and Na-Cl. This change was consistent with change in water type of the underlying strata.

Table 5. Comparison of water quality of Central Condamine Alluvium, Walloon Coal Measures and Marburg Sandstone

		Central Condamine Alluvium	Walloon Coal Measures	Marburg Aquifer
Conductivity	average	2385	4305	1319
(μS/cm)	minimum	187	50	20
	maximum	30000	31000	39000
TDS	average	1437	2667	763
(mg/L)	minimum	103	30	12
	maximum	24473	21794	39819
pH	average	3.6	7.8	7.9
	minimum	7.9	3.8	2.3
	maximum	11	11.6	11

6 Assessment of Impacts on Surface and Groundwater in the MDB

Review of the fluxes presented in Figure 4 and Table 2 shows that CSG operations are not likely to affect a number of the fluxes. These fluxes are summarised in Table 7.

6.1 System Interactions: processes and significance

The water fluxes in the conceptual model (Section 5) will be influenced by CSG development to varying degrees. In this section, the flows between system components and the processes via which they occur are categorised in terms of significance. The category of main interest is where significant changes in flows are created by the introduction of CSG extraction. These changes include consideration of the management and technical challenges not just the magnitude of the changes to flows. For example, reinjection of water has significant engineering and sequencing challenges as well as difficult water quality issues including changes in mineral saturation status.

Flows were separately categorised into significant, intermediate and minor changes. Also, flows where no changes are expected are identified. Minor or no changes could be because of limited footprint of development and/or being dependent on factors not affected by CSG development (e.g. diffuse recharge dependent on flood frequency and hydraulic conductivity of alluvium).

Finally, flows that are part of realisation of other beneficial uses that may be enabled by the availability of associated water are identified. For example, water availability for agriculture and town supplies as well as surface water flows may be increased by availability of associated water.

The processes, interactions and their relative significance are summarised in Table 6. Four interactions are identified as creating significant changes and/or local impacts. Three interactions are categorised as intermediate, six as minor and eight with no changes.

Table 6. Processes of water recharge, discharge and redistribution post-CSG. White = no significant changes; yellow = minor changes ; green = intermediate changes; blue= significant changes and/or local risk

		To				
		Surface water	Groundwater			Mixed S/G
		Rivers	Alluvium	WCM	GAB	Other uses
From	Rivers		14. recharge from losing streams	15. recharge from losing streams into outcrop intake beds	16. recharge from losing streams into outcrop intake bed	12. crops, forestry, municipal
	Alluvium	17. discharge (gaining streams)	3. redistribution potentially with water quality change	7. redistribution potentially with water quality change	10. redistribution potentially with water quality change	12. crops, forestry, municipal
	WCM	1. discharge of associated water (with treatment if required)	2. reinjection of co-produced water via surface bores 5. redistribution potentially with water quality change	8. reinjection of co-produced water via surface bores	6. reinjection of co-produced water via surface bores	13. crops, forestry, municipal
	GAB	11. discharge (gaining streams)	9. redistribution potentially with water quality change	4. redistribution potentially with water quality change	redistribution potentially with water quality change	12. crops, forestry, municipal
	Other Uses	Discharge (Municipal effluent)	recharge (Drainage below root zone)		recharge (Drainage below root zone)	

6.1.1 Significant Changes and/or local impact

1. *Discharge of associated water from Walloon Coal Measures to Rivers*
    - Proponents have identified discharge of treated associated water to MDB streams as a water management option. Discharge of treated associated water could supplement streamflow.
    - APLNG have modelled potential permeate discharge between 20 - 100 ML/d (APLNG, 2010 Vol 5 att 23). This discharge volume represents 3 - 15 % of the volume currently being extracted from the Condamine River, upstream of Chinchilla Weir, under water entitlements (240, 000 ML/y, DERM).
    - QGC estimate total peak water production to be 190 ML/d and average production to be ~165 ML/d between 2015 – 2025 (QGC Vol 3, Chapt 11). If all associated water was treated and discharged this would represent ~25 % of the volume currently being extracted from the Condamine River, upstream of Chinchilla Weir, under water entitlements.
    - Santos stated that stream discharge is not a preferred option for the Roma development (Santos, 2010; Appendix Q).
    - Timing of discharge will be critical to ensure natural flow regimes are maintained and environmental flow objectives are met.
    - Where more than one operator is discharging associated water to streams, stream flow modelling will need to be conducted to determine the cumulative impact of multiple discharges.
    - Brine management will need to be carefully considered where associated water is treated.
2. *Reinjection (of associated water via surface bores) from Walloon Coal Measures to Alluvium*
    - Options for direct re-injection of associated water to the Central Condamine Alluvium is currently being investigated in Healthy Headwaters Program.
3. *Redistribution (potentially with water quality change) within the Alluvium*
    - Local redistribution of water in the alluvium in response to water table drawdown may result in water quality compromise of some water bores (Section 6.2.1,

6.2.2). Significant differences in bore water chemistry have been noted in some areas of the Central Condamine Alluvium (Section 5.2.4).

- During water table drawdown, water in the alluvium may be redistributed so that in some cases low quality water may flow to areas where water quality was previously high. This local (individual water bores) change to water quality may be significant, but the number of bores likely to be affected and the locations cannot currently be predicted or the magnitude of change estimated.

4. *Redistribution (potentially with water quality change) from GAB to Walloon Coal Measures*

   - Even though this process is from one non-MDB water component to another, it represents a change to system flows.
   - It is possible that water that has redistributed from other aquifers to the Walloon Coal Measures is subsequently extracted as associated water. Therefore, if this is licensed for other beneficial uses, it may actually be a re-allocation of entitlement from the source aquifer. Therefore, overall, entitlements may be increased if this is not monitored and appropriate corrections made. It is likely that this water will have been the subject of make good provisions if it was previously allocated to an entitlement holder.
   - GA and Habermehl (2010) presented an order of magnitude comparison between estimated aquifer recharge and estimated leakage from various GAB aquifers induced by dewatering of the Walloon Coal Measures. This analysis was only possible for QGC and Santos development areas. Depending on associated water production scenarios, development area and affected aquifer, these induced leakage was estimated to range between 0.07 – 111 % of recharge.
   - Reinjection of associated water to GAB aquifers may mitigate the induced leakage from GAB.

6.1.2 Intermediate Changes

5. *Redistribution (potentially with water quality change) from Walloon Coal Measures to Alluvium*

- For areas where Walloon Coal Measures is currently hydraulically connected to the alluvium and flow is from Walloons to the Alluvium (Section 5.2.3.2) this exchange may decrease as the Walloon Coal Measures are dewatered. The magnitude of this exchange is currently not quantified.

6. *Reinjection (of associated water following treatment via surface bores) from Walloon Coal Measures to GAB aquifers*
   - Even though this process is from one non-MDB water component to another, it is a driver of potential changes to MDB water flows and has management and/or technical challenges. All proponents are investigating re-injection (APLNG, 2010, Vol. 5, Ch. 24; Santos, 2010, Appendix Q). QGC suggesting reinjection to GAB aquifers only. 2 - 4ML/well/d expect to need 70 wells targeting Hutton/Precipice Sandstone (QGC 2010, Vol. 3, Ch. 11).
7. *Redistribution (potentially with water quality change) from Alluvium to Walloon Coal Measures*
   - It is possible that water that has redistributed from other aquifers to the Walloon Coal Measures is subsequently extracted as associated water. Therefore, if this is licensed for other beneficial uses, it may actually be a re-allocation of entitlement from the source aquifer. Therefore, overall, entitlements may be increased if this is not monitored and appropriate corrections made. It is likely that this water will have been the subject of make good provisions if it was previously allocated to an entitlement holder.
   - The only proponent to predict water table drawdown (APLNG, 2010, Vol 5 att 21) has not estimated leakage rate from the alluvium to underlying strata. The predicted drawdown was on average 2 m and was not predicted to extend beyond the current boundaries of CSG tenements. Thus drawdown of the alluvium water table may be restricted to a small area of the Central Condamine Alluvium.
   - A conceptualisation of the basement of the Central Condamine Alluvium is currently being undertaken in the Healthy Headwaters Program. Water level analysis and bore water chemistry suggest that direct connectivity between the alluvium and Walloon Coal Measures may exist, although mostly outside of the

CSG development area (Sections 5.2.3.1, 5.2.3.2). Exchange between these units has not been quantified and will be dependent on the hydraulic conductivity.

6.1.3 Minor Changes

8. *Reinjection (of associated water via surface bores) from Walloon Coal Measures to Walloon Coal Measures*
    - Even though this process is from one non-MDB water component to another, it is a driver of potential significant changes to MDB water flows and has significant management and/or technical challenges. All proponents are investigating re-injection. However, reinjecting water back into the Walloon Coal Measures is not likely to be feasible during CSG operations without storing water for significant periods of time.
    - Reinjection into other aquifers affected by dewatering of the Walloon Coal Measures is the preferred option of the Queensland Government (see point 6 above).

9. *Redistribution (potentially with water quality change) from GAB aquifers to Alluvium*
    - GAB aquifers underlie the Condamine Alluvium in some areas. Water levels in the Marburg aquifer are typically higher than in the alluvium (Section 5.2.3.2) and water quality data suggest there may be some exchange from the Marburg aquifer to the alluvium. This exchange has not been quantified. It should also be noted that the area of the alluvium where water level analysis has suggested that Marburg aquifer waters may exchange with the alluvium is not located within the area of CSG development or the area of predicted drawdown of this aquifer. Hydraulic relationship between the Springbok or Gubberamunda aquifer and the Condamine Alluvium has not been quantified.
10. *Redistribution (potentially with water quality change) from Alluvium to GAB aquifers*
    - Water level analysis suggests that Marburg aquifer water levels are neutral or higher than water levels in the Alluvium (Section 5.2.3.2). Drawdown of the Marburg aquifer could reverse the gradient. The area where this water level

analysis has been conducted is outside of the area where drawdown of the Hutton/Marburg aquifer is predicted.

11. *Discharge (gaining stream reaches) from GAB aquifers to Rivers*
    - Only a limited number of river reaches possibly receive baseflow from GAB aquifers, this baseflow contribution is likely to occur only sporadically (Section 5.1.3.2). Regional impact on flow in MDB streams is likely to be minimal. Local effect is also likely to be limited.
12. *Licensing of associated water (potentially following treatment) extracted from any system component other than the Walloon Coal Measures to other beneficial uses*
    - It is possible that water that has redistributed from other aquifers to the Walloon Coal Measures is subsequently extracted as associated water. Therefore, if this is licensed for other beneficial uses, it may actually be a re-allocation of entitlement from the source aquifer. Therefore, overall, entitlements may be increased if this is not monitored and appropriate corrections made. It is likely that this water will have been the subject of make good provisions if it was previously allocated to an entitlement holder.
13. *Licensing of associated water (potentially following treatment) extracted directly from the Walloon Coal Measures to other beneficial uses*
    - It is possible that water that has redistributed from other aquifers to the Walloon Coal Measures is subsequently extracted as associated water. Therefore, if this is licensed for other beneficial uses, it may actually be a re-allocation of entitlement from the source aquifer. Therefore, overall, entitlements may be increased if this is not monitored and appropriate corrections made. It is likely that this water will have been the subject of make good provisions if it was previously allocated to an entitlement holder.
    - Use of treated associated water to supplement town water supply, crops and forestry plantations has been proposed.

6.1.4 No changes

14. *Recharge (from losing stream reaches) from Rivers to Alluvium*

- This “no change” categorisation assumes that cumulative water entry under conditions including associated water regulated discharge is the same as under current conditions because historical water extraction has disconnected the alluvial aquifer from the streams.
- Alluvium water table drawdown for streams not at maximum losing capacity may reduce stream flow for short periods of time (Section 5.1.3.1).

15. Recharge from losing streams into intake beds (Walloon Coal Measures)

- Recharge mechanisms of Walloon Coal Measures have not been quantified. However, dewatering is unlikely to affect recharge because it will be dependent on rainfall and stream input in exposed outcrops. The recharge rate will be dependent on the hydraulic conductivity of intake beds.

16. Recharge from losing streams into intake beds (GAB aquifers)

- It is expected that recharge of GAB aquifers via intake beds will not be affected by CSG activities and therefore will not impact streamflow.

17. Discharge (gaining stream reaches) from Alluvium to Rivers

- Central Condamine alluvial aquifer may be connected to Condamine River for only brief periods (days) after large rainfall events (Section 5.1.3.1). Contribution of alluvial aquifer to stream flow is negligible (Table 4).
- Balonne River alluvium water levels are not likely to be impacted by CSG activities.

6.2 Groundwater Impacts

Based on the analysis presented above CSG development is likely to principally impact the alluvial aquifer in the following ways:

1. Alluvial aquifer water availability due to:
    a. drawdown of the water table by induced leakage into the Walloon Coal Measures.
    b. drawdown of the water table by induced leakage into GAB aquifers. This is a secondary effect of induced leakage of GAB aquifers created by dewatering of the Walloon Coal Measures.
2. Alluvial aquifer bore water quality may be affected by local re-distribution of water responding to drawdown.

6.2.1 Groundwater Quantity

From the information available in the EIS documents it is not possible to separately assess drawdown of the alluvium water table resulting from direct connectivity with the Walloon Coal Measures and drawdown as a result of connectivity of the alluvial aquifer with other aquifers, in particular GAB aquifers.

Drawdown of aquifers predicted by all proponents is summarised in Table 7. It can be clearly seen that the predicted drawdown varies considerably between aquifers and between proponent estimates. Interestingly, although QGC state that the conservative assumptions in their model would provide estimates of drawdown that are likely to represent maximum values, APLNG estimates for drawdown in the Springbok aquifer (for example) in a similar area are on the order of 3 times greater. Possible explanation of the differences between proponent estimates include:

- Differences in sophistication of models: number of layers and size of spatial elements.
- Values used for hydraulic properties.
- Assumptions used as boundary conditions- QGC assumed constant head conditions beyond the model boundary
- Reported drawdown on different spatial basis. For example, QGC estimated drawdown is for a point 1.8 km from the edge of the depressurised zone. Neither the extent of the depressurisation zone or maximum drawdown was specified.

In general the largest predicted drawdown occurs in areas where the coals are located at deeper depths and the confining units are thin.

The predicted drawdown by APLNG for the cumulative case (i.e. considering all proponents) was “essentially the same as predicted for their project case, with an extension in the predicted area of drawdown” (APLNG, 2010, Vol 5 att 21). No figures or data were available to assess the increased extent. Higher than average drawdown might be expected to occur in tenements of each of the proponents with a higher concentration of producing wells (Figure 2).

APLNG was the only proponent to estimate drawdown of the water table (APLNG, 2010, Vol 5 att 21). Numerical groundwater modelling showed that for the APLNG tenement area only, maximum average drawdown occurred in 2049 with average watertable drawdown estimated to be less than 2 m with localised areas of higher drawdown (APLNG, 2010, Vol 5 att 21). Drawdown between 5 – 7 m was predicted to occur in two small areas. These areas are located immediately downstream of the Chinchilla Weir and in an area on the margin of the alluvium just south of Miles (Figure 8). Higher drawdown was coincident with the area of greater predicted drawdown of the underlying Gubberamunda and Springbok aquifers (Figure 9, Figure 10) and where the confining layer was thin or absent (APLNG, 2010, Vol 5 att 21). APLNG (2010) suggest that operation of the weir may compensate for the expected decrease in baseflow in the Condamine River due to drawdown of the water table in the area downstream of the Chinchilla Weir. It should be noted that groundwater use downstream of the Chinchilla Weir is low.

APLNG modelling results for all proponents (cumulative case) suggested that on average drawdown was < 2 m, although again with localised higher drawdown predicted in the same areas as above and also to the north and northwest of their Gilbert Gully development area. Although the area of increased drawdown for this southern area was not shown in the APLNG EIS the location is likely to correspond to the southern extent of Arrow and QGC development areas (APLNG, 2010, Vol 5 att 21).

The timing of maximum drawdown for the cumulative case was not specified in the APLNG EIS (APLNG, 2010, Vol 5 att 21).During CSG production the areal extent of watertable drawdown was projected to be close to the tenement boundaries and projected to increase during the recovery phase. No maximum areal extent was given in the APLNG EIS (APLNG, 2010, Vol 5 att 21).

Water level drawdown in some areas of the Condamine Alluvium due to groundwater abstraction has been on the order of 5 – 30m (Macalister – Dalby – Cecil Plains) in the decade between 1990 -2000. By comparison the projected drawdown of the alluvial water table predicted by APLNG, on average 2 m by 2049, is comparatively small. Even the greater drawdown predicted in localised areas of 5 - 7m is comparatively small. Thus on average, CSG activities are not likely to dramatically impact water availability in the Condamine Alluvium. However, local impacts may be more significant. Data and model outputs were not available for this report to determine the likely local drawdown. APLNG and other proponents used average hydraulic properties in the models. Hydraulic connectivity between the alluvium and underlying sequences, including the Walloon Coal Measures, has been indicated by both water level analysis and water quality data (Hillier, 2010; KCB draft in review). Currently there are no estimates of the magnitude of this exchange. This connectivity is likely to be heterogeneous and will therefore result in drawdown that deviates from the average in some areas.

It should be noted that only one water bore was identified in the area where drawdown of the water table was predicted to be greater than 5 m by APLNG (2010). However, a significantly greater number of bores are located along the western margin of the Condamine Alluvium (the Eastern extent of CSG development, Figure 1). Further work is required to predict magnitude and spatial and temporal extent of drawdown along the western margin of the Central Condamine Alluvium.

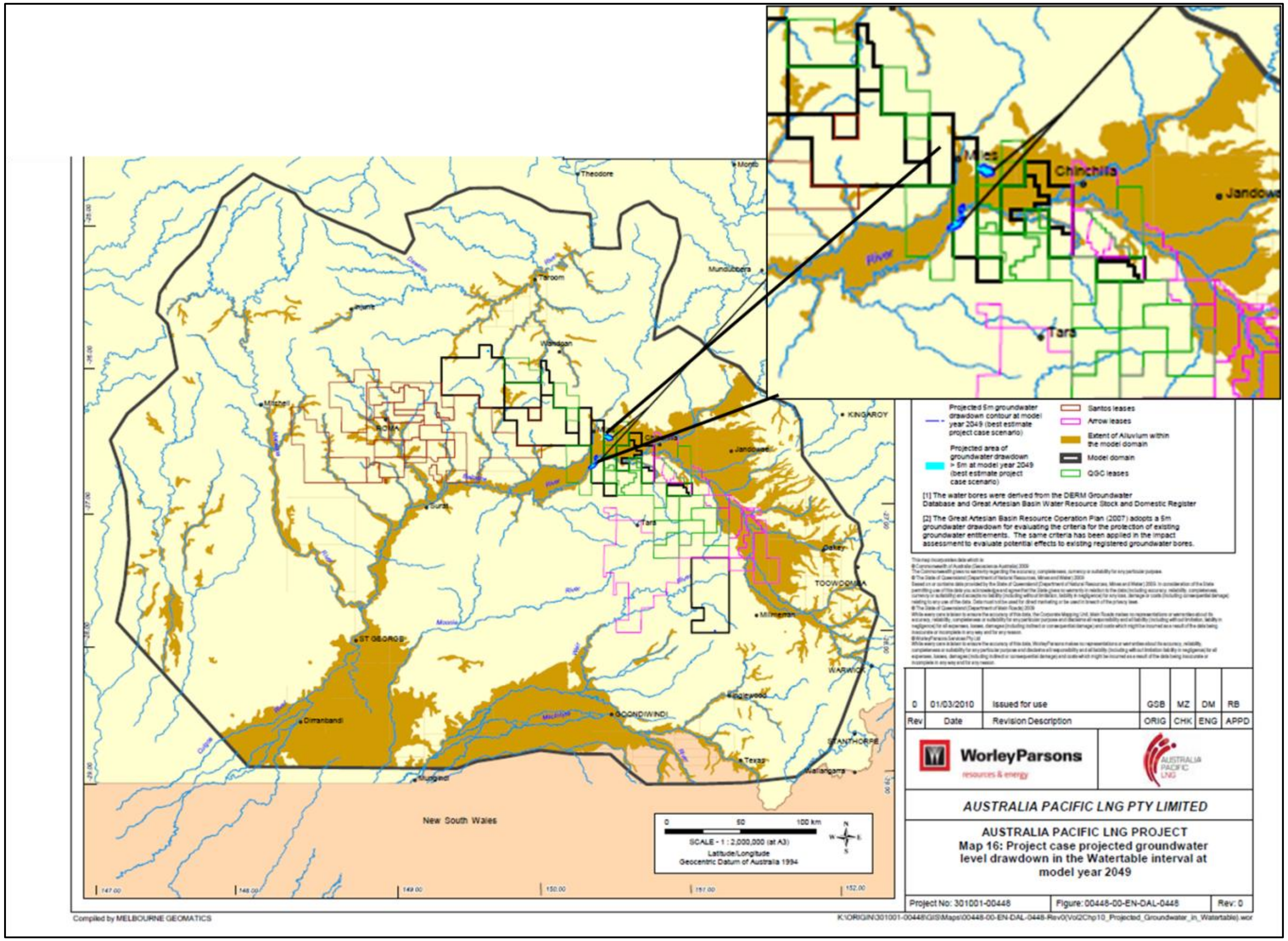

Figure 8. Area of > 5m drawdown of the water table predicted by APLNG (APLNG, 2010, Vol 5 att 21).

