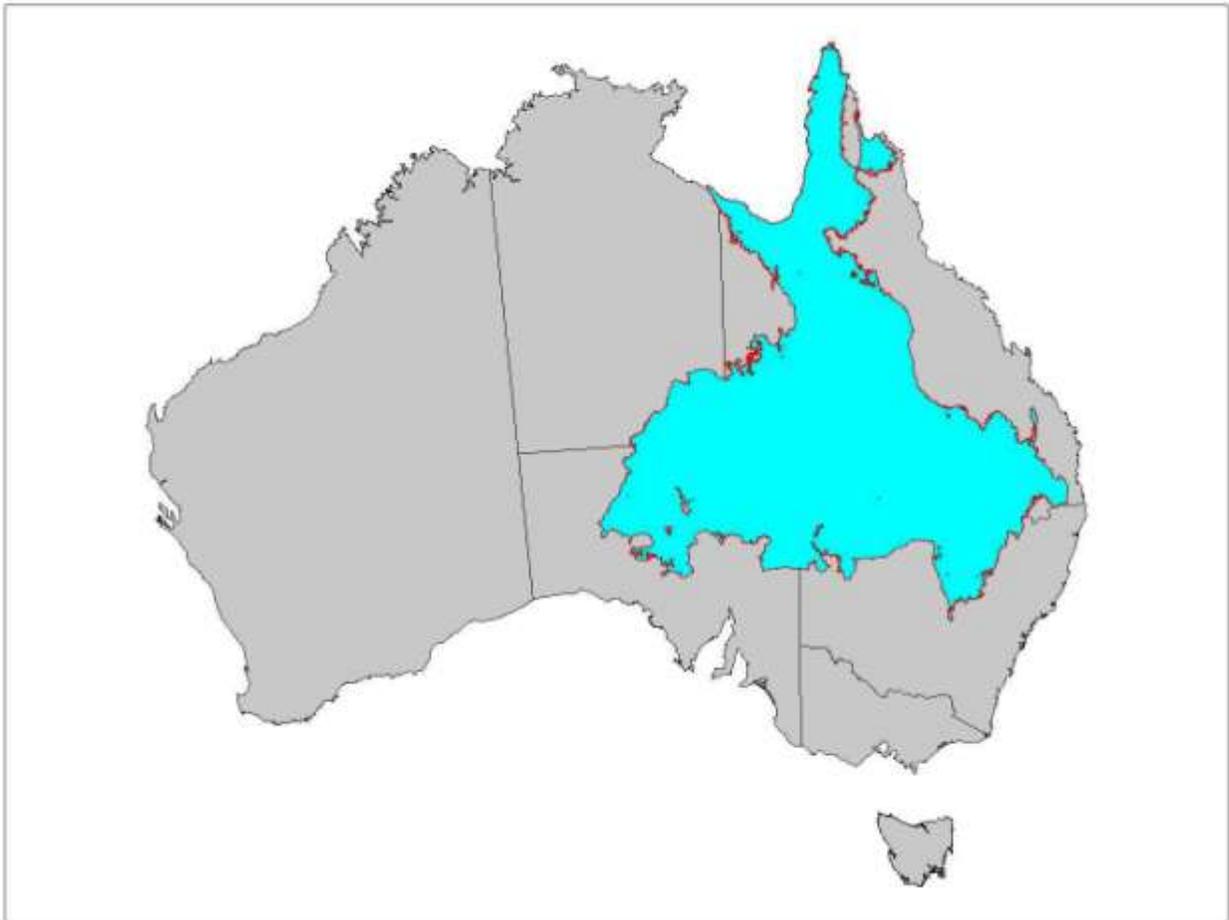


SoilFutures Consulting Pty Ltd

**GREAT ARTESIAN BASIN RECHARGE SYSTEMS
AND EXTENT OF PETROLEUM AND GAS LEASES**
REVISED EDITION



Prepared for

THE ARTESIAN BORE WATER USERS ASSOCIATION

December 2014

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Acknowledgements

SoilFutures Consulting Pty Ltd would like to acknowledge the following people who assisted in the preparation and review of this report:

Technical Editing and layout: Dr Vera Banks

Pre Publication Technical and peer review 1st Edition: Andrea Broughton-Maloney. MSc. Hydrogeologist (Groundwater Solutions International Pty Ltd, NZ).

Post Publication technical and peer review for Revised Edition: Professor Ian Acworth. Hydrogeologist (University of NSW, Water Research Laboratories); Dr Brian Smerdon. Senior Hydrogeologist. (Alberta Energy Regulator, Canada); Dr Beke Gredner Manager Groundwater Protection Zones, Verden (Bremen), Germany.

Thanks and acknowledgement is also given to the many senior technical and scientific staff of both state and federal agencies who provided encouraging and constructive comment on the 1st Edition, but cannot be named for political reasons.

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Preface to Revised Edition

Following the release of the first edition of this document, by the Artesian Bore Water Users Association, this document has received much attention in the media and multimedia, including criticism which has both been educated and constructive, as well as some very ill informed and non-technical criticism.

In order to address issues arising from the constructive criticism, this revised document has been prepared. Please note that this report has had wide peer review from both Australian and international hydrogeologists, and scientists. It remains substantively unchanged, but incorporates the results of considered critique and some small changes to maps presented.

One significant change in this revised edition is that recharge of less than 1 mm has been removed as being substantial or critical recharge within the GAB.

This document and its predecessor are not attempts to describe