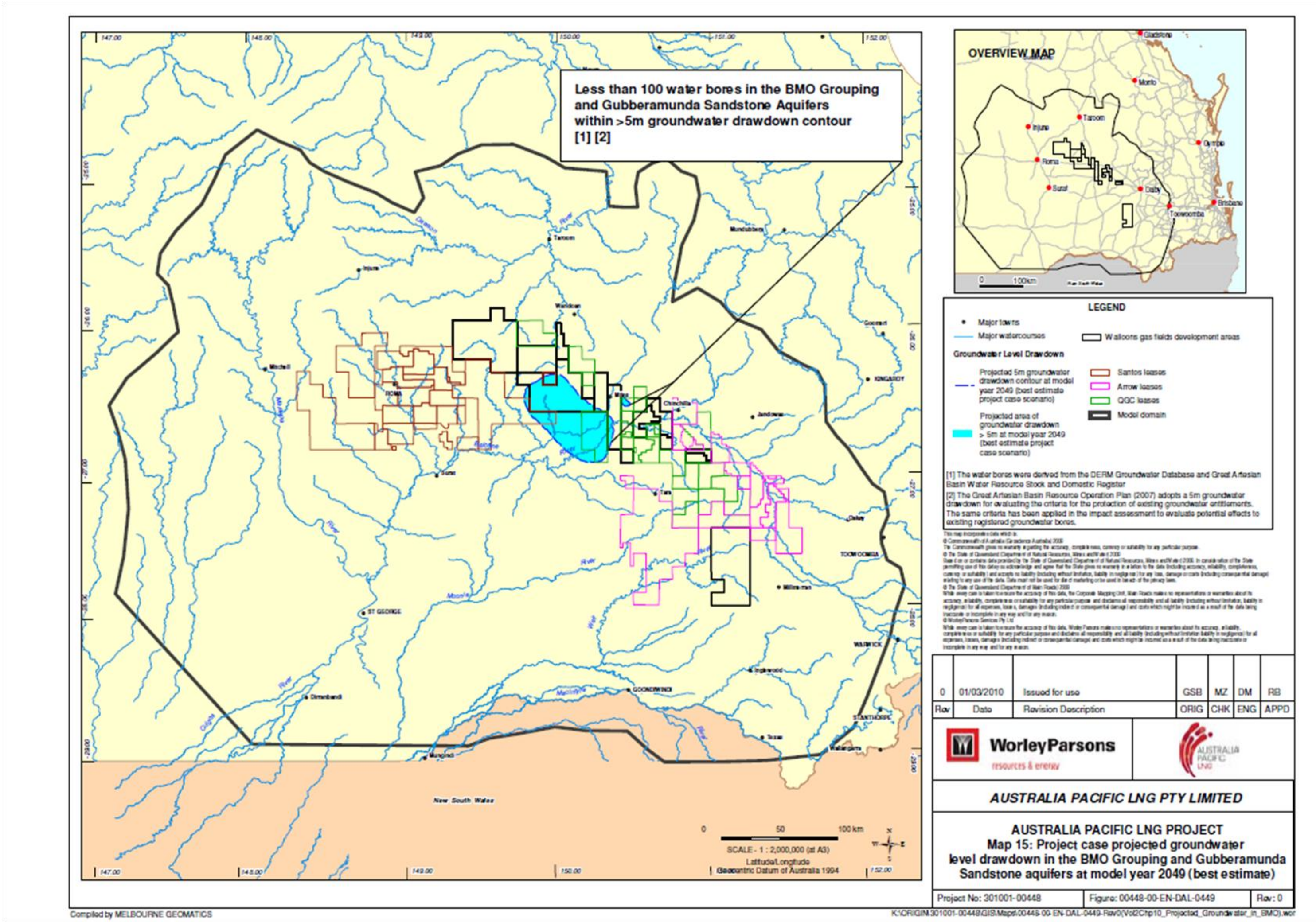

Figure 9. Predicted drawdown area of > 5m in the Gubberamunda Aquifer for APLNG project (APLNG, 2010, Vol 5 att 21).

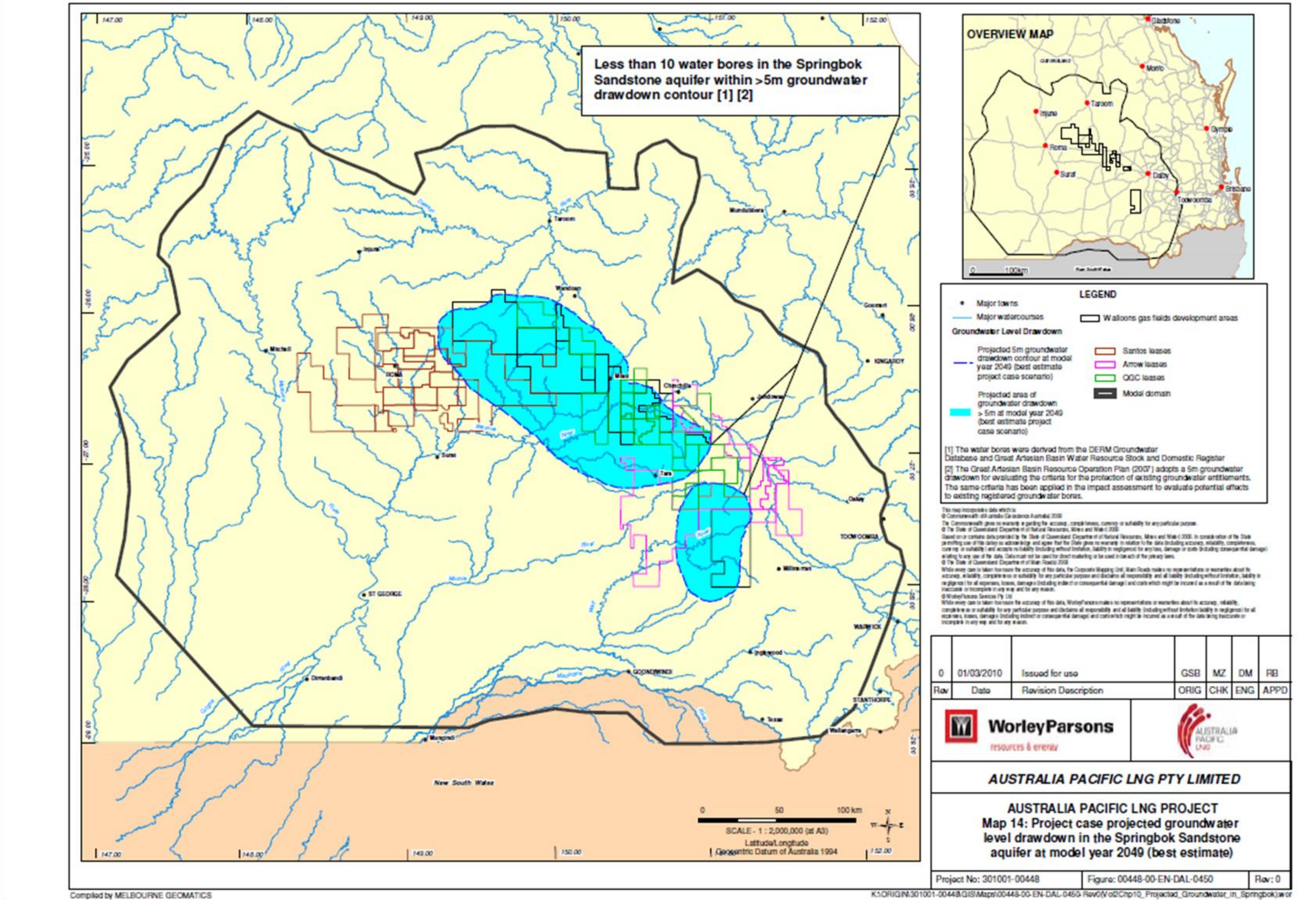

Figure 10. Predicted drawdown area of > 5 m in the Springbok Sandstone for APLNG Project (APLNG, 2010, Vol 5 att 21).

Table 7. Summary of predicted drawdown for aquifers potentially affected by CSG activities (from APLNG 2010; QGC 2010; Santos2010).

Aquifer		APLNG - Project	QGC	Santos (Roma field)	APLNG- Cumulative
Water Table	average (m)	2			2
	max (m)	5-7			
	Area of maximum drawdown	East of Condabri Central and South			East of Condabri Central and South; north and Northwest of Gilbert Gully
BMO and Gilbert	average (m)	3			
	max (m)	8			
	Area of maximum drawdown	Carinya			
Gubberamunda	average (m)		minimal		3
	max (m)	10			10
	Time	2029 - 2199			
	Area of maximum drawdown	Southwest Miles			100km SW Pine Hills
Springbok	average (m)	15			15
	max (m)	300	85		
	Range (m)		10 - 85		
	Time	2019-2039			
	Area of maximum drawdown	South Miles	CDA		
Hutton	average (m)	2			10
	max (m)	10	8	3.2	
	Range (m)		0 - 8		
	Time	2029 - 2149		20y	
	Area of maximum drawdown	West Miles	SEDA	Tenement boundary	
Precipice	average (m)	0			
	max (m)	0	6		
	Range (m)		0 - 6		
	Time				
	Area of maximum drawdown		SEDA		

6.2.2 Groundwater water quality

Determining the impact of CSG activities on water quality in the alluvial aquifer, and more specifically the impact on individual bore water quality is difficult to quantify with the data that is currently available.

Given the wide range of salinity and water types determined in the alluvial aquifer, CSG activities are perhaps not likely to significantly impact general water quality in the aquifer. Dewatering of the Walloon Coal Measures in areas where the alluvium is hydraulically connected will likely alter the hydraulic gradient between the two units so that water will tend to flow from the alluvium to the coal measures. On average, therefore, water with lower salinity would be expected to move from the alluvium to the Walloon Coal Measures. Similarly, where GAB aquifers are hydraulically connected to the alluvium, drawdown of the GAB aquifers will tend to weaken or reverse the hydraulic gradient between the alluvium and GAB aquifers. However, given the heterogeneity of water quality in the alluvium and particularly the variation in hydrochemistry between boreholes in some areas (Section 5.2.4), local redistribution of groundwater within the alluvium in response to the changes in hydraulic gradient may result in movement of poorer quality water to areas where water quality was previously good. This local redistribution may therefore compromise water quality of individual bores.

Changes to alluvium water quality during re-pressurisation of the Walloon Coal Measures and GAB after CSG extraction has ceased cannot currently be predicted.

In addition, alluvial aquifer water quality may changed in cases where CSG wells are compromised, e.g. due to lack of maintenance, faults or accidents.

6.3 Surface water changes

6.3.1 Surface water quantity

All proponents have identified discharge of treated associated water (permeate) to rivers as a management option. Santos have indicated that it is not their preferred option for the Roma development. All proponents have conducted modelling to estimate the impact of associated water discharge on stream flow.

APLNG have proposed to discharge permeate into the Condamine River downstream of the Chinchilla Weir at Talinga and Condabri. APLNG (2010) undertook IQQM modelling to establish the expected changes to flow regime in the Condamine River under a range of release scenarios. This modelling showed that while continuous discharge would significantly alter low/no flow periods, releases could be managed to conform to the Environmental Flow Objectives in the Water Resource (Condamine and Balonne) Plan (2004). Permeate discharge by APLNG only was estimated to be in the range of 20-100 ML/d (APLNG, 2010, Vol. 5 Att. 23) would represent 3 - 17 % of the volumes currently being extracted upstream of the Chinchilla Weir in the Condamine River.

The modelling conducted by APLNG (2010) showed that the timing and volume of permeate discharge to the Condamine River could be managed so that the flow regime was not significantly altered.

If either of the other proponents discharge associated water to the Condamine River in addition to APLNG, an assessment will required to determine the cumulative impact of discharges from multiple proponents. Timing and volumes of discharge from different proponents will most likely need to be managed in a coordinated fashion in order to avoid significant changes to river flow regimes.

6.3.2 Surface water quality

The Queensland regulatory framework under the Environmental Protection Act (EP ACT) requires that any CSG water discharged to surface water needs to be of an appropriate quality to ensure the receiving waters environmental values are protected. Discharges will be conditioned through an environmental authority issued under the EP Act. In addition, town water quality requirements to protect public health are addressed under the proposed amendment to the Water Supply Act currently under consideration by the Queensland Parliament.

Some proponents have identified some dissolved constituents in permeate may be present in concentrations that exceed ANZECC/ARMCANZ (2000) water quality guidelines. The constituents of primary concern are Boron and Fluoride (APLNG, 2010, Vol. 5 Att. 22; Santos, 2010, Section 6.5). Conversely, permeate discharge may reduce the concentration of key constituents such as calcium. These impacts can be managed through setting appropriate discharge criteria for aquatic ecosystem protection and in some cases selected ion addition prior to discharge.

Increased erosion and delivery of sediment the streams could result from three activities. These are construction activities, including road construction; changes to stream hydraulics during permeate discharge; and, changes to overland flow paths as a result of subsidence.

All proponents identified increased erosion during construction activities as a risk to stream water quality. Activities include road construction and in some areas waterway crossings. The mitigation activities such as undertaking activities during the dry season and containment of runoff in sedimentation dams should minimise the water quality risk to streams.

Each of the proponents conducted hydraulic modelling to determine possible changes to stream hydraulics during permeate discharge that may result in increased erosion of stream banks or stream meander migration. Mitigation activities including managing discharge volume and conditions at the point of discharge (e.g. rock armouring of streambed etc.) should minimise impacts of these activities.

Each of the proponents estimated compaction of the coal seams and consequent subsidence. The predicted compaction from these studies is similar to predictions from CSG field in the Western United States (Case, 2000). A subsidence bore was established in the Condamine in the early seventies and indicates that there may have been minor subsidence due to water extraction. DERM has recently established a bore line for monitoring subsidence along a transect across the alluvium that will be monitored on an ongoing basis.

Based on current knowledge, subsidence due to dewatering of the coal seams is likely to be significant in spatial extent but minor, by comparison with long wall mining for example, in magnitude vertically. However, consequences of subsidence and small changes to land surface topography in the study region could be important in terms of changing overland flow patterns, which may increase erosion and gully formation.

In addition, proponents did not consider whether compaction of coal seams in the Walloon Coal Measures after dewatering might result in deformation of overlying or underlying aquifers or confining units. This deformation may result in opening of new or existing fractures in these units which would change the hydraulic relationships and may change groundwater flows between aquifers.

6.4 Mitigation activities

The CSG industry water management and environmental performance in Queensland is regulated under the EP Act (EIS/EA and adaptive environmental regulatory regime) and the Water Act 2000.

The proposed WOLA Bill amends the *Water Act 2000* to ensure any impacts on landholder's water supply bores are properly managed in order to maintain a reasonable or alternative water supply. WOLA includes an obligation on CSG companies to enter into an agreement to "make good" any impairment on landholder's bores prior to these impacts actually occurring. Importantly, the WOLA Bill requires the production of underground water impact reports at least every three years. These reports will provide an assessment of monitoring results, a projection of predicted water level impacts using progressively updated groundwater flow models, a spring impact management strategy, and an updated water monitoring strategy. This adaptive management regime will apply to allow progressive improvement in the understanding of impacts and also to support timely implementation of "make good" arrangements.

Make good obligations will continue beyond the life of the tenure – this is due to the fact that the impacts on underground water resources may possibly continue beyond the life of the tenure. As such, there will be no cap on the period for which tenure holders' underground water obligations continue.

It should be noted that 'make good' provisions only apply to the impact resulting from water extracted under CSG activities not general water extraction for other purposes or natural change.

Two issues are raised by these provisions. Firstly the length of time that the water supply might be affected and secondly the spatial heterogeneity in water quality and quantity must be considered. Predicting the time when re-pressurisation is likely to be achieved is difficult and although associated water could be treated during CSG production phase and used to supplement existing bore owners this option will become increasingly difficult as gas production ramps up and water production declines. Sourcing water after gas production has ceased and until aquifer re-pressurisation has occurred may be required for a considerable length of time.

The Queensland State Government's preferred option for management of associated water from CSG development is aquifer reinjection and proponents have included reinjection as part of their water management strategy. The timing of re-injection and targeted aquifers will be critical to mitigate some of the potential impacts on surrounding aquifers. A substantial amount of additional work will be required to better quantify changes to hydraulic interactions between aquifers and the dewatered coal seams.

7 Discussion

The spatial scope of this study has been restricted to activities directly upon alluvium as opposed to impacts of activity anywhere on alluvium and related surface and ground water flows. Only 22% of the total area of CSG tenements in the MDB is classed as alluvial in this study. Consequently, the volumes of water are relatively small by comparison to the volumes for agriculture and urban uses that are extracted from the alluvium.

There are significant challenges to separate changes from CSG from activities on the alluvium with CSG activities more generally and other activities that impact the water balances of the alluvium. For example, Great Artesian Basin Strategic Management Plan aims to save 211,000 ML/y across the basin over a 15 year period. The total water savings during the Phase 1 of the GABSI for Queensland has been 53,771 ML/y (Surat only = 10, 782 ML/y) and for the whole of the GAB has been 98,004 ML/y (SKM, 2008). Total average water production reported in GA and Habermehl (2010) for APLNG and QGC was 36,656 ML/y (APLNG: 15,931 ML/y; QGC: 20,725 ML/y based on 829 GL produced over 40 years). Using the estimates of water production for these two proponents provided to GA and Habermehl (2010) and assuming the same average water production both on and off the alluvium, the total water production for activity of these two proponents on the alluvium would be expected to be on the order of 7,223 ML/y.

The proponents however acknowledge uncertainty in the estimates of water production and the values noted above are lower than previously predicted in the EIS documents:

- QGC estimated total peak water production to be 190 ML/d (in 2012/2013) and average production to be ~165 ML/d between 2015 – 2025 yielding 1,200 GL over the life of the project (QGC Vol 3, Ch. 11).
- Santos estimated water production from the Roma field to peak at around 20 ML/d in 2014, declining to 10 ML/d for the following 5 years, with a maximum total estimated production of 91,336 ML over the life of the field (Santos, 2010, Att. Q).
- APLNG anticipate their water production to peak 170 ML/day (62,050 ML/year) in sometime in the first twenty years (APLNG, 2010, Vol. 5, Att. 24).

7.1 Regional Impact

As noted earlier, the scope of this report is restricted to activities undertaken on the alluvial plains of the MDB. Therefore, it is important that the water volumes and changes in aquifer interaction are interpreted in terms of this area and not confused with the entire extent of proposed CSG activities. The analysis above, and the analysis conducted by GA and Habermehl (2010) suggests that although large volumes of water will be extracted from the Walloon Coal Measures during extraction of CSG across the entire spatial extent of CSG, the changes to regional groundwater fluxes and balances of MDB aquifers due solely to CSG activities on the floodplain may be relatively minor. Depending on the water production scenario, estimated leakage between GAB aquifers induced by dewatering of the Walloon Coal Measures in any given development area varies between 0.07 – 111 % of recharge for individual GAB aquifers (GA and Habermehl, 2010). Reinjection into GAB aquifers could alleviate some of the predicted drawdown of these aquifers.

No estimates of induced leakage from the alluvial aquifer have been made, although drawdown of this aquifer has been predicted by one proponent (APLNG, 2010) to be on average 2m. This average drawdown predicted to occur over the next ~ 40 years is smaller than the drawdown that has occurred due to abstraction from some areas of the alluvium for agricultural production and smaller than drawdown predicted for GAB aquifers.

Induced leakage from the alluvial aquifer is likely to be variable depending on whether the Walloon Coal Measures have direct hydraulic connectivity to the alluvium or whether drawdown is induced indirectly via a GAB aquifer. CSG activity is likely to have little impact on processes of diffuse recharge to the alluvial aquifers. Riverine recharge may be impacted but, again, the volumes are not large, particularly in comparison to the abstractions associated with irrigation from aquifers and downstream surface waters.

Several aspects of the regional water balance remain unestimated or have only been estimated using analogue (by area equivalent) approaches rather than the preferred method of direct measurement. Recharge rates were computed using an area estimate by GA and Habermehl (2010) to provide an order of magnitude estimate for comparing with induced leakage rates for GAB aquifers. Current numerical modelling by proponents either does not include recharge or uses average rates. In reality, this process for both GAB and Alluvial aquifers is likely to be a stochastic process and only occur during high rainfall events. Sensitivity analyses for hydraulic properties and for stratigraphical conceptualisation could be conducted to improve understanding of likelihood of regional effects.

At a regional level better understanding of recharge processes and subsurface redistribution of water recharged to the GAB aquifers is required to better predict changes during repressurisation of the both GAB and alluvial aquifers and the coal measures. This is also important for determining reinjection strategy. Better constraining these hydraulic relationships will also help better understand potential consequent water quality changes in some parts of the system.

7.2 Local impacts

Although the proponents did not provide detailed estimates or contour maps of the predicted drawdown, the APLNG EIS modelling and subsequent information provided to GA suggests that in some areas large local decreases in potentiometric head could occur (APLNG, 2010, Vol 5 att 21; QGC, 2010; Santos, 2010). In particular, the area south of Miles and North East of Chinchilla and the area north of APLNG's Gilbert Gully tenement were identified in the APLNG EIS cumulative case as areas of great drawdown of both the water table and underlying GAB aquifers (APLNG, 2010, Vol 5 att 21). It is important to note that the areas of greater drawdown were predicted from numerical models using regional average hydraulic parameters. Local drawdown will be determined by local hydraulic conditions, including thickness of confining layers, and the presence of fractures or faults. There is currently insufficient information to determine the extent to which local drawdown will deviate from the average.

Data on hydraulic properties is scarce, there is evidence of considerable spatial heterogeneity in the hydraulic properties of some aquifers (Hodgkinson etal., 2010; KCB, draft in review), confining units (Hodgkinson et al. 2010) and Walloon Coal Measures (Hodgkinson et al., 2010; APLNG, 2010, Vol 5 att 21). Isopach thickness of the confining units is similarly variable. This variability could result in local drawdown that is dramatically different from the average predicted by current models.

In addition, the location of fractures and faults have not been included in the models or considered by the proponents. These features may alter local drawdown and connectivity of aquifers.

Numerical groundwater models will be required to be updated to include local data as it becomes available, this will likely necessitate improved parameterisation and process/stratigraphic representation in the models. Targeted areas for monitoring and additional data on hydraulic properties should be prioritised. Ongoing validation of model predictions of drawdown and water production could provide insights into areas that may require better characterisation and/or additional monitoring. Water production data must also include water produced during exploration as this extraction will contribute to the water deficit of the system. It is not clear that this is currently included in water production estimates.

Water quality analyses, including isotope tracers and dating of waters may aid in identification of changes to local hydraulic conditions. Changes in water types and salinity in the Central Condamine Alluvium in combination with analysis of water levels have been interpreted to be indicative of hydraulic exchange between the alluvium and underlying Walloon Coal Measures and sandstone aquifers. Colloquial reports of changes to water quality in some Condamine Alluvium water bores have been reported. However, good quality water quality time series from individual bores were not available for this study. Given the heterogeneity of water quality in the alluvium (KCB, draft in review) changes to bore water quality may occur due to lateral migration of poor quality water rather than changes to vertical connectivity with the underlying Walloon Coal measures or GAB aquifers.

In summary, given the certainty of variability/spatial heterogeneity in stratigraphy, hydraulic properties, recharge rate variations and hydraulic connectivity of aquifers and intervening regolith, it is certain that local effects will occur. The nature of these effects can be described. However, where and when they will manifest will remain unpredictable until more data is available. It is important that communities are made aware of the types of effects that may occur and that the governing authorities have adaptive management processes in place to deal with them when they arise.

7.3 Gaps

Many of the gaps identified in this work are similar to those identified by GA and Habermahl (2010). In particular, there appears to be little data that quantifies spatial variation in fundamental aquifer hydraulic properties. For impacts to be predicted and adequate management to be put in place then these data would need to be collected and be made available to the government, and the Queensland Water Commission.

To allow improvements in the assessment of aquifer drawdown and impact on other water users, the proponents would need to provide spatially explicit contour maps of the drawdown areas. The cumulative effect of all proponent activities is currently not able to be assessed.

All the proponents have postulated an adaptive management regime to development, with monitoring networks of water levels and water quality. The adaptive management loop will also need to include ongoing updating of the groundwater models used to predict drawdown with data on the hydraulic properties as well as ongoing review of the predicted with measured drawdown. Data required for this would need to include storativity, horizontal and vertical permeability for both aquifers and confining units. It will be critical to establish in advance what corrective measures will be enacted (risk mitigation strategies) when local effects occur.

The proponents acknowledge uncertainty in their estimates of water production. The average annual production estimates of QGC for example are ± 50% (GA and Habermehl, 2010). There are significant differences between different methods for estimating the amount of associated water depending on modelling approach, information available and assumptions regarding gas production quantities over time. Individual well water production should be monitored and data made available to the government along with water:gas profiles. These would be required to monitor predicted and actual water production allowing better forecasting predicted drawdown and aquifer impacts. Further, to improve modelling and forecasting assumptions and methods for estimating associated water would need to be explicitly stated with error estimates to ensure comparability of different estimation techniques and the volumes predicted.

A great deal of relevant data is currently held by the proponents. To enable this data to be included in models and assessments of cumulative impacts, data provided by proponents could be held as confidential for a period of time before becoming publically available. This would ensure the competitive and commercial interests of the companies while allowing the government to review model predictions and monitoring results thereby increasing the certainty of impact prediction and a timely and appropriate management response.

Vertical permeability and connectivity between aquifers has not been well quantified.

Full sensitivity analyses should be done using project and cumulative scenarios for the likely range of hydraulic variables. Results need to be spatially explicit and presented as contour plots.

The impact of such large scale dewatering and changes to capillary pull of the coal seams is completely unknown.

Existing faults and fractures must be accounted in the models, or at least signalled as areas of concern. To enable models to be kept up to date, ongoing monitoring of water levels and water production (including during exploration) in areas with known faults or fractures should be compared with modelled predictions and the models updated. In some areas analysis of the water:gas profile of different wells in relation to known locations of faults or fractures may be a useful first assessment of the importance of these fast flow paths.

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9 Appendix 1: Terms of Reference

Terms of Reference for an independent expert study under s255AA of the Commonwealth *Water Act 2007*

Background

1. Section 255AA – Mitigation of unintended diversions – of the Commonwealth *Water Act 2007* states that:

> *"Prior to licences being granted for subsidence mining operations on floodplains that have underlying groundwater systems forming part of the Murray-Darling system inflows, an independent expert study must be undertaken to determine the impacts of the proposed mining operations on the connectivity of groundwater systems, surface water and groundwater flows and water quality".*

2. The preconditions for triggering this provision and necessitating an independent expert study (referred to hereafter as "the study") are:

- It needs to be a subsidence mining operation;
- It needs to be on a floodplain; and
- It needs to have potential to impact on Murray-Darling Basin (MDB) system inflows.

3. Based on advice in a report by Geoscience Australia (Geoscience Australia and Habermehl 2010), the location and nature of current proposed coal seam gas (CSG) developments in Queensland mean that the above preconditions may potentially be met and it is therefore prudent to commission an independent expert study.

Scope of work

4. The study will seek to determine the impacts of the proposed mining operations on the connectivity of groundwater systems, surface water and groundwater flows and water quality in the Murray-Darling Basin.

5. The study will be conducted by an independent expert with relevant science qualifications and experience and be assisted by Geoscience Australia. .

6. The study will involve a review of all available information on the proposed developments, including reports by the Queensland Coordinator General, Geoscience Australia, and other relevant information. The independent expert will be able to request further information from the CSG proponents and other experts as they see fit. In particular, the independent expert will engage with holders of relevant technical data, information and knowledge, including:

- the proponent companies: Santos, British Gas, AP LNG, Arrow, and Shell;
- science and data agencies within the Commonwealth and Queensland governments; and
- the Murray-Darling Basin Authority.

Governance

7. The Commonwealth Department of Sustainability, Environment, Water, Population and Communities (DSEWPAC) and the Queensland Department of Environment and Resource Management (DERM) will jointly facilitate technical and logistical support as requested by the independent expert. Senior officials of both agencies will form a joint liaison committee for this purpose.

8. The final report will be provided to the Commonwealth and Queensland governments, who may make the report publicly available.

Timeframe

9. The review will be completed no later than 22 November 2010. A draft report will be provided to the joint liaison committee by no later than 8 November 2010.

10 Appendix 2: CSG Proponent Groundwater Modelling for assessing impacts on groundwater.

Three CSG operators have used groundwater models to estimate drawdown in surrounding aquifers due to CSG activity. APLNG used FEFLOW a finite element groundwater simulation model with 22 layers and variable sized elements. The model had a finer (3km) mesh close to APLNG tenements that increased to 12km at distances greater than 70km from the tenements. QGC and Santos used MODFLOW, a finite difference model approach, in their EIS. All models were assessed by GA and Habermehl (2010) as providing reasonable preliminary estimates of likely impacts of dewatering for CSG extraction. The model used by APLNG was clearly superior in its extent, conceptualisation, discretisation (i.e. greater number of layers represented, particularly in the Walloons and smaller spatial elements) and calibration.

No information was available from Arrow to provide an assessment. However, the cumulative case presented by APLNG includes projected water production from the development of all tenements in the area under study.

The conceptualisations of the groundwater systems used by the proponents were consistent with previous work. The models also represented structural geological features based on stratigraphic interpretation derived from company records, DERM and GSQ.

All the proponent models contained significant assumptions that introduce uncertainty into the predicted drawdowns and changes to water balance of surface water, alluvial and GAB groundwater systems.

These assumptions include:

- Average hydraulic parameter values for each layer based on literature values for all layers - except perhaps Walloons in APLNG
- Vertical hydraulic conductivity data is lacking; APLNG used assumed aniostrophy values
- APLNG assumed uniform storativity value 4 x 10-6 (derived from pump test in precipice near Kogan Ck) and specific yield 0.03 in upper layers. GA and Habermehl (2010) suggested that these values may be low estimates.

- The APLNG model included recharge estimates for the upper alluvial layers based on Kellett et al., (2003), Lane (1979) and Huxley (1982). The QGC model did not include recharge.
- The QGC model assumed constant head boundary at the model domain
- All models assumed the Precipice sandstone to be a no flow boundary (ie no connectivity with the underlying Bowen Basin)

There was a general consensus that there is a paucity of data against which to calibrate the models. The methods by which the models were calibrated varied between proponents. QGC calibrated the model by matching predicted water production. Estimates of water production were reported to have an uncertainty of ± 50% and four water:gas typologies were identified. The method by which these typologies were used to estimate water production is not clear. APLNG and Santos calibrated the models against measured water levels. The models relied heavily on calibration to set the values used in model runs in particular hydraulic conductivity values. None of the proponents specified hydraulic properties after calibration used to produce drawdown estimates.

There was no representation of fractures and faults- this could represent a significant source of underestimation of drawdown and may be exacerbated where well completion includes fraccing.

SENATE RURAL AFFAIRS AND TRANSPORT REFERENCES COMMITTEE

Inquiry into the management of the Murray-Darling Basin

Public Hearing Tuesday, 9 August 2011

Questions Taken on Notice – CSIRO

19. HANSARD, PG 64

Senator WATERS: What are they sealing that coal with, concrete and steel again?

Dr Underschultz: Well completion strategies would be the same: steel casing, cement.

Senator WATERS: So moving to that now, and I think Senator Gallacher may have asked you that, has the CSIRO done studies, and if not you then who has and can we be provided with them, into the longevity of concrete and steel in these contexts?

Dr Walker: As we said before, to my knowledge we have not done studies into the longevity of bores, or at least there has not been any in recent times. I am not sure whom I can refer you to who has looked into that.

Senator WATERS: So why are the companies so confident that it will last forevermore when there have been no studies done into it? Is that faith misplaced?

Dr Underschultz: There is quite a lot of data in the scientific domain and we could provide you with a list of references on that.

Inquiry into the management of the Murray-Darling Basin

CSIRO's response to a Question on Notice taken on Tuesday, 9 August 2011

QUESTION FROM HANSARD, PAGE 64

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ANSWER

There are relatively few published studies available in the scientific literature that focus solely on the longevity of coal seam gas well bores; however, there are numerous published studies which have investigated the potential use of abandoned well bores for carbon dioxide storage and carbon sequestration, or the leakage risks posed by pre-existing or new wellbores at geological carbon storage sites (see below for a selection of references).

Consequently, many published studies have focused on the durability of well bores exposed to high levels of carbon dioxide or carbonated brine, mostly by analysing the cement and casing. For examples, see Carey *et al.* (2007), Kutchko *et al.* (2007), Jacquemet *et al.* (2008), Zhang *et al.* (2011), Bachu and Bennion (2009), Brandvoll *et al.* (2009), Crow *et al*. (2010), D'Alesio *et al*. (2011), and Gasda *et al.* (2011).

It is difficult to apply the results of these studies to other contexts. For instance, the concrete and steel in well bores exposed to high levels of carbon dioxide in groundwater (as in carbon sequestration) is more likely to undergo corrosion than when exposed to methane in groundwater (as in coal seam methane extraction), because carbon dioxide in groundwater is more chemically aggressive than methane.

One recent study that has investigated the long-term ageing of a well bore in the absence of high levels of carbon dioxide is described in Scherer *et al*. (2011). In this study, concrete cores were sampled from a 19-year-old well bore and the concrete properties were characterised. The authors concluded that the ageing of well bores can cause modifications to the concrete; however, in this study the effect of these modifications on overall well bore integrity and performance was not investigated. For a review of the degradation phenomena of concrete, and some of the changes that can occur when concrete is exposed to chemicals, see Glasser *et al.* (2008) and Wang *et al.* (2010).

The Australian Drilling Industry Association (http://adia.com.au) provides guidelines for the construction of water bores in Australia. The Association has prepared the document “Minimum construction requirements for water bores in Australia – October 2010” which includes details of mandatory construction requirements that are enforceable by regulatory authorities as well as the Association’s recommendations for repairing and decommissioning water bores in Australia. This document is available at http://adia.com.au/resources/waterwell-sector/water-bore-construction.

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SENATE RURAL AFFAIRS AND TRANSPORT REFERENCES COMMITTEE

Inquiry into the management of the Murray-Darling Basin

Public Hearing Tuesday, 9 August 2011

Questions Taken on Notice – National Water Commission

20. HANSARD, PG 71

Senator EDWARDS: When is the report being handed down? The report you referred to earlier.

Mr Cameron: We expect to release that in the next few weeks.

Senator EDWARDS: Will it be available to us?

Mr Cameron: We would be happy to provide it to you in that time frame.

Australian Government
National Water Commission

Onshore co-produced water: extent and management

RPS Australia East Pty Ltd

Waterlines Report Series No 54, September 2011

Waterlines

A SERIES OF WORKS COMMISSIONED BY THE NATIONAL WATER COMMISSION ON KEY WATER ISSUES

Waterlines

This paper is part of a series of works commissioned by the National Water Commission on key water issues. This work has been undertaken by RPS Australia East Pty Ltd on behalf of the National Water Commission.

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Disclaimer

This paper is presented by the National Water Commission for the purpose of informing discussion and does not necessarily reflect the views or opinions of the Commission.

Australian Government
National Water Commission

RPS

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Foreword

This report was commissioned in 2010 to raise and discuss issues associated with the management of water produced during oil and gas production, including coal-seam gas (CSG) production. Since 2010, both CSG development and the regulatory responses by state governments have continued to progress rapidly.

In late 2010, objective information on CSG co-produced water volumes and management options was not readily available. While the Commission recognises that there are possible impacts on other water users—including the environment—at every stage of oil and gas production, this report is intended to objectively review the available information to explore possible water extraction volumes and management options of co-produced water at the surface. These options include a variety of treatment and beneficial use options as well as a limited number of disposal options, each of which may or may not be appropriate for the particular circumstances of individual oil and gas projects.

Other impacts that are beyond the scope of this report include changes in water availability for other water users and the environment, and water quality impacts associated with extraction or reinjection that could change the beneficial use characteristics of aquifers. The responsibility for managing these impacts lies primarily with state and territory governments.

The Commission recognises that rapid development of the petroleum sector presents significant economic opportunities as well as water resource management challenges. To this end, in December 2010 the Commission released a position statement on the CSG and water challenge which is available on the Commission's website.

James Cameron

Acting Chief Executive Officer

National Water Commission

Abbreviations and acronyms

2P	Proved and Probable
ABARE	Australian Bureau of Agricultural and Resource Economics
ACT	Australian Capital Territory
APPEA	Australian Petroleum Producers and Explorers Association
CSG	Coal Seam Gas
CWIMI	Centre for Water in the Minerals Industry
DEEDI	Department of Employment, Economic Development and Innovation
DERM	Department of Environment and Resource Management
DME	Department of Mines and Energy
DMP	Department of Mines and Petroleum
DPI	Department of Primary Industries
EMP	Environmental Management Plan
GL	Gigalitre
LNG	Liquefied Natural Gas
ML	Megalitre
NSW	New South Wales
NT	Northern Territory
NTU	Nephelometric Turbidity Unit
NWI	National Water Initiative
PEPS-SA	Petroleum Exploration and Production System – South Australia
PESA	Petroleum Exploration Society of Australia
PIRSA	Department of Primary Industries and Resources SA
PJ	Petajoule
QGC	Queensland Gas Company
Qld	Queensland
RO	Reverse osmosis
SA	South Australia
SAR	Sodium Absorption Ratio
SPP	State Planning Policy
USA	United States of America
WA	Western Australia

Executive summary

This report is designed to raise and discuss issues regarding the current and future extent of co-produced water and the management options for water produced during the oil and gas extraction process. It is acknowledged that some regulators, industry and stakeholders have been addressing CSG co-produced water issues for some time. The National Water Commission's interest is in the sustainable management of all water resources, including co-produced water. The scope of the paper includes only the volume and management of co-produced water associated with onshore (land-based) oil and gas reserves. There are two types of reserves: conventional (natural gas and oil) and unconventional (gas from coal seams). While it is recognised that there are broader impacts on other water users—including the environment—associated with CSG development, the focus of this paper is on the practical management of co-produced water at the surface.

Extent of co-produced water

In 2010, the co-produced water volume in Australia was estimated at 33 GL/year, of which 60% was from conventional sources. Estimated future water volumes are substantially larger, at over 300 GL/year, of which just 3% will be from conventional sources. The projected development of CSG sources in Qld and NSW is driving this new supply.

The estimated co-produced water volume over the next 25–35 years is projected to average over 300 GL/year from known reserves. To put this in perspective, 540 GL/yr is the approximate annual groundwater extraction in Qld from the Great Artesian Basin, which underlies most of the CSG reserves.

The extraction of co-produced water is not permanent. The CSG reserves from any given area are currently predicted to have 5–20 years life per well, and a typical CSG to Liquefied Natural Gas (LNG) project with multiple supply areas may have a 25–35 year production window. Moreover, the water production from each well declines exponentially over its life, so the main supply point migrates with the development drilling activity. There are also risks that changes in economic conditions and state legislation could abruptly influence the reliability of the water supply if used for other purposes.

Management of co-produced water

There are a number of possible management options for co-produced water, including water supply for urban and industrial consumption, storage for future use (e.g. managed aquifer reinjection) and agricultural use including stock watering and substitution of existing irrigation demand. Most management options will involve some form of water treatment prior to use or disposal due to water quality considerations such as salinity and sodicity.

Urban and industrial (e.g. coal washing, power plant cooling) water supply would be ideally suited for CSG water reuse, however relatively constant flows at a particular location are required that may not be available from CSG operations. Such uses are being investigated for the Surat Basin, but the lack of large population centres and industrial areas is likely to limit demand. High reliability of supply is a requirement for urban and industrial users, and the short supply period—allied to the uncertainty of supply volumes—is not a strong incentive for major investment in pipeline infrastructure. At best, the supply would allow deferral of investment in alternative supplies.

Aquifer recharge (i.e. returning co-produced water to geological formations) is technically feasible, although there are a range of issues such as geochemical incompatibility (when recharge waters mix with native groundwater) and locations of acceptable aquifers for CSG wells in Australia. This option is often favoured in many areas of North America as the lowest cost salt water disposal option. It may need to be undertaken to limit environmental effects from the concentrated brine from CSG water processing units and to reduce handling costs for the poorest quality water. By reinjecting into the coal measures some distance from the CSG operations, it may be possible to limit regional depressurisation of groundwater sources and contamination of good quality groundwater. If water is returned to depleted areas of coal seams, it is unlikely to be suitable for subsequent use because it will re-salinise within the aquifer. Further assessment of whether aquifer recharge could be an important management option to minimise effects on groundwater levels and pressures is required.

Environmental water releases may also be subject to practical limitations. Unless substantial water storage capacity is available, sustained low flows are a potential adverse affect on waterways that normally have episodic flows. Off-stream and floodplain wetlands rely naturally on floods rather than in-channel flows, and water would need to be pumped and transported. For example, the volumes available in the Condamine–Balonne system would be valuable to the Narran Lakes during drought, but the multichannel system downstream of St George would deliver little or no water during normal flows, even supplemented with co-produced water.

1. Introduction

The CSG sector is developing rapidly in Australia, particularly in Qld. CSG (converted to LNG) already supplies some of the domestic gas market, and is expected to become a significant export product by 2014. The industry will have a life of approximately 25–35 years for each production development. The development of CSG reserves generally produces large volumes of co-produced water. The water is typically saline and sodic, and can contain other impurities. These large volumes of poor quality water present significant challenges for sustainable management of water resources.

1.1 Purpose

The National Water Commission (the Commission) commissioned this paper to raise the issue of CSG and co-produced water as a discussion starter for water planners and managers. We acknowledge that some regulators, industry and stakeholders have been addressing CSG co-produced water for some time. The purpose of this discussion paper is to report on the current and future extent of the co-produced water volumes, including but not limited to CSG, and examine the water management options and issues associated with co-produced water.

1.2 Scope

The scope of the paper includes only onshore (land-based) oil and gas reserves. The reserves are divided into two types: conventional (natural gas and oil) and unconventional (gas from coal seams).

While this report is national in scope, 97% of projected future water production will be from unconventional sources of CSG, largely in Qld with the balance in NSW. Consequently, most of the discussion about production volumes and management options is restricted to those two states.

1.3 Method and consultation

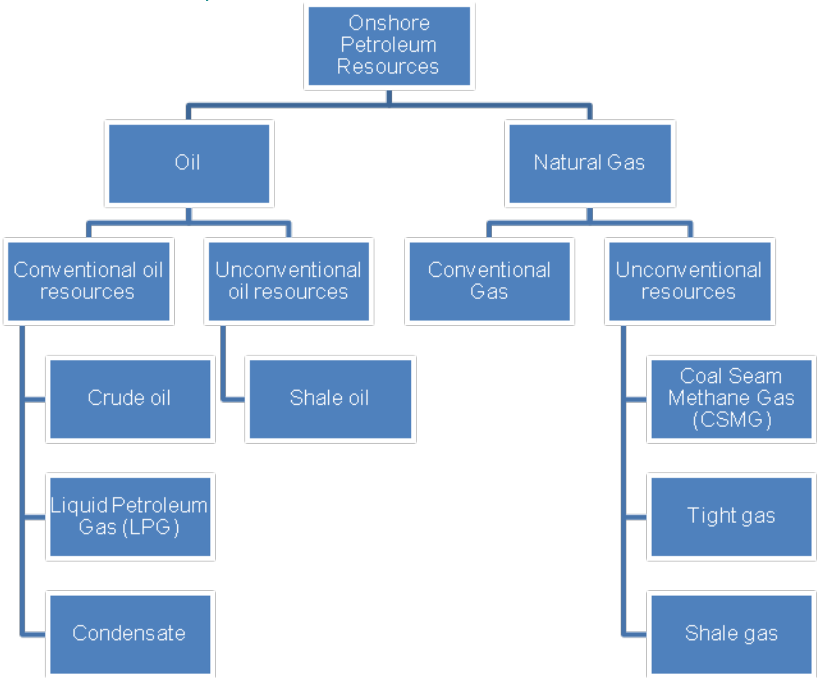
This paper was based on published information, augmented with interviews and information provided by government agencies (both within Australia and overseas), gas and oil companies and one peak industry organisation.

2. Co-produced water in Australia

2.1 Australia's onshore petroleum reserves

Australia's conventional and unconventional onshore petroleum reserves are shown in Figure 1, in terms of a classification of resource types.

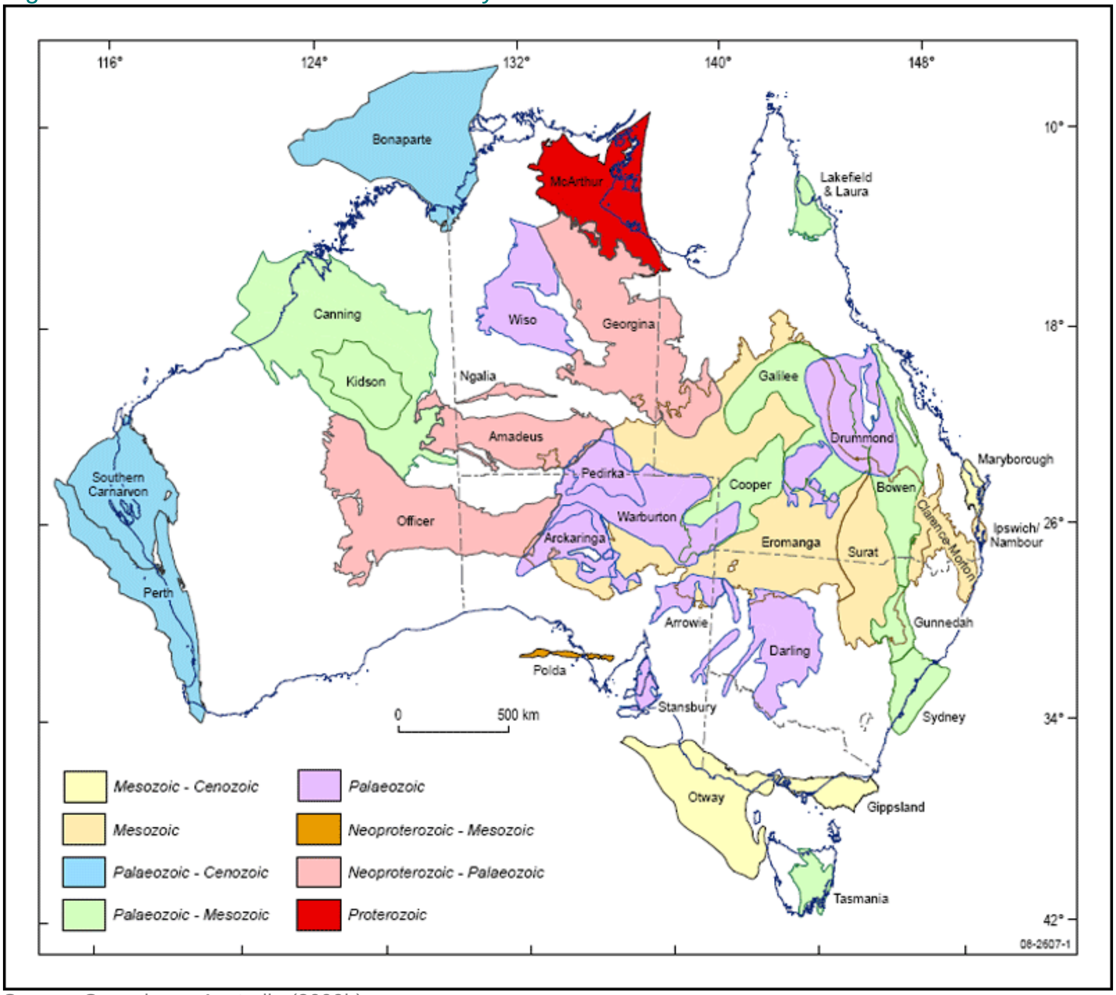
Figure 1: Australia's onshore petroleum reserves



All conventional resources are currently under production in Australia. Of the unconventional resources, only CSG is being produced. Shale oil, shale gas and tight gas were not considered in this paper, as there is no current production of these unconventional petroleum reserves in Australia (Geoscience Australia and ABARE 2010).

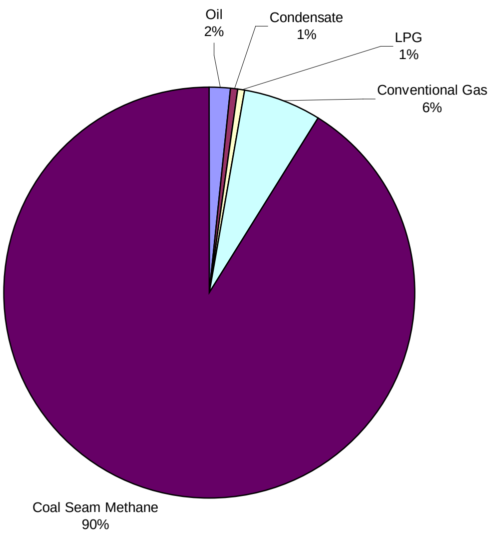
Onshore petroleum resources under current production from Australia's sedimentary basins (Figure 2) consist of conventional oil resources and natural gas (conventional gas and CSG) for which proved and probable (2P) reserves are highly variable (Figure 3).

Figure 2: Australia's onshore sedimentary basins



Source: Geoscience Australia (2009b).

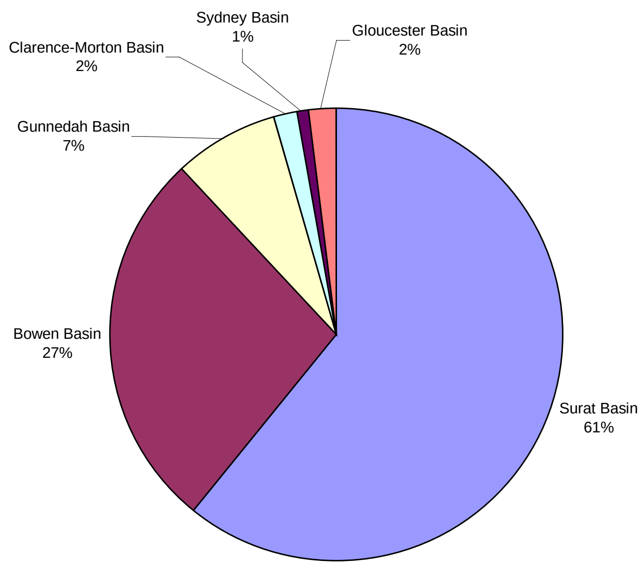
Figure 3: Australia's onshore proved and probable (2P) petroleum reserves (based on energy content)



Source: Geoscience Australia 2009b; DMP 2009, DEEDI 2010; Eastern Star Gas 2010; Metgasco Limited 2010; AGL Energy Limited 2010.

Although a relatively new addition to Australia's energy resource portfolio, CSG constitutes 90% of 2P onshore petroleum reserves in terms of energy, which is equivalent to 28 000 PJ. Australia's known CSG reserves occur in the eastern states, with 88% of 2P CSG reserves associated with Qld's Bowen and Surat basins and 12% located in NSW basins (Figure 4).

Figure 4: Distribution of Australia's proved and probable (2P) CSG reserves by basin (based on energy content)



Source: DEEDI 2010; Eastern Star Gas 2010; Metgasco Limited 2010; AGL Energy Limited 2010.

Although current CSG production is limited in geographic extent, exploration is continuing in Qld and NSW and is underway or planned for the Perdika Basin (NT), Perth Basin (WA), Ackaringa Basin (SA) and Fingal–Dalmayne Coalfields (Tasmania) (Baker and Slater 2008). While some early CSG exploration was occurring in WA it is generally considered that significant reserves would be unlikely. Previous CSG exploration in Victoria's Otway and Gippsland basins yielded non-economically viable reserves (Baker and Slater, 2008). In terms of future CSG sources, the Galilee (Qld) and Ackaringa basins are described as having potentially significant gas-in-place reserves, with early industry estimates of potential CSG reserves for those basins in excess of 30 000 PJ each (Resourcestocks 2008).

The balance of Australia's onshore 2P petroleum reserves are largely located in the Cooper–Eromanga Basin (SA), the Bowen and Surat basins (Qld), the Perth Basin and the Amadeus Basin (NT).

Australia's onshore oil and conventional gas resources are dwarfed by the CSG resource, which industry estimates indicate has significant potential to be 15 times greater than the current 2P reserves (Santos Limited 2009). With future oil and conventional gas production expected to be almost exclusively from offshore basins (Geoscience Australia and ABARE 2010), CSG is the only proven onshore petroleum resource expected to significantly grow and contribute to Australia's energy mix over the next 20 years or more. The Australian Bureau of Agricultural and Resource Economics (ABARE) predicted that CSG production would grow by 14.9% per annum, accounting for 30% of Australia's natural gas production by 2029–30 (ABARE 2010).

2.2 Co-produced water

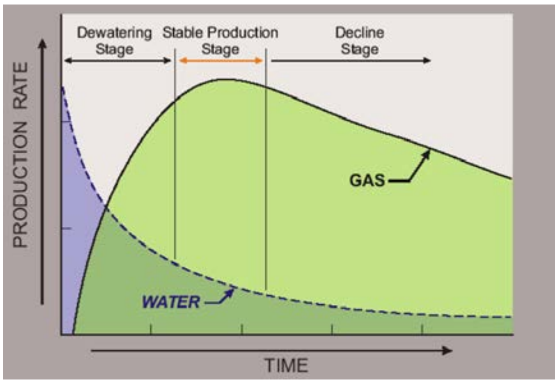
Groundwater is often extracted as a by-product during the production of oil and gas from underground reserves. The oil and gas industry commonly refers to this groundwater as 'co-produced water', 'produced water', 'produced formation water' or 'associated water'. For consistency, the term 'co-produced water' is used in this paper and applies to all groundwater generated as a by-product from onshore petroleum production.

An inverse relationship typically exists between co-produced water generation and petroleum production. However, the nature of the relationship varies for different types of petroleum.

In a conventional oil and natural gas reservoir, the petroleum resource often occurs above groundwater due to its lower density, where it is trapped against the reservoir rock. To recover the resource, a well is drilled into the reservoir where the water pressure often drives the oil and gas to the earth's surface. The water separated from the oil and gas is co-produced water. During the initial production phases, oil and gas is the principal component of the liquid stream. Over time, water production gradually increases until it is a significant proportion of production.

The relationship between CSG production and water production is the reverse of that for conventional petroleum types due to the conditions under which the CSG gas is stored. CSG is trapped on the surfaces and in the fractures and cleats of a coal seam by groundwater pressure (hydrostatic pressure). To produce CSG, the hydrostatic pressure must be lowered to release the gas from the coal seam. This is achieved by dewatering the coal seam (removing the groundwater from the coal seam by pumping it to the surface where it becomes co-produced water). As opposed to conventional petroleum production, water production rates are typically highest in the initial stages of CSG production and decrease over time (Figure 5).

Figure 5: Typical CSG production decline curve



Source: DME 2008a; original picture courtesy of CH4 Pty Ltd (Arrow Energy Limited).

The actual production rates and times within and between coal measures vary considerably. From their CSG production experience in the Surat Basin, Queensland Gas Company Pty Ltd (QGC) indicated that initial water quantities extracted from a well ranged from 0.4 Ml/day to 0.8 ML/day before decreasing to about 0.1 ML/day over a period of six months to a few years (Environmental Resources Management 2009). At the Fairview field in the Bowen Basin, Santos reported an average initial daily water production rate of 0.20 ML/day/well, which decreased to 0.02 ML/day/well after 12 years (URS 2009).

In general, onshore petroleum production generates significant quantities of co-produced water. This water is generally of poor quality due to elevated salinity and sodium levels and other adverse chemical properties, which dictate available management options. The issues of co-produced water quantity, quality and management of this water are expanded on later in this paper.

2.3 Current and future extent of co-produced water in Australia

Onshore petroleum production generates large quantities of co-produced water but aside from recent efforts in Qld, little effort appears to have been applied in Australia to understand the likely magnitude and distribution of this potentially significant water extraction.

In 2008, the Queensland Government commissioned the Centre for Water in the Minerals Industry (CWIMI) to investigate the potential groundwater impacts associated with Qld's CSG industry. The study considered the Surat and Bowen basins, and identified enormous variability in water production both within and between coal measures due to spatial and geological variability, different stages of gas production and inconsistencies in reporting (CWIMI 2008). There was little specific knowledge of the total volumes of co-produced water in Qld, however knowledge was increasing over time. The CWIMI developed a conceptual model to estimate the possible magnitude and spatial extent of water production associated with CSG as insufficient data and other uncertainties restricted the development of a more precise regional numerical model (CWIMI 2008) (refer section 2.3.2). This study superseded the previous range of inferred estimates developed by Parsons Brinckerhoff (2004) for the Surat Basin.

The only other available example of an attempt to quantify water co-production rates beyond the project scale was from NSW. Sleeman Consulting (2004) used average daily gas and water production data from 2002 for the Powder River Basin in Wyoming, USA, to derive an indication of the potential scale of co-produced water associated with the CSG industry in north-eastern NSW. Sleeman Consulting's annual estimate was calculated on a simple pro rata basis by applying a water–energy ratio factor from the Powder River Basin to potential CSG production in NSW. This method has a high degree of uncertainty as it does not account for the numerous factors that govern gas and water production from CSG development or geologic differences between NSW and the Powder River Basin.

In line with the findings of the CWIMI (2008), quantifying the current and future extent of co-produced water in Australia with any degree of accuracy is restricted by the current availability and quality of data and the enormous variability associated with factors that govern water co-production rates. Notwithstanding, an indication of the possible magnitude of current and future water co-production associated with onshore petroleum production has been developed for this paper. Some values were derived from actual measured data or modelling results, but due to the paucity of available data, many values were crudely estimated using the pro rata method previously applied in NSW (Sleeman Consulting 2004). The data sources and inherent limitations are discussed further in this section.

2.3.1 Current production

Onshore petroleum production occurs in a number of basins across Australia and is managed by the states and territories. The availability and quality of current petroleum and water production data varied significantly between the jurisdictions.

Current onshore petroleum and co-produced water data were freely available for SA and Qld. In SA, PIRSA provides detailed monthly production data, including co-produced water data, via the PEPS-SA database (available as a free download). In Qld, six-monthly petroleum (conventional and unconventional) and water production data are published on the DEEDI website, although co-produced water data are only reported for the production phase. The most significant peak water flows occur during the de-watering phase (Figure 5) but these quantities are not reported.

Western Australia was the only other jurisdiction that recorded co-produced water data. Although this data were not openly published, it was readily provided by the DMP.

Discussions with the relevant administering authorities confirmed that co-produced water data were not currently recorded in NSW, Victoria or the NT.

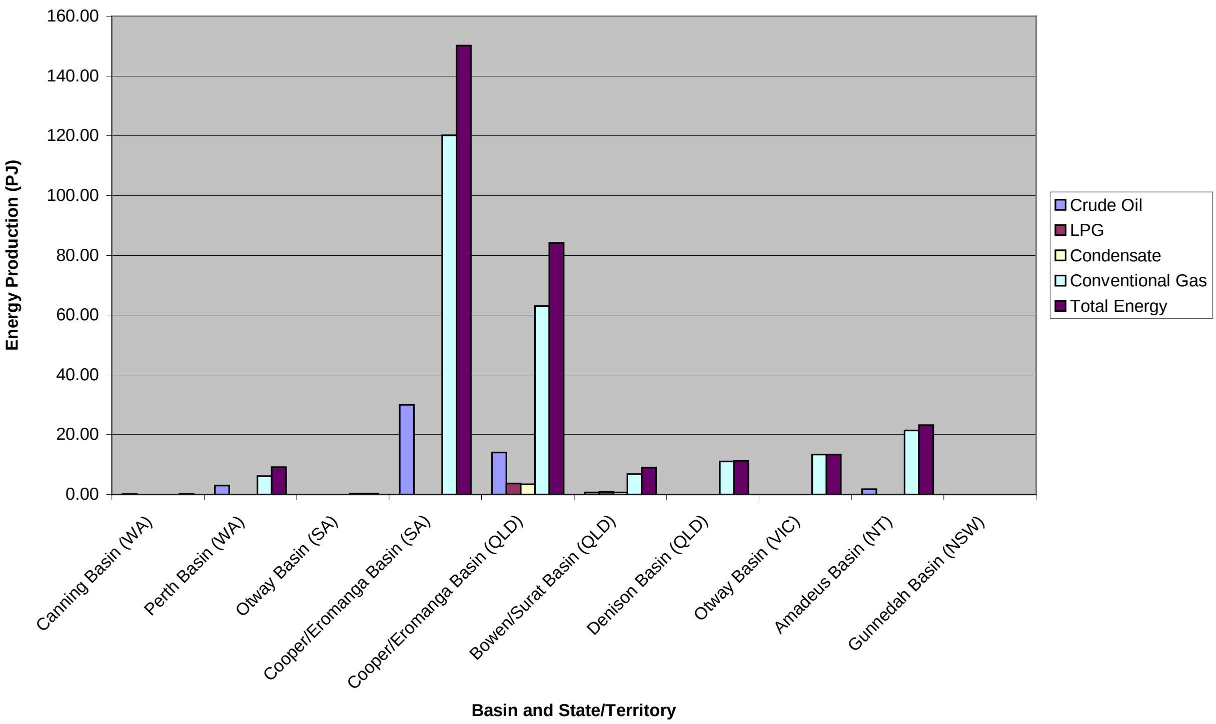
Current co-produced water generation rates across Australia's onshore petroleum industry were compiled for CSG and collectively for conventional petroleum resources. This approach was adopted because, in almost all cases, co-produced water data for conventional petroleum (crude oil, liquefied petroleum gas or LPG, condensate and conventional gas) production were reported as a single cumulative total for production of all types of conventional petroleum resource.

Actual production data were also compiled to allow for determination of a water–energy ratio value for each production basin. Where petroleum production data were reported in non-energy units (e.g. volume or weight units), it was converted using accepted average energy content conversion factors provided by Geoscience Australia and ABARE (2010) for comparative purposes.

2.3.1.1 Conventional petroleum resources

Onshore production of conventional petroleum resources in Australia is dominated by the Cooper–Eromanga Basin (Figure 6). In terms of total energy, the Cooper–Eromanga Basin accounts for almost 80% of onshore energy production from known conventional petroleum resources. As demonstrated in Figure 6, conventional gas is the principal energy source, not only in the Cooper–Eromanga Basin but also in Australia's other onshore conventional petroleum basins.

Figure 6: Current conventional petroleum production in Australia (2008–09)



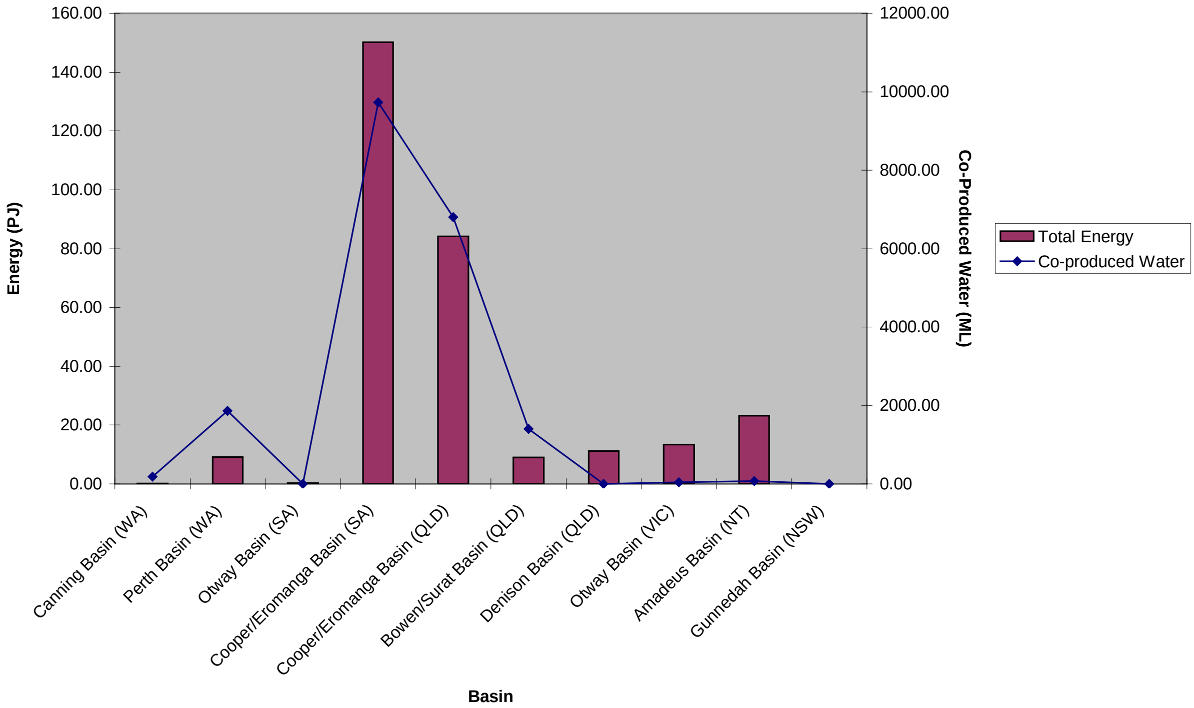
Note:

1. All data are for the 2008–09 financial year with the exception of Canning Basin (2009 calendar year), Perth Basin (2009 calendar year) and Amadeus Basin (2008 calendar year)

Source: DMP 2010; PIRSA 2010; DEEDI 2010; DPI 2009; DRDPIFR 2009; Eastern Star Gas Limited 2009.

As a result of the high intensity of production activity in the Cooper–Eromanga Basin compared with other onshore basins, it produces the largest volumes of co-produced water (Figure 7). In the 2008–09 financial year, petroleum production in the Cooper–Eromanga Basin from SA and Qld generated more than 16.5 GL of co-produced water. This constituted over 80% of the estimated total co-produced water yield (20.1 GL) for onshore conventional petroleum production.

Figure 7: Total current energy production and co-produced water from conventional sources



Note:

1. All data are for the 2008–09 financial year with the exception of Canning Basin (2009 calendar year), Perth Basin (2009 calendar year) and Amadeus Basin (2008 calendar year)
2. Due to an absence of data, co-produced water values for the Otway Basin (Victoria), Amadeus Basin and Gunnedah Basin (NSW) were estimated using the energy–water ratio for conventional gas production in the Cooper–Eromanga Basin (SA) (3.13 ML/PJ)

Source: DMP 2010; PIRSA 2010; DEEDI 2010; DPI 2009; DRDPIFR 2009; Eastern Star Gas Limited 2009.

Although gross volumes of co-produced water peaked in the Cooper–Eromanga Basin, petroleum production from this basin was far more efficient in terms of water–energy outputs than several other basins. Table 1 shows that far greater amounts of co-produced water were generated for each PJ of energy produced in the Canning, Perth and Bowen–Surat basins than in any other basin.

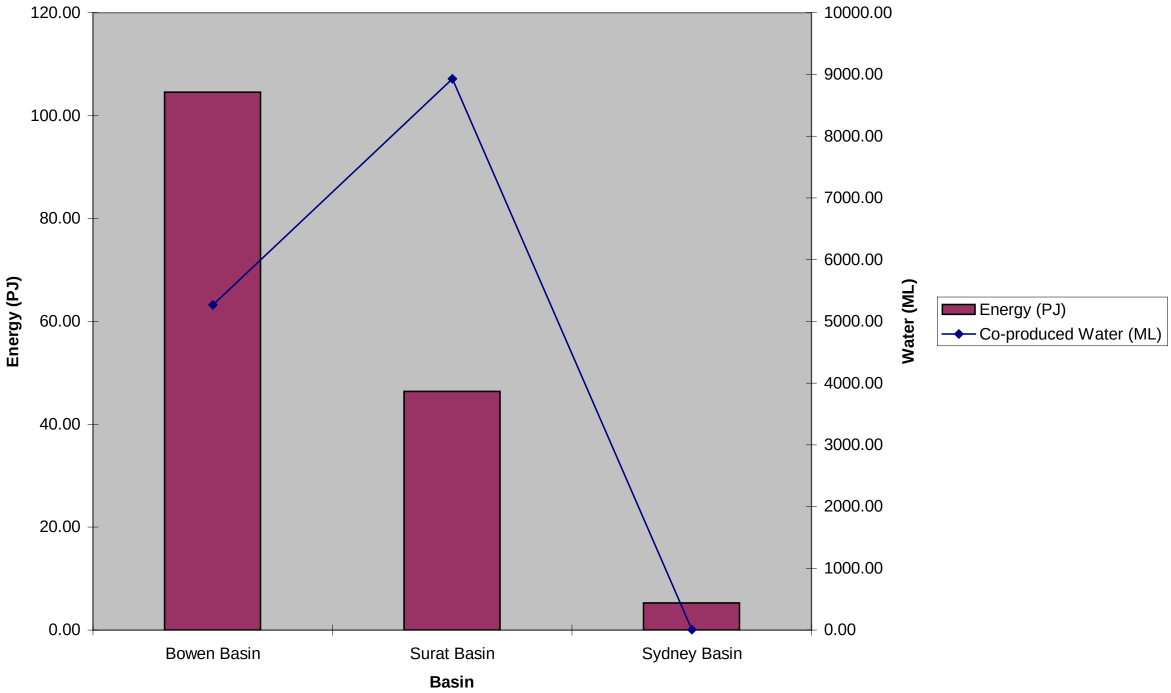
Table 1: Co-produced water–energy ratio by basin for conventional petroleum resources

Basin	*Co-produced water–energy ratio (ML/PJ)*
Canning Basin (WA)	926.35
Perth Basin (WA)	203.05
Bowen–Surat Basin (Qld)	156.44
Cooper–Eromanga (Qld)	80.86
Cooper–Eromanga (SA)	64.77
Denison Basin (Qld)	0.32
Otway Basin (SA)	0.00

2.3.1.2 Coal seam gas

Current CSG production occurs predominantly in Qld's Bowen and Surat basins with minor production from the Sydney Basin (NSW), and to a much lesser extent the Gunnedah Basin (NSW). Figure 8 shows that significant quantities of co-produced water are generated during current CSG production in Qld, particularly in the Surat Basin.

Figure 8: Total CSG energy production and co-produced water



Note:

1. All data are for the 2008-09 financial year with the exception of Sydney Basin (water production data for 2007–08 financial year and CSG production data for 2008 calendar year)
2. Water production data for Sydney Basin refers to water removed from site for disposal and does not include the volume of water reused on site
3. Insufficient data were available for the Gunnedah Basin

Source: Geoscience Australia 2009b; DEEDI 2010; AGL Gas Production (Camden) Pty Ltd 2008.

In the 2008–09 financial year, CSG production in Australia generated more than 14.2 GL of co-produced water. Almost all water was associated with production from Qld's CSG basins, with less than 1% of this estimated yield produced in the Sydney Basin.

In terms of water efficiency, production from the Sydney Basin outstrips the Bowen Basin and the Surat Basin by one and two orders of magnitude, respectively (Table 2). AECOM (2010) made the following observation about water and CSG production from the Camden Gas Project in the Sydney Basin:

'The nature of CSG gas extraction for the Camden Gas Project is not comparable to the CSG projects located in Queensland. For example, the Queensland projects, due to their local geology, generate and impact upon large volumes of groundwater, which require detailed technical assessments on impacts to the environment and community. The operation of the Camden Gas Project has demonstrated that groundwater generation is not a key environmental impact, and has been successfully managed over the last ten years of the Project through EMPs.'

Table 2: Co-produced water–energy ratio by basin for CSG production

Basin	*Co-produced water–energy ratio (ML/PJ)*
Bowen Basin (Qld)	50.4
Surat Basin (Qld)	192.5
Sydney Basin (NSW)	1.2
Gunnedah Basin (NSW)	NA
Powder River Basin (Wyoming, USA)	245.1
Alberta Plains (Alberta, Canada)	0.0–30.0

Notes

1. Water production data available for the Sydney Basin refers to water removed from site for disposal and does not include the volume of water reused on site
2. Insufficient data were available for the Gunnedah Basin
3. Powder River Basin data are for the 2003 calendar year (Ruckelshaus Institute of Environment and Natural Resources 2005)
4. Alberta Plains data are for the 2008–09 financial year (Waffle et al. 2010).

The water–energy ratio for the Powder River Basin in Wyoming, USA, and the Alberta Plains in Alberta, Canada, are provided for comparative purposes (Table 2). The Powder River Basin is the principal CSG producing basin in the US, and relatively mature in terms of development and production when compared with Australia's CSG basins. Only the ratios for the Surat Basin and Powder River Basin were reasonably similar (Table 2).

The Alberta Plains data indicate a marked variability in water-to-gas production ratios from this CSG producing area (Table 2). The Horseshoe Canyon coal formation of the Alberta Plains is described as 'dry' and requires little-to-no de-watering to facilitate gas production (Waffle et al. 2010). At the other end of the spectrum, the Mannville coals are described as 'wet' coals, with a typical water-to-gas production ratio under steady production of approximately 30 ML/PJ (Waffle et al. 2010). The very low to moderately high water-to-gas production ratios of the Alberta Plains are comparable to those for Australia's Sydney and Bowen basins, respectively.

2.3.1.3 Conventional petroleum versus CSG production

In terms of total energy and water production from Australia's conventional petroleum and CSG basins, available data indicate that CSG production (average 90 ML/PJ, with significant variability) generates almost 35% more co-produced water per unit of energy than conventional petroleum production (67 ML/PJ). This is significant considering the sheer size of Australia's 2P CSG reserves (Figure 2) and the anticipated increase of the CSG–LNG industry. Potential future quantities of co-produced water from Australia's onshore petroleum industry are described in the following section.

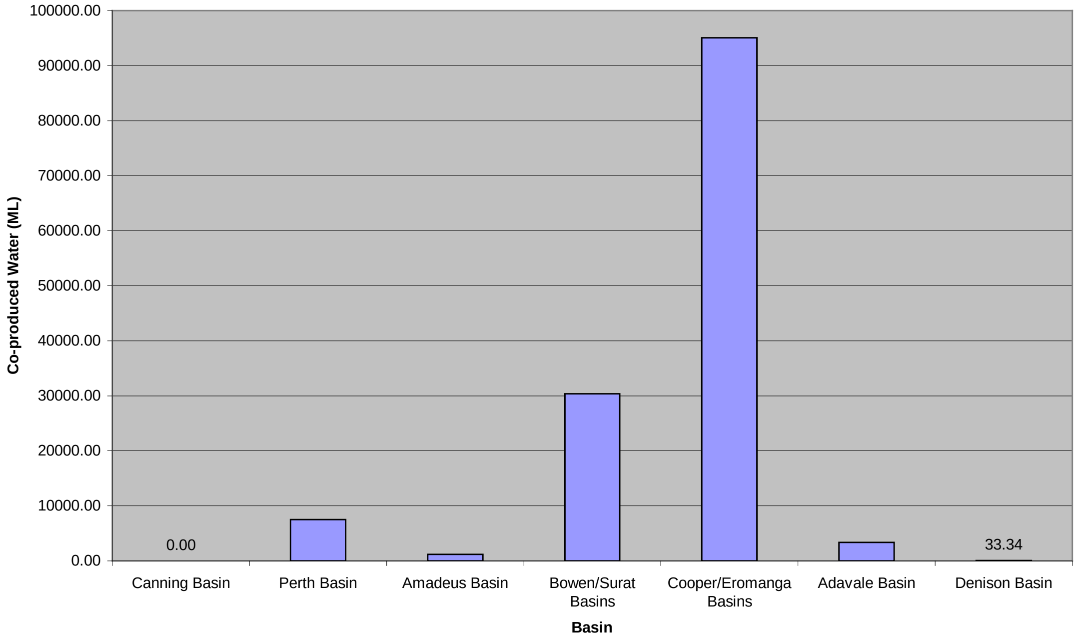
2.3.2 Future co-produced water quantities

2.3.2.1 Conventional petroleum

Australia's conventional petroleum resources are largely located in offshore basins where almost all growth in conventional petroleum resource production is expected to occur. In terms of future onshore petroleum production, most growth is anticipated in unconventional resources such as CSG (refer section 2.1).

Although little growth is predicted for onshore conventional petroleum resources, an estimate of potential co-produced water quantities for these resources (Figure 9) was developed from current 2P reserve estimates and the derived water–energy ratios (Figure 7). No other estimates of future co-produced water quantities for conventional petroleum resources at a project or basin scale were available.

Figure 9: Predicted co-produced water quantities for conventional petroleum resource basins



Notes:

1. An average water–energy ratio value was used for the Cooper–Eromanga Basin based on previously calculated ratios for SA and Qld portions of the basin
2. The ratio value for the Bowen–Surat Basin used for the Adavale Basin

Source: Geoscience Australia 2009b; DMP 2009; DEEDI 2010; Eastern Star Gas Limited 2010; Metgasco Limited 2010; AGL Energy Limited 2010.

Future production of the current 2P onshore conventional petroleum reserves could potentially generate 138 GL of co-produced water over the life of the onshore conventional basins. More than 90% of this water would potentially be produced in the Cooper–Eromanga and Bowen–Surat basins.

2.3.2.2 Coal seam gas

The only available information regarding future estimates of co-produced water from onshore petroleum production pertained to the CSG industry. In Qld and NSW, attempts have been made at both the state and basin scale to estimate the potential quantities of co-produced water from CSG production.

Queensland

As discussed in section 2.3, the CWIMI investigated the potential groundwater impacts associated with Qld's CSG industry in the Surat and Bowen basins. The CWIMI developed a conceptual model to estimate the possible magnitude and spatial extent of water production associated with CSG. In addition to an estimated annual average of 25 GL of co-produced water from domestic CSG production, the CWIMI estimated potential annual co-produced water volumes for three different CSG–LNG industry scenarios over a 25-year period (Table 3).

Table 3: Queensland CSG–LNG industry scenarios and estimated annual co-produced water volumes in 2020

Development scenario	*CSG–LNG industry annual production (PJ)*	*CSG–LNG industry co-produced water (GL/yr)*
Scenario 1	550 (10 Mt)	126
Scenario 2	1885 (28 Mt)	196
Scenario 3	2262 (40 Mt)	281

Source: Adapted from CWIMI (2008).

The CWIMI (2008) report estimated that Qld's CSG–LNG industry could produce between 110 GL and 11 200 GL of co-produced water over its life. DEEDI (2009) reported annual water production rates (Table 4) that were used to broadly estimate total co-produced water quantities over the expected life of Qld's CSG–LNG industry. Over an estimated 25-year period, approximately 3000–7000 GL of co-produced water may be generated, depending on the size of the CSG–LNG industry. Over this period, there could also be 625 GL of water associated with domestic production in the Surat Basin.

The CWIMI (2008) report predicted the distribution of water associated with the CSG–LNG industry by coal measure but not by basin. Based on tenement and estimated water distributions by coal measure reported by CWIMI (2008), a general indication of potential CSG–LNG industry water production distribution by basin was developed based on the following assumptions:

- production from Moranbah and Baralaba coal measures is restricted to the Bowen Basin
- production from the Walloon Coal Measures is restricted to the Surat Basin
- production from the Bandanna Coal Measures is evenly split between the Bowen and Surat basins.

Table 4: Estimated CSG–LNG industry water distribution by basin

	Surat Basin (%)	*Bowen Basin (%)*	*Total (%)*
Walloon Coal Measures	35.3	0.0	35.3
Bandanna Coal Measures	31.1	31.1	62.2
Moranbah Coal Measures	0.0	2.3	2.3
Baralaba Coal Measures	0.0	0.2	0.2
TOTAL	66.4	33.6	100

Note:
1. Average values calculated from CWIMI (2008) water distribution estimates for three industry-size scenarios.
2. Water production associated with Bandanna Coal Measures was assumed to be distributed evenly between Bowen and Surat basins

Source: Adapted from CWIMI (2008).

From the estimated distributions in Table 4, approximate water quantities generated in the Surat and Bowen basins were determined for the three different CSG–LNG industry scenarios over 25 years (Table 5).

Table 5: Estimated CSG–LNG industry water quantity by basin

Basin	*Distribution of CSG–LNG industry water (%)*	*Estimated co-produced water (GL)*		
		Scenario 1 (3150 GL total)	Scenario 2 (4900 GL total)	Scenario 3 (7025 GL total)
Bowen Basin	33.6	1058	1646	2360
Surat Basin	66.4	2092	3254	4665

Note: Scenario 1 and 2 cover low-development scenarios and are not considered likely. Scenario 3 is a likely development scenario assuming current reserves, noting that future development may exceed this estimate.

As described earlier, domestic production from the Surat Basin over 25 years is estimated to be about 625 GL. Hence, the potential total water production from Surat Basin for LNG and domestic CSG production ranges from 2717 GL for a low development scenario to 5290 GL for a probable development scenario.

The potential quantity of water generated in Qld over the next 25 years from CSG production for LNG and domestic industries is 3775 GL for a low development scenario to 7650 GL for a probable development scenario. These estimates are subject to the same uncertainties as the Sleeman Consulting (2004) estimates discussed in section 2.3. Approximately 70% of this water is expected to be generated in the Surat Basin, with the balance attributed to the Bowen Basin.

Individual industry estimates were also available for QGC's and Santos' proposed CSG–LNG projects. QGC indicated that over the life (20–30 years) of their Queensland Curtis LNG project in the Surat Basin, an estimated 1200 GL of co-produced water would be generated (Environmental Resources Management 2009). Santos predicted an estimated 157–461 GL of co-produced water over the life (25 years) of their CSG fields in the Surat and Bowen basins (URS 2009). Both producers reported substantial uncertainty associated with their estimates, and that more accurate predictions would be developed with future field development and further data collection.

Life-of-project estimates of co-produced water quantity for Origin's and Conoco Phillips' Australia Pacific LNG joint venture project, and Arrow Energy's and LNG Limited's Gladstone LNG project, were not available in late 2010.

Queensland's other potential CSG basins include the Clarence–Moreton Basin, Galilee Basin, Ipswich Basin, Laura Basin, Maryborough Basin and Nagoorin Graben (DME 2008b). While some exploration has occurred in these basins, there were no available data relating to CSG reserves or co-produced water.

New South Wales

Until recently, NSW had been completely reliant on petroleum from interstate or overseas sources (DPI 2005b). Since 2002, CSG has been produced from the Sydney Basin and—to a lesser extent—the Gunnedah Basin (DPI 2005a). Sleeman Consulting (2004) estimated an annual co-produced water value of 15 GL for the NSW CSG industry based on a water–energy ratio of 278 ML/PJ. More current data and estimates described below suggest water–energy ratios in NSW's CSG basins ranging from 1.15 ML/PJ to 23.64 ML/PJ.

Limited data were available at a basin or project scale for the CSG industry in NSW. The Gunnedah Basin contains more than 60% of current 2P CSG reserves in NSW but no estimates or reliable data were available to predict future co-produced water quantities from this basin. Using derived water–energy ratios described below and current 2P reserves, total co-produced water quantities from the Gunnedah Basin may range from 1.8 GL to 36.0 GL.

The Gloucester Basin is the second largest 2P CSG reserve in NSW. Under a production rate of 30 PJ/year estimated by the Gloucester Coal Seam Gas Project joint venture (AECOM, 2009), the resource life based on current estimates (423 PJ) (AGL Energy Limited 2010) is 14 years. The project estimated annual co-produced rates of 200–700 ML/yr. However, they also stated that

'…It's impossible to say with certainty how much water is present in the coal seams within the Gloucester Basin' (Gloucester Coal Seam Gas Project 2008).

An estimated total quantity of co-produced water over the life of the project was not specified. Based on available reserve data and project estimates, the potential total future co-production of water from the Gloucester Basin may be between 3–10 GL. This equates to a water–energy ratio of 7.10–23.64 ML/PJ.

By late 2010, Metgasco had applied for approval to produce CSG and conventional gas in the Clarence–Moreton Basin. The total cumulative quantity of co-produced water for the project over a 25-year period was estimated as 697 ML (MHA Petroleum Consultants 2008). Based on current 2P reserves, this equates to a water–energy ratio of 1.76 ML/PJ. The co-produced water would be largely related to CSG production as generally, little water is removed during production from a conventional gas well (Metgasco 2008).

CSG production in the Sydney Basin occurs at the Camden Gas Project, a joint venture between AGL and Sydney Gas Company. The project has been producing CSG from the Sydney Basin since 2001 (DPI 2005a). Estimates of total future co-produced water quantities for the Camden Gas Project were not available but only minor volumes of co-produced water were anticipated (AECOM 2010). Apex Energy NL, who is undertaking CSG exploration outside of the Camden Gas Project area, noted that quantities of water likely to be co-produced with CSG could not be predicted, but based on regional hydrogeological data, only minimal quantities were expected (Olsen Consulting Group Pty Ltd 2009).

Using the derived water–energy ratio for the Sydney Basin (1.15 ML/PJ) and current reserve estimates (129 PJ) (AGL Energy Limited 2010), the potential total quantity of co-produced water may be about 150 ML.

The water production estimates for NSW's CSG basins are summarised in Table 6.

Table 6: Summary of total estimated water production from known reserves in NSW CSG basins

Basin	*Current 2P CSG Reserves (PJ)*	*Water–energy ratio (ML/PJ)*	*Estimated total water production (GL)*
Gunnedah Basin	1520	1.15–23.64	1.800–36.000
Clarence–Moreton Basin	397	1.76	0.697
Gloucester Basin	423	7.10–23.64	3.000–10.000
Sydney Basin	129	1.15	0.150
Total	2469		5.647–46.847

Note:
Insufficient data were available for the Gunnedah Basin to calculate a basin-specific water–energy ratio. Reserve estimates for Gunnedah and Clarence–Moreton Basin as at 31 December 2009. Reserve estimates for Gloucester and Sydney basins as at 30 June 2009.
Source: Eastern Star Gas 2010; Metgasco Limited 2010; AGL Energy Limited 2010.

Based on the reported water production estimate for the Clarence–Moreton Basin and calculated estimates for the other basins using derived water–energy ratios and current 2P reserve estimates, approximately 5.7–46.9 GL of co-produced water may be generated from production of NSW's current 2P reserves (2469 PJ). Due to the infancy of this industry in NSW, there are few estimates of resource life and the period over which this water may be produced. However, as a possible indication, Metgasco applied a 25-year outlook to their estimates for the Clarence–Moreton Basin.

National estimate of future co-produced water volumes

Limited reliable data is available that relates to likely future quantities of co-produced water from Australia's onshore petroleum industry. From research and crude estimates, approximately 8000 GL of co-produced water may potentially be generated over the next 25 years from known reserves. Santos (2009) indicated the significant potential for up to 15 times greater than current 2P reserves and that the range quoted here is therefore likely to be conservative. Approximately 96% of the water is expected to result from CSG production in Qld's Bowen and Surat basins (Table 7).

Table 7: Estimated potential water co-production from onshore petroleum production of known proved and probable (2P) reserves

Source	*Potential future water production (GL)*	*% contribution*	*Comment*
Onshore Conventional Petroleum Production	138.0	3	Estimate based on production of current 2P reserves and derived water–energy ratios
CSG Production – Bowen Basin (Qld)	2360.0	29	Estimates adapted from CWIMI (2008) with water production forecast to occur over the next 25 years
CSG Production – Surat Basin (Qld)	5290.0	68	
CSG Production NSW	5.7–46.9	<1	Estimate based on known potential recoverable reserves and derived water–energy ratios
Total	7835.0		

Note: Based on the most likely production estimate from NSW and Qld using known reserves.

3. Water management

The management of co-produced water is a key environmental, social, technical and economic challenge for Australia's onshore petroleum industry, yet several factors can limit the feasibility of water management options. Contemporary management practices from Australian and international operations are explored here. Limitations to co-produced water management methods and the future of onshore co-produced water management in Australia are also discussed.

3.1 Options for co-produced water management

Australian experience is relatively limited in terms of CSG co-produced water management practices, but other countries provide a wealth of practical experience. For example, the Powder River Basin in the USA has similar environmental issues to the Murray–Darling Basin (Parsons Brinckerhoff, 2004). Since CSG production in the Powder River Basin commenced in 1987, a set of best practice co-produced water management options have evolved and are briefly discussed below under the categories of beneficial use, disposal and treatment.

The beneficial use of co-produced water represents an opportunity for petroleum producers to maximise the resource by providing (including trading) water to other parties for use. Given the range of possible end uses, a variety of beneficial use options are available for waters of varying quality, as long as the water is fit for purpose for the intended use (Table 8).

In addition to beneficial use options, in a dry continent such as Australia where water resources are frequently under stress due to drought, climate change and over-allocation, it may be possible to use fit-for-purpose CSG water to manage short-term transitions in water management and the acute ecosystem effects of drought (e.g. sustaining waterways and wetlands). However the volumes and locations of water production may limit the applicability of this option.

It is important to reiterate that CSG and production water flows are not permanent. The gas reserves from any given area are currently predicted to have a 5–20-year life per well, and a typical CSG to LNG project with multiple supply areas may have a 25–35 year production window. Moreover, the water production from each well declines exponentially over its life, so the main supply point migrates with the development drilling activity. There are also risks that changes in economic conditions and state legislation could abruptly influence water management arrangements and therefore the reliability of the water supply.

Table 8: Possible beneficial use options for co-produced water

Beneficial use	*Description*
Irrigation	Irrigation of agricultural or forestry crops with co-produced water
Livestock watering	Co-produced water used for stock consumption
Industrial use	Industrial uses of co-produced water (e.g. coal washing, drilling activities, dust control, enhanced oil recovery, fire protection, slurry piping, cooling water, plant and vehicle washing)
Impoundments	Water storages for co-produced water for various uses (e.g. shallow aquifer recharge, fisheries, recreation, aesthetic purposes, livestock or wildlife watering)
Water supply	Potable water supplies supplemented with co-produced water
Aquifer storage and recovery	Storage of co-produced water in aquifers for future recovery
Aquifer recharge	Recharge of depleted aquifers using co-produced water

Source: ALL Consulting and Montana Board of Oil and Gas Conservation 2002; Western Governor's Association 2006.

Although opportunities exist for beneficial use of co-produced water, there may be situations where treatment may not be economically feasible (ALL Consulting and Montana Board of Oil and Gas Conservation 2002). Disposal options are described in Table 9.

Table 9: Possible disposal options for co-produced water

Disposal	*Description*
Deep injection	Injection of co-produced water into deep subsurface formations (non-potable water reservoirs)
Direct discharge to land surface	Disposal of co-produced water by discharging directly to the land surface
Direct surface water discharge	Disposal of co-produced water by discharging directly to a surface water body
Impoundments	Disposal of co-produced water to evaporation or infiltration ponds

Source: ALL Consulting and Montana Board of Oil and Gas Conservation 2002.

In addition to volume, water quality is the other key determinant of suitable management options (Parson Brinckerhoff 2004). As co-produced water typically contains significant salt concentrations, has a high sodium adsorption ratio (SAR) and may contain other contaminants (such as hydrocarbons), some beneficial use and disposal options may be limited without prior treatment of the water (Environmental Protection Agency 2007). Table 10 provides a brief overview of available treatment technologies.

Table 10: Possible treatment options for co-produced water

Treatment	*Description*
Artificial wetlands treatment	Use of natural biologic reactions to reduce concentrations of some dissolved constituents (e.g. sodium, hydrocarbons, metals) in co-produced water
Chlorination	Chlorination of co-produced water to remove micro-organisms
Ultraviolet sterilisation	Removal of microscopic organic contaminants from co-produced water using ultraviolet energy
Desalination	Using a range of available technologies (e.g. reverse osmosis, ion exchange, distillation, capacitive desalination, electrodialysis reversal and freeze/thaw evaporation), which can also remove other undesirable constituents
Atomisation	An enhanced evaporation process to reduce the quantity of poor quality co-produced water that requires management

Source: ALL Consulting and Montana Board of Oil and Gas Conservation 2002; Western Governor's Association 2006.

3.2 Current management of co-produced water in Australia

There are a number of options available to manage the potential environmental, social and economic effects of co-produced water. However, as we will discuss later, several factors can limit the feasibility of management options. Consequently, in the Powder River Basin for example, even though the CSG industry and government have identified a suite of best practice management strategies, direct surface water discharge and irrigation are the two most common management techniques for good quality water. Most poor quality water has been disposed of through evaporation and infiltration impoundments (Ruckelshaus Institute of Environment and Natural Resources 2005), but more recent North American petroleum industry experience suggests that poor quality water is now largely reinjected.

This is a similar situation to the current onshore petroleum industry in Australia, where evaporation ponds are still widely used due to the generally poor quality of co-produced water but are currently being phased out. There is a growing uptake of alternative management measures for a number of reasons, such as legislative drivers, the CSG industry wanting to be seen as a good 'corporate citizen' and community pressure. Current approaches to co-produced water management in Australia are discussed below under the categories of beneficial use, disposal and treatment.

These management options are currently decided for individual projects on a case-by-case basis, with no overall integration with state water sharing processes. Water made available by treatment for beneficial use or disposal is not yet explicitly included in NWI compliant planning and management processes (refer section 3.4).

3.2.1 Current beneficial use

As the potential values of co-produced water are realised, there have been increased efforts from Australia's onshore petroleum industry to transition away from evaporation ponds and towards beneficial use of the resource. These efforts are briefly summarised in Table 11 with some examples discussed further below.

Table 11: Current beneficial uses of co-produced water in Australia (2010)

Beneficial use	*Description*	*Petroleum resource class*	*Basin*
Irrigation	Irrigation of agricultural or forestry crops with co-produced water	Conventional and unconventional	Perth (WA), Surat (Qld), Bowen (Qld), Gloucester (NSW)
Livestock watering	Co-produced water used for stock water at cattle feedlot	Unconventional	Surat (Qld)
Industrial use	Onsite use of co-produced water for construction, operations and maintenance, and drilling activities	Conventional and unconventional	Numerous
	Enhanced oil recovery trials	Conventional	Cooper–Eromanga (SA)
	Maintenance of reservoir pressure using co-produced water	Conventional	Perth (WA), Otway (Victoria)
	Power station use for cooling and steam raising	Unconventional	Surat (Qld)
	Coal washing	Unconventional	Surat (Qld), Bowen (Qld)

Beneficial use of co-produced water for industrial purposes is currently the most common reuse strategy for conventional and unconventional petroleum producers. At most petroleum production projects—depending on the quality of the co-produced water—treated and untreated water is often used for site operations such as drilling, hydraulic fracturing, dust suppression and hydrostatic pipeline testing. However, more sophisticated industrial reuse of co-produced water has been undertaken at a small number of conventional and unconventional petroleum operations.

An example of innovative industrial reuse of co-produced water is demonstrated by CSG producers in Qld's Surat Basin. At QGC's CSG-fired Condamine Power Station near Chinchilla, raw co-produced water is drawn from QGC's CSG gas fields and treated onsite for cooling and steam production. Other power stations in the region are also using CSG co-produced water for operational purposes.

Other industrial uses of co-produced water include coal washing and stock water for feedlots. Arrow Energy provides untreated CSG co-produced water to Wilkie Creek coal mine for its coal washing plant and up to 4 ML/day to local beef cattle feedlots for stock watering (Ogg 2009).

Urban and industrial water supply would be ideally suited for CSG water reuse, however relatively constant flows at a particular location are required that may not be available from CSG operations. Such uses are being investigated for the Surat Basin, but the lack of large population centres and industrial areas is likely to limit demand. High reliability of supply is a requirement for urban and industrial users, and the short supply period—allied to the uncertainty of supply volumes—is not a strong incentive for major investment in pipeline infrastructure. At best, the supply would allow deferral of investment in alternative supplies.

Reinjection of co-produced water has been undertaken in the Cooper and Otway basins to maintain reservoir pressures and enhance petroleum recovery. In SA's Cooper Basin, the South Australian Cooper Basin Joint Venture undertook pilot testing of water flooding using co-produced water. This involved treating co-produced water to a suitable standard and then reinjecting the treated water at a rate of 250 m^3/day into the target formation to enhance oil recovery (Santos 2003b). At the Iona gas storage field in Victoria's Otway Basin, conventional gas from onshore and offshore sources is stored in underground reservoirs at the facility and recovered as needed. Co-produced water generated during gas recovery is reinjected back into the storage reservoir to maintain pressure and enhance recovery (TRUenergy 2009). Similar uses of co-produced water are employed in the Perth Basin in WA, where reinjection is widely used to preserve reservoir pressures.

Uses of untreated and treated co-produced water for agriculture and forestry are becoming increasingly popular in the CSG industry. In the Gloucester Basin (NSW), untreated co-produced water from CSG pilot projects is being used for pasture irrigation (Gloucester Coal Seam Gas Project 2008). CSG producers, Santos and Origin Energy, are committed to large-scale irrigated forestry projects in Qld’s Bowen Basin. At the time of writing, Santos is providing up to 8 ML/day of reverse osmosis (RO) treated water to irrigate a 243 ha pasture crop and an 800 000 tree timber plantation (Santos 2009), one of Australia’s largest irrigated forestry plantation projects. Origin Energy has committed to providing RO treated water for irrigation of a 300 ha plantation of pongamia, a legume that may have potential as a biofuel source (Worley Parsons 2010).

As noted in section 3.1, CSG water is estimated to be available for approximately 25–35 years, limiting the longer-term usefulness of this co-produced water for beneficial ecological or consumptive uses. The availability of this temporary resource should not replace development and implementation of water resource planning and cannot offset the need to make permanent adjustments to entitlements where necessary.

While not currently in use Australia, the other options such as aquifer recharge or environmental releases may also be considered in future. Aquifer recharge (i.e. returning co-produced water to geological formations) is technically feasible, although there are a range of issues such as geochemical incompatibility (when recharge waters mix with native groundwater) and locations of acceptable aquifers for CSG wells in Australia. This option is favoured in many areas of North America as the lowest cost salt water disposal option. It may need to be undertaken to limit environmental effects from the concentrated brine from CSG water processing units and to reduce handling costs for the poorest quality water. By reinjecting into the coal measures some distance from the CSG operations, it may be possible to limit regional depressurisation of groundwater sources and contamination of good quality groundwater. If water is returned to depleted areas of coal seams, it is unlikely to be suitable for subsequent use—even if treated—because it will re-salinise within the aquifer. We require further assessment of whether aquifer recharge could be an important management option to minimise effects on groundwater levels and pressures.

Environmental water releases may also be subject to practical limitations. Unless substantial water storage capacity is available, sustained low flows are a potential adverse affect on waterways that normally have episodic flows. Off-stream and floodplain wetlands rely naturally on floods rather than in-channel flows, and water would need to be pumped and transported. For example, the volumes available in the Condamine–Balonne system would be valuable to the Narran Lakes during drought, but the multichannel system downstream of St George would deliver little or no water during normal flows, even supplemented with co-produced water.

3.2.2 Disposal

Evaporation ponds are currently the main disposal method of co-produced water but a few other strategies are practiced by the onshore petroleum industry (Table 12).

Table 12: Current disposal strategies for co-produced water in Australia (2010)

Disposal	*Description*	*Petroleum resource class*	*Basin*
Evaporation ponds	Disposal of co-produced water to evaporation ponds	Conventional and unconventional	Numerous
Infiltration basins	Disposal of co-produced water to infiltration basins	Conventional	Cooper–Eromanga (SA), Amadeus (NT)
Reinjection	Injection of co-produced water into deep subsurface formations	Unconventional	Bowen (Qld)
Direct surface water discharge	Disposal of co-produced water by discharging directly to a surface water body	Unconventional	Bowen (Qld), Gunnedah (NSW)
Offsite disposal	Disposal of co-produced water at an offsite facility	Unconventional	Sydney (NSW)

Due to the often-poor quality of co-produced water, the most common approach to management in Australia's conventional and unconventional petroleum industries has historically been disposal via evaporation ponds (Santos Limited 2003b; Environmental Protection Agency 2007; Gloucester Coal Seam Gas Project 2008; Department of Infrastructure and Planning 2009), although these are being phased out except in exceptional circumstances.

Evaporation ponds are typically shallow, lined or unlined ponds that may be bunded or free-form (using natural topographic features). Evaporation ponds are designed to store and evaporate co-produced water. In most cases, prevailing climatic conditions provide adequate evaporative capacity without the need for enhanced evaporation. During conventional petroleum production, co-produced water is generally treated to remove hydrocarbons prior to disposal to evaporation ponds. Whereas in the CSG industry, water charged to evaporation ponds is generally untreated. In all cases, the use of evaporation ponds leads to an accumulation of salts and other contaminants at and near the disposal site.

In the Cooper–Eromanga Basin in SA, disposal of co-produced water is largely to evaporation ponds but infiltration basins are used where necessary. Infiltration basins are generally unformed and allow infiltration of co-produced water to near-surface aquifers. While the co-produced water may be highly saline and contain other contaminants, this disposal method is reportedly limited to water with low hydrocarbon content (10 mg/L) (Santos Ltd 2003a). Similarly, in the NT's Amadeus Basin, evaporation ponds are typically used, but co-produced water is also discharged to nearby salt pans, as required, for infiltration and evaporation.

Disposal via environmental release is highly limited for untreated water. At the time of writing, Santos's Fairview operation in the Bowen Basin was the only example of disposal by direct discharge to a surface water body. Santos discharges up to 4.5 ML/day of untreated co-produced water to Hutton Creek upstream of the Dawson River (URS 2009), and its other disposal option is reinjection of up to 2.4 ML/day of untreated water into the Timbury Hills formation (URS 2009).

There were other examples of direct discharge to surface water but the water was treated prior to disposal. At its Gunnedah Basin CSG operations, Eastern Star Gas uses RO technology to treat co-produced water. The treated water is largely used for site operations but disposal of up to 1 ML/day of treated water to Bohena Creek is possible (Eastern Star Gas Limited 2006). Origin Energy was using a local watercourse for disposal of RO-treated water from its Spring Gully CSG project, but this practice is being phased out in favour of other beneficial uses (Worley Parsons 2010).

The most unusual example of co-produced water disposal comes from the Camden Gas Project in the Sydney Basin. Most co-produced water is reused onsite, but any surplus water is disposed offsite at a municipal waste facility. In the 2007–08 financial year, more than 6 ML of water was disposed of to the Campbelltown City Council Sanitary Depot (AGL Gas Production (Camden) Pty Ltd 2008). As most petroleum production occurs in remote areas, the applicability of this approach is obviously restricted.

Box 1: Evaporation ponds: cost-effective solution or dinosaur?

Evaporation ponds have long been the preferred method for managing co-produced water in Australia, but their days may be numbered. They have the advantage of being low cost, but the ability to evaporate large volumes of water relies on a large land area and leaves a legacy of salt and other contaminant residue.

For these reasons, the Queensland Government has adopted a policy direction that will promote the discontinuation of evaporation ponds for disposal of CSG water and a move towards alternative management practices. This policy direction may potentially affect the economic viability of some CSG projects, depending on water production rates. A project with high gas production could absorb water management costs regardless of the amount of co-produced water, based on profitability from gas sales. For projects with low gas production, high water producers could provide sufficient water to supply a commercial beneficial reuse market to offset the associated management costs, whereas low gas and low water production may be uneconomical without the option to use a lower cost management method for co-produced water disposal, such as evaporation ponds. This is in part due to low gas production rates, but mainly the result of low co-produced water output. Such a project may not produce a commercial and secure volume of water for an end user to offset the higher costs of alternative water management techniques, possibly encouraging greater total groundwater extraction for the same energy production.

As found in the Powder River Basin, this may potentially lead to a lower level of CSG development as projects become unfeasible due to high capital, operating and maintenance costs (Advanced Resources International 2002).

3.2.3 Treatment

Treatment of co-produced water has long been standard practice for the conventional petroleum industry, but CSG producers are adopting treatment technologies. Current treatment methods used by the onshore petroleum industry are identified in Table 13 and discussed below.

Table 13: Current treatment methods for co-produced water in Australia

Treatment	*Description*	*Petroleum resource class*	*Basin*
Oil–water separation	Gravity or chemical separation of oil and water	Conventional	Numerous
Reverse osmosis (RO)	Removal of salts and other contaminants by 'forcing' co-produced water through a semipermeable membrane	Unconventional	Gunnedah (NSW), Bowen (Qld) and Surat (Qld)

During conventional oil production, water and oil are often extracted together and require separation in a two-stage process. The oil–water separation process typically commences with gravity separation in a separation tank. In some cases, chemical separation may also be required at this stage to break emulsions. Following this, the free oil is recovered and the water is directed to a lined interceptor dam for additional gravity separation. Oil is recovered during this stage by skimming booms and the clean water is drawn off for disposal.

During the earlier discussion of available management options, a number of available water treatment technologies considered to be best practice management in the Powder River Basin were described. In Australia's growing CSG industry, RO is the only treatment technology that has been adopted to date. RO technology is currently used by several CSG producers to improve the quality of co-produced water for disposal or reuse.

Depending on the co-produced water quality and required output quality and quantity, co-produced is generally pretreated prior to RO treatment. The RO process involves 'forcing' water through a semipermeable membrane to remove salts and other contaminants. This process can generally achieve a recovered clean water stream of 80–94% of the co-produced water volume, with the balance forming a brine concentrate waste (Parsons Brinckerhoff 2004). The potential uses of RO-treated water are extensive because this process can produce very high quality water. The brine stream requires careful management due to its high concentration. Evaporation ponds are the most common disposal for the brine stream from RO plants (Parsons Brinckerhoff 2004), but suffer from the same legacy of salt accumulation as conventional evaporation ponds. Secondary RO is being trialled as a means to reduce brine production by 50% (Worley Parsons 2010).

The principle that treatment of raw co-produced water may be necessary as a prerequisite for a number of beneficial use or disposal options is widely understood and discussed among regulators and gas producers, but treatment of co-produced water could be better defined. There are certainly technical options (as indicated in Table 10) that aim to alter chemical or microbiological characteristics of water. Physical adjustment of water is possible to address issues such as water temperature, clarity, flow rates, residency times, interbasin and inter-aquifer movement, and matching of receiving environment hydrology. Effective and site-specific treatment of raw co-produced water is most likely a combination of a number of physical, chemical and biological elements. Importantly, treatment targets for water quality will vary, so blanket industry expectations may not be appropriate. Singular attention to water chemistry may have too narrow a focus for many projects.

Box 2: Could clear water effluent lead to poor water quality?

Turbidity—a measure of water clarity—is the cloudiness or haziness of water caused by individual particles (suspended solids) that are generally invisible to the naked eye. In non-coastal rivers and streams of Qld and NSW, turbidity can be highly variable. The ephemeral nature of most of these rivers and streams means that flow events may be high and shortlived (flashy) resulting in high entrainment of suspended solids, and their substratum or entrained-sediment type is such that settling rates of suspended solid are extremely low.

Ambient turbidity levels in the Condamine–Balonne river system, for example, have been variously reported but recent sampling in the Chinchilla region showed average turbidity at sites in the Condamine River of 238.3 ± 168.6 NTU with a median turbidity of 155 NTU. These levels are high but expected for this part of the Murray–Darling Basin. The standard deviations are also very high, supporting the case that turbidity in these river systems is extremely variable between locations and through time. Turbidity is an issue that has been difficult to manage from a regulator perspective, and the potential for CSG water discharge to surface waters has stimulated significant debate.

The current—and default—water quality guidelines for the Qld part of the Murray–Darling Basin are the *Australian and New Zealand guidelines for fresh and marine water quality (2000)*. These guidelines provide turbidity trigger levels ranging from 2 to 50 NTU depending on elevation. For 'upland rivers' higher than 150m above sea level, the guideline is 2–25 NTU. For 'lowland rivers', the guideline is 6–50 NTU (ANZECC 2000).

These guideline levels are much lower than ambient turbidity concentrations for inland waterways, such as the Condamine–Balonne river system. For this reason, many regulator documents prefer to consider variation from ambient levels as a measure of compliance, and to this end, ambient median turbidity plus or minus 10% is often discussed as an appropriate guideline for water management. For the Condamine River system near Chinchilla, a working turbidity range for regulatory purposes might be approximately 140–170 NTU[1].

Treated CSG water is likely to be very clear, with a turbidity of less than 1 NTU being typical of an RO plant. This being the case, output RO water will have turbidity that is two orders of magnitude lower than potential receiving waters.

In small volumes, discharge of this clarity may not be significant with respect to the receiving water's water quality and ecology. However, in large volumes, clear water has the potential to dramatically alter aquatic ecosystem function given background turbidity levels for the region, especially during periods of naturally low flow. A number of potential mitigation options need to be considered as part of any environmental impact assessment. One potential solution currently favoured in Wyoming is to discharge the water via outcropping aquifers rather than directly into the river. While continuous release of CSG co-produced water to ephemeral systems is not a preferred management option, there may be opportunities in Australia (in certain circumstances) to pulse treated CSG water via outcropping aquifers. As a minimum, the condition of these aquifers (e.g. salinity levels) would need to be determined beforehand, and much more work in this area is needed.

3.3 Water management decisions for major projects

3.3.1 Practical limitations

There is a long list of possible options available to manage the potential environmental, social and economic impacts of co-produced water, but a number of key constraints must be considered. Outside Qld, there appears to have been little work undertaken to evaluate the limitations of the many different approaches to co-produced water management.

[1] Much larger and more rigorous data sets are available to calculate these figures. This example provides approximate turbidity figures that illustrate the difference in turbidity between treated water and receiving waters.

In Qld, the state government has announced a policy preference for reinjection of co-produced water and the CSG industry have attempted to understand the potential constraints and identify feasible co-produced water management options. In 2004, Parson Brinckerhoff undertook a broad review of potential water management strategies for the CSG industry on behalf of the Queensland Government. However, due to the rapid rate at which the industry, policy and legislation in Qld is evolving, this discussion paper refers to more current work undertaken by the CSG–LNG project proponents.

At the time of writing, there were eight proposed CSG–LNG projects for Qld, four of which include development of CSG fields in the Surat and Bowen basins. The other proposals relate to LNG processing facilities and do not include a CSG development component. By late 2010, three of the CSG project proponents have prepared co-produced water management plans. These plans include a review of available water management options that generally reflect the options described in Tables 10–13. More importantly, the plans also include a constraints analysis to identify feasible management strategies from the proponent's perspective. As almost all co-produced water over the next 25 years is expected to be derived from Qld's CSG industry, an overview of the key constraints and feasible co-produced water management options identified by Qld's major CSG–LNG industry players has been provided. Some legacy issues associated with co-produced water management that may persist well beyond the current estimated industry life have also been raised.

A list of common constraints to water management identified by the Queensland Curtis LNG, Gladstone LNG and Australia Pacific LNG project proponents is summarised in Table 14.

Table 14: Key constraints to CSG water management in Qld

Key constraint	*Description*
Regulatory framework	Restrictions to management options imposed by legislation
Geography	Production areas are often remote, hence the distance to a beneficial user or disposal point may determine feasibility
Water quality	Due to the poor quality of co-produced water, treatment is generally required, which introduces potential economic, technology and environmental challenges
Water quantity	Includes the quantity of water that can be taken for beneficial uses, the stability in demand and the level of uncertainty around projected quantities, which may affect a producer's ability to guarantee supply
Economic	Costs associated with management options vary and may influence the feasibility of particular management techniques
Environment	Includes the natural, social and economic environments and the potential short- and long-term effects associated with different management options
Technology	Refers to the proven capability of water management and treatment technologies

Source: Environmental Resources Management 2009; URS 2009; Worley Parsons 2010.

Many of the beneficial use or disposal options for CSG co-produced water are constrained by environmental challenges. Environmental impact as a key constraint is indicated in Table 14 but the importance of geography, water quality and water quantity is, perhaps, less clearly articulated in an ecosystem context by assessments with social, policy and economic foci.

3.3.2 Feasible management options

In developing their proposed water management strategies, the CSG–LNG proponents undertook a constraints analysis of available management options. An example of an options–constraints summary from Santos's proposed Gladstone LNG project is provided in Table 15.

Table 15: Gladstone LNG water management options constraints summary

Water management option	*CSG field*		
	Roma	*Fairview*	*Arcadia*
Potable use	green	red	red
Other municipal uses	green	red	red
Agricultural use	green	green	green
Industrial use	green	red	red
Injection into overlying aquifers—brine stream	red	red	red
Injection into overlying aquifers—associated water	red	amber	red
Injection into CSG aquifers	red	red	red
Injection into underlying aquifers—brine stream	red	green	red
Injection into underlying aquifers—associated water	red	red	red
Storage dams—large scale (> 250 ML)	red	red	red
Storage dams—small scale (< 250 ML)	green	green	green
Large-scale evaporation ponds for associated water	red	red	red
Evaporation ponds for managing brine stream	amber	amber	amber
Treated discharge to surface water	amber	amber	amber
Untreated discharge to surface water	red	red	red

Key to constraint levels: green (low); amber (medium); red (high)
Source: URS 2009.

From the results of their constraints analyses, the CSG–LNG project proponents identified their initial preferred management options (Table 16). All project proponents qualified their proposals by stating that it is likely that management arrangements may vary over time to reflect changing conditions associated with the key constraints.

Table 16: Summary of management strategies preferred by project proponents

CSG–LNG project	*Beneficial use*	*Disposal*	*Treatment*
Queensland Curtis LNG	• Irrigation of tree crops with blended water (a mix of treated and untreated water) • Supply of treated or untreated water to mines (includes coal wash water) • Reinjection of treated or untreated water	• Disposal of water to evaporation ponds (short- to medium-term solution)	• Reverse osmosis with evaporation ponds for brine stream
Australia Pacific LNG	• Treated water for agricultural use, crop and plantation irrigation • Opportunistic discharge of treated water to surface water		• Reverse osmosis with evaporation ponds for brine stream
Gladstone LNG	• Treated and untreated water irrigation of food, fodder and tree crops • Treated water provided to supplement potable water supply • Treated water supplied for industrial use		• Reverse osmosis with injection wells and evaporation ponds for brine stream

Source: adapted from Environmental Resources Management 2009; URS 2009; Worley Parsons 2010.

Table 15 demonstrates that the constraints analyses undertaken for the three proposed CSG–LNG projects returned reasonably similar results. Irrigation was generally found by the proponents to be the least constrained management option. Reverse osmosis was the preferred method of treatment for all projects. Mine wash water supply and power plant cooling were also seen as viable beneficial uses, depending on geographic location.

3.4 NWI consistency of co-produced water management options

The previous section indicates that there is no universal solution to co-produced water management and the available options must be considered for each project. Economic, social and environmental contexts vary widely and are taken into account in preparing and evaluating projects.

All Australian governments agreed to implement the NWI 'in recognition of the continuing national imperative to increase the productivity and efficiency of Australia's water use, the need to service rural and urban communities, and to ensure the health of river and groundwater systems by establishing clear pathways to return all systems to environmentally sustainable levels of extraction.' The objective of the agreement is to 'provide greater certainty for investment and the environment, and underpin the capacity of Australia's water management regimes to deal with change responsively and fairly'.

This section reviews co-produced water management options against the key elements of the NWI (clause 24). It is intended to raise discussion on the issue of bringing co-produced water into NWI consistent planning and management frameworks rather than providing a definitive analysis of current and future practice.

3.4.1 Key elements of the NWI

The NWI calls for the use of Water Access Entitlements within a water-planning framework as a means of allocating the consumptive use of water. By default, these entitlements should be defined as a perpetual share of water within a defined consumptive pool for a planned area, and should be separate to land title.

Clause 34 of the NWI is particularly relevant to the CSG industry as it specifically addresses the special circumstances of the minerals and petroleum sectors. Clause 34 notes that specific water-related issues may be associated with these sectors that need to be addressed and lie outside the scope of the NWI. In addressing such issues, the NWI specifies that projects will need to address environmental, economic and social considerations, and that these considerations should be addressed in terms of factors specific to resource development projects (e.g. isolation, relatively short project duration, water quality issues, obligations to remediate and offset impacts). The remainder of the water management arrangements may be within the scope of the NWI and could be brought into the planning framework where possible.

The NWI covers a broad range of issues that may be summarised as the 'key elements' of clause 24. Of the eight key elements listed in the NWI, four are of direct relevance to CSG co-produced water and are discussed here:

- water access entitlements and planning framework (clauses 25–57)
- water markets and trading (clauses 58–63)
- integrated management of water for environmental and other public benefit outcomes (clauses 35, 78)

- water resource accounting (clause 80).

This brief analysis only addresses these four elements, for the purpose of raising issues associated with the various co-produced water management options, although it is recognised that there may be other relevant considerations elsewhere. Table 17 examines CSG co-produced water related to these key elements.

Table 17: CSG co-produced water management considerations and key elements of the National Water Initiative (NWI)

Key element	*Current management arrangements*	*Possible policy considerations for including co-produced water in the NWI framework*	*Possible practical considerations*
Water access entitlements and planning framework	• Co-produced water is not explicitly included in any current water plans • Water access entitlements are not clearly defined for CSG projects in terms of the consumptive pool	• Temporarily available water (e.g. CSG water) is outside the consumptive pool description (NWI clause 28). Should description and definition be expanded to include this temporary water resource? • If the consumptive pool was to include a temporary CSG water resource, how could water plans be modified to manage this temporary water resource? • When the period of water availability ends, how would water access entitlements and planning frameworks manage environmental, social and economic issues associated with community and commercial dependence built on 25–35 years of reliance on CSG water? • How would the planning process manage transition issues for water resources post-CSG water availability? • Could CSG water be managed as a fixed term or other type of entitlement (i.e. NWI clause 33) and if so, how will risks be assigned and managed? How can security of entitlement for other users in connected systems be guaranteed? (e.g. 'make good' provisions) • How would CSG water that is not part of the current consumptive pool (e.g. water that is bought and piped directly to users) be managed? Could this add another management or planning layer, and would this type of water access influence priority or right to surface water access within the consumptive pool? (i.e. affect security)	A significant policy and legislative effort would be required to amend state government water plans. There would also be substantial inter-jurisdictional issues to manage (e.g. CSG water source and beneficial-use destination may fall under separate jurisdictional water plans and separate management arrangements). Guaranteeing the security of entitlement could potentially become a significant cost to government or CSG producers, and would require an administrative structure able to manage the long timeframes of some potential effects. The details of risk assignment would have to be carefully considered.
Water markets and trading	• Potential markets for co-produced water have not been developed	• A complex legislative system (particularly across jurisdictions) can lead to poor CSG water management (as experienced in the US's Powder River Basin). Can Australia's interstate legislative system be coordinated and streamlined to ensure common goals for policy and legislation to optimise environmental, social and economic outcomes associated with CSG water? • The use of waterways to transfer temporary water (e.g. CSG water) for commercial use downstream is not permitted in Qld, and is assessed on a case-by-case basis in NSW. Piping and pumping	Interstate legislation would have to be coordinated and streamlined, and the practicalities of CSG water trade resolved in an environmentally, socially and economically acceptable manner.

Key element	*Current management arrangements*	*Possible policy considerations for including co-produced water in the NWI framework*	*Possible practical considerations*
		CSG water to buyers for commercial use can be cost-prohibitive. Given this, could CSG water be traded cost competitively in an open market? • Can CSG water be traded temporarily on access entitlements? • If CSG water were to be traded, would CSG companies be required to become water service providers, or could some other mechanism be established?	
Integrated management of water for environmental and other public benefit outcomes	• Co-produced water is not currently used for environmental purposes. • The impact of extraction is not currently known in sufficient detail to plan for possible environmental and other outcomes	• Could CSG water be used as a substitution for or to enhance existing water resources used for environmental and other public benefit outcomes in the short term? Could this outweigh possible cumulative effects in the long term? • Could CSG water be substituted for water currently allocated from the consumptive pool, freeing this water for environmental and other public-benefit outcomes? • What processes need to be developed and implemented to transition back to longer-term water planning and management following the cessation of CSG activities? Should CSG water be used for short-term environmental and other public-benefit outcomes? • The use of CSG water for environmental or public benefit would currently be controlled under existing regulations (e.g. for water quality, volumes, release timing) with a general focus on local conditions. How would more geographically distant and diverse uses (including cumulative non-volumetric issues) be managed?	Concerning water allocated for environmental and other public-benefit outcomes, Qld has a rules-based approach and NSW uses a combination of rules and entitlements (depending on location). The NWI calls for assessment on a case-by-case basis. These approaches would have to be coordinated to ensure a consistent interstate approach within a common framework. Inter and intra-jurisdictional links with non-hydrographical (volumetric) water planning (e.g. values and threats) would also be a challenge to incorporate.
Water resource accounting	• Co-produced water is not currently accounted adequately or reported consistently (refer section 2.3.1)	• While most of the larger CSG companies collect water resource data (e.g. volumetric data and EC levels), how should this data be provided to the state and Australian governments? • Should the scope of water resource accounting be expanded to include non-volumetric issues? (e.g. biological condition, physicochemical measures) • How would CSG companies' commercial-in-confidence information be treated? • How would CSG water resource accounting information be used for	Commercial-in-confidence issues and the mechanism for water service providers would have to be addressed.

Key element	*Current management arrangements*	*Possible policy considerations for including co-produced water in the NWI framework*	*Possible practical considerations*
		water planning and adaptive management? • Would CSG companies be required to be water service providers, or is there another effective and efficient method of trading and accounting?	

While clause 34 of the NWI was developed to cater for the special needs of the petroleum and minerals sectors, Table 17 shows that there is an opportunity to largely include CSG water within the NWI framework, giving all water users greater certainty about their share of the consumptive pool. Clause 34 could then be used only where there are genuinely special circumstances for individual projects.

4. Conclusions

The volumes of co-produced CSG water are significant at a subregional scale. Water volumes are uncertain, but Qld has the overwhelming majority of known CSG reserves, located in the Bowen and Surat basins. All of the main CSG production basins are in rural areas where water resources are already under pressure, and unless reinjected, co-produced water may represent a further increase in consumptive take.

Overall co-produced water volumes are expected to increase rapidly over the next few years. These flows are not permanent. The gas reserves from any given area are currently predicted to have 5–10 years life per well, and a typical CSG–LNG project with multiple supply areas may have a 25–35 year production window. If some or all of the water is released to surface waters or shallow aquifers, there will be significant transitional effects at both ends of this period for ecosystems and water users. The transitional effects will be more acute at local scale where the production periods for individual gas fields are shorter.

Treatment of co-produced water is usually essential if it is to be used for beneficial purposes. Treatment technologies are available and there appears to be acceptance by CSG producers that untreated water disposal will not be permitted on a large scale and that the costs and responsibility of treatment are borne by the producer. Treated water discharge also requires a licence. The most promising uses of the water are to substitute existing demand for irrigation, mine wash water and power plant cooling. Using co-produced water to provide environmental flows to nationally or internationally important wetland systems (e.g. Narran Lakes) would be limited by the short availability window and system losses, and unlikely to succeed.

State water quality legislation is well established, and although water clarity and temperature are potential effects, state regulatory processes are capable of dealing with most issues at the surface. The main legislative constraint is the lack of integration between co-produced water volumes and water plans. The challenge is to minimise the effects of extraction and devise a system of beneficial uses, such as substituting irrigation demand that can adequately address the risks of the additional groundwater take.

Achieving NWI objectives will require state and Commonwealth cooperation to ensure that the long-term effects of groundwater extraction for CSG production do not adversely affect water availability for other users and the environment. This will require quantification of the cumulative effects on connected water systems and an awareness of the long timeframes involved.

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SENATE RURAL AFFAIRS AND TRANSPORT REFERENCES COMMITTEE

Inquiry into the management of the Murray-Darling Basin

Public Hearing Tuesday, 9 August 2011

Questions Taken on Notice – QLD Dept of Environment and Resource Management

21. HANSARD, PG 78

Senator WATERS: I am the third one you would not shoot, Bill. There is a reference in a media report to Queensland testing 2,700 wells, of which two per cent were leaking. So that is 54 leaking wells. Can you tell me more about that testing and can you tell me what the government is doing about those 54 leaking gas wells? Is that leaking regulated or permitted? Does that leaking have to be monitored? How does that factor into the greenhouse gas intensity profile of coal seam gas? There are a number of sub-questions there, but the first was about the details of that study and what the government is doing about these leaking wells? I hope it is not just permitting them to continue leaking.

Mr Brier: The short answer is that those leaks are definitely unacceptable. The companies have been ordered to fix those leaks and, to my knowledge, all of those leaks have been rectified. The CSG wellhead safety report—

Senator WATERS: Was there any penalty for the breach?

Mr Brier: I am unsure.

Senator WATERS: Would you mind taking it on notice?

Mr Brier: Yes.

22. HANSARD, PG 83

Senator EDWARDS: I have questions on notice for you because it would be unfair to ask you fellows what the answers are right now. Hopefully, we are going to hear from the government again. How much longer can the Queensland and New South Wales governments, whom you cannot speak for, go on being the regulators and the beneficiaries of royalties without the people in the streets starting to get restless, which they are? How long before you can ignore trying to find some other way of monitoring the issues in coal seam gas mining?

23. HANSARD, PG 83

Senator EDWARDS: On the theme of the questions behind me, has the government given any thought to establishing a provision for any issues down the track? For example—excuse the pun—a sinking fund from the royalties it gets from coal seam gas mining to repair the damage in the longer term in the same way as you make provision for long service leave in any business or government?

26. Written question on notice, Senator Waters

Can the Queensland Government inform the inquiry whether coal seam gas extracted in Australia is less greenhouse gas intensive than black coal on a life cycle analysis basis (particularly when exported) and, if so, by what percentage?

27. Written question on notice, Senator Waters

Has the Queensland Government conducted or commissioned any independent life cycle analysis of the greenhouse gas intensity of coal seam gas produced in Australia (for domestic energy generation, as well as for export) or is the government relying on industry studies from here and from overseas to form its views on this issue?

28. Written question on notice, Senator Waters

Can the Queensland Government advise whether the studies it has undertaken has 1/ taken into account not only the fugitive emissions from leaking wells and pipes (and pls advise the basis on which fugitive emissions are calculated or estimated) and 2/ taken into account the energy requirements of reverse osmosis of produced water, liquefication and transport domestically and export (and the assumptions underpinning these calculations), 3/ and in the case of CSG for export, what are the assumptions around the power generation technology used?

29. Written question on notice, Senator Waters

BTEX ban – why did the Queensland Government take so long to bring the BTEX ban announced in October 2010 into effect?

INQUIRY INTO THE MANAGEMENT OF THE MURRAY-DARLING BASIN
QUESTION ON NOTICE

No. 21

Asked at the Public Hearing on Tuesday, 9 August 2011

Senator WATERS: I am the third one you would not shoot, Bill. There is a reference in a media report to Queensland testing 2,700 wells, of which two per cent were leaking. So that is 54 leaking wells. Can you tell me more about that testing and can you tell me what the government is doing about those 54 leaking gas wells? Is that leaking regulated or permitted? Does that leaking have to be monitored? How does that factor into the greenhouse gas intensity profile of coal seam gas? There are a number of subquestions there, but the first was about the details of that study and what the government is doing about these leaking wells? I hope it is not just permitting them to continue leaking.

Mr Brier: The short answer is that those leaks are definitely unacceptable. The companies have been ordered to fix those leaks and, to my knowledge, all of those leaks have been rectified. The CSG wellhead safety report—

Senator WATERS: there any penalty for the breach?

Mr Brier: I am unsure.

Senator WATERS: Would you mind taking it on notice?

Mr Brier: Yes.

ANSWER:

The media report is not correct. The correct information can be found in the "Coal seam gas well head safety program final report April 2011" published on the Department of Employment, Economic Development and Innovation website (http://mines.industry.qld.gov.au/safety-and-health/petroleum-gas-safety.htm).

As a result of the well head safety program a code of practice was developed to provide a consistent industry approach to wellhead leak testing, reporting and remediation. ("Code of Practice for coal seam gas well head emissions detection and reporting" - see http://mines.industry.qld.gov.au/safety-and-health/petroleum-gas-safety.htm).

Failure to comply with a direction is an offence under the *Petroleum and Gas (Production and Safety) Act 2004* (P&G Act).

Author Stephen Matheson Approved Stewart Bell

Business Unit	Chief Inspector Petroleum and Gas Safety and Health	Business Unit	Deputy Director General Safety and Health
		Date	25 August 2011

INQUIRY INTO THE MANAGEMENT OF THE MURRAY-DARLING BASIN
QUESTION ON NOTICE

No. 22

Asked at the Public Hearing on Tuesday, 9 August 2011

Senator EDWARDS: I have questions on notice for you because it would be unfair to ask you fellows what the answers are right now. Hopefully, we are going to hear from the government again. How much longer can the Queensland and New South Wales governments, whom you cannot speak for, go on being the regulators and the beneficiaries of royalties without the people in the streets starting to get restless, which they are? How long before you can ignore trying to find some other way of monitoring the issues in coal seam gas mining?

RESPONSE:

All Queenslanders are the owners of the state's rich resources and all Queenslanders benefit from the royalties that government collects from the mining companies.

These royalties help build our schools and hospitals, put police on the beat and teachers in our classrooms.

Treasury has carriage of royalties, not the Department of Environment and Resource Management.

Queensland has some of the toughest regulations in the world when it comes to protecting our environment.

The State Government has significantly toughened legislation relating to the environmental regulation of the coal seam gas industry and has increased funding for compliance and enforcement.

Author: Petrina Prowse	Approved: ADG ENRR
	Approved: ADG OER
Date: 25 August 2011	Approved: Office of the Director-General
CTS No.	

INQUIRY INTO THE MANAGEMENT OF THE MURRAY-DARLING BASIN
QUESTION ON NOTICE

No. 23

Asked at the Public Hearing on Tuesday, 9 August 2011

Senator EDWARDS: On the theme of the questions behind me, has the government given any thought to establishing a provision for any issues down the track? For example—excuse the pun—a sinking fund from the royalties it gets from coal seam gas mining to repair the damage in the longer term in the same way as you make provision for long service leave in any business or government?

RESPONSE:

The Queensland Government believes that the existing framework is comprehensive and is sufficient to deal with the impact of the coal seam gas industry.

The *Water Act 2000* imposes a range of obligations on coal seam gas operators including undertaking baseline assessment of private water bores and forward modelling to improve our predictive capacity as part of Underground Water Impact Reports.

Companies are also required to enter into make good agreements with landholders to ensure that impacts on water supplies in a private water bore are made good. The make good obligations are binding on anyone who inherits title of the petroleum tenure and the water bore and any person to whom title of the water bore/tenure is transferred. The Department of Environment and Resource Management may also direct actions by the company if necessary, including to make good.

There are also financial assurance provisions under the *Environmental Protection Act 1994* that require companies to provide the department with access to funds in the event that the department needs to remediate any impacts on behalf of the company (e.g. if it goes insolvent). There are a range of other tools such as Environmental Protection Orders and Clean-up Notices which the department can issue to companies that can direct them to take certain action including stopping work or rehabilitation.

Author: Petrina Prowse	Approved: ADG ENRR Approved: ADG OER
Date: 25 August 2011	Approved: Office of the Director-General
CTS No.	

INQUIRY INTO THE MANAGEMENT OF THE MURRAY-DARLING BASIN QUESTION ON NOTICE

No. 26

Asked at the Public Hearing on Tuesday, 9 August 2011

Senator WATERS: Can the Queensland Government inform the inquiry whether coal seam gas extracted in Australia is less greenhouse gas intensive than black coal on a life cycle analysis basis (particularly when exported) and, if so, by what percentage?

Answer

Electricity generated domestically from **coal seam gas (CSG)** produces approximately 50 per cent lower emissions than coal-fired generation.

This reduction in emissions for electricity generated domestically from CSG is supported by a 2009 ACIL Tasman report, commissioned by the Australian Energy Market Commission. The report shows that the emissions intensity of new entrant Combined Cycle Gas Turbine (CCGT) generators in Queensland is around half that of black coal generators based on a 'like-for-like' comparison of gas and coal used for base-load generation.

The reduction in emissions is also supported by actual results. As an example of a like-for-like comparison of most current technologies, Queensland's Kogan Creek power station is an efficient supercritical coal plant that produces around 860kg CO2-e per MWh, whereas Queensland's Swanbank E power station is an efficient combined cycle gas turbine generator using CSG that produces around 400kg of CO2-e per MWh, less than 50 per cent of Kogan's emissions.

Life cycle emissions from **liquefied natural gas (LNG)** used to generate power are approximately 60 per cent of those from the use of coal, depending upon the processing and electricity generation technologies used.

Three currently available analyses support this assessment:

- CSIRO, December 1996, Lifecycle Emissions and Energy Analysis of LNG, Oil and Coal
- Pace, February 2009, Life Cycle Assessment of GHG Emissions from LNG and Coal Fired Generation Scenarios: Assumptions and Results and
- WorleyParsons, April 2011, Greenhouse Gas Emissions Study of Australian CSG to LNG.

Author	Paul Connolly, Director Gas Policy	Approved	Bernadette Ditchfield, GM
Business Unit	Mining and Petroleum Industry Policy	Business Unit	Mining and Petroleum Industry Policy
		Date	25 August 2011

INQUIRY INTO THE MANAGEMENT OF THE MURRAY-DARLING BASIN
QUESTION ON NOTICE

No. 27

Asked at the Public Hearing on Tuesday, 9 August 2011

Senator WATERS: Has the Queensland Government conducted or commissioned any independent lifecycle analysis of the greenhouse gas intensity of coal seam gas produced in Australia (for domestic energy generation as well as export) or is the Government relying on industry studies from here or overseas to form its views on this issue?

ANSWER:

The Queensland Government has drawn its analysis from a number of national and international studies of the greenhouse intensity of gas to be used in electricity generation in domestic or export markets. There was no need to duplicate this work.

In terms of coal seam gas used for domestic electricity generation, the analysis undertaken by consultants ACIL Tasman for the Australian Energy Market Operator provides an assessment of the emissions intensity of a range of potential new entrant electricity generation technologies in the Australian market. The estimates of emissions intensity include emission factors associated with the combustion of fuels as well as fugitive emissions from the extraction equipment and pipelines. These factors are sourced from the National Greenhouse Accounts Factors produced by the Federal Department of Climate Change and Energy Efficiency.

Based on these emissions factors, ACIL Tasman estimates the emissions intensity of a new combined-cycle gas turbine in Queensland to be between 0.39 and 0.41 tonnes of carbon dioxide equivalents per megawatt hour (tCO2-e per MWh). In contrast, the emissions intensity of a new supercritical black coal-fired generator in Queensland is estimated to be between 0.8 and 0.84 tCO2-e per MWh.

Author	Andrew Burnett, Manager	Approved	Benn Barr, GM
Business Unit	Energy Markets and Pricing Policy	Business Unit	Energy Industry Policy
		Date	25 August 2011

INQUIRY INTO THE MANAGEMENT OF THE MURRAY-DARLING BASIN
QUESTION ON NOTICE

No. 28

Asked at the Public Hearing on Tuesday, 9 August 2011

Senator WATERS: Can the Queensland Government advise whether the studies it has undertaken has 1/ taken into account not only the fugitive emissions from leaking wells and pipes (and please advise the basis on which fugitive emissions are calculated or estimated) and 2/ taken into account the energy requirements of reverse osmosis of produced water, liquefaction and transport domestically and export (and the assumptions underpinning these calculations), 3/ and in the case of CSG for export, what are the assumptions around the power generation technology used?

Answer

For production wells, the estimates of emissions intensity include emission factors associated with fugitive emissions from the extraction equipment and pipelines. These factors are sourced from the National Greenhouse Accounts Factors produced by the Federal Department of Climate Change and Energy Efficiency.

Emissions created by treating water have not been considered due to the obligations to treat water being different dependent on the original water quality, proposed end use and requisite proximity to gas production.

The energy requirements, and associated emissions, required to extract, process and transport the LNG are included in the analyses. These analyses typically use data from existing or projected normal operating conditions using commonly employed and proven technologies, including GHG mitigation. The analyses assume that projects apply best practice in GHG and environmental management.

In the case of CSG for export most analyses assume that either an efficient combined cycle or open cycle gas turbine generation technology is employed.

Author	Paul Connolly, Director Gas Policy	Approved	Bernadette Ditchfield, GM
Business Unit	Mining and Petroleum Industry Policy	Business Unit	Mining and Petroleum Industry Policy
		Date	25 August 2011

INQUIRY INTO THE MANAGEMENT OF THE MURRAY-DARLING BASIN QUESTION ON NOTICE

No. 29

Asked at the Public Hearing on Tuesday, 9 August 2011

Written question on notice, Senator Waters: BTEX ban – why did the Queensland Government take so long to bring the BTEX ban announced in October 2010 into effect?

RESPONSE:

The strict regulation of stimulation fluids to ensure BTEX was not added has been in place since legislation took effect in October 2010. However, the mechanism through which this had been in force has changed.

It is important to note that during the time between the introduction of the legislation in October 2010 and the standard set in July 2011, coal seam gas companies were already committed to not adding BTEX to their stimulation fluids. Environmental authorities issued for LNG projects also restricted the deliberate addition of BTEX to stimulation fluids. The *Environmental Protection Act 1994* also provided the added protection of making it an offence to cause serious environmental harm.

No other jurisdiction in Australia regulates BTEX concentrations in stimulations fluids. Queensland is a test case for this form of regulation and extensive research and consultation was necessary to ensure that the standard selected was both practical and enforceable. There were a number of complex issues that needed to be addressed, including the existence of naturally occurring BTEX in the water sourced for use in the stimulation fluid, and technological limits in the level of detection possible.

Given the important community and environmental issues at stake, this was not a regulation that the Queensland Government was willing to rush into. However, we are now confident that we have set a BTEX standard that is sufficiently stringent to ensure the protection of human and ecosystem health and is able to be enforced.

Author: Petrina Prowse

Date: 25 August 2011

CTS No.

Approved: ADG ENRR
Approved: ADG OER
Approved: Office of the Director-General

INQUIRY INTO CSG MINING

QUESTION ON NOTICE

No.

Asked at the Public Hearing on Tuesday, 9 August 2011

Could the Queensland government prosecute some one for providing Stock and Domestic supplies to the CSG companies?

Response:

Yes. The provision of water to a CSG company from an existing stock and domestic licence would constitute an offence under s.808 of the *Water Act 2000* because it would amount to the unauthorised supply or take of water.

Author: Saji Joseph	Approved: ADG ENRR Approved: ADG OER
Date: 25 August 2011	Approved: Office of the Director-General
CTS No.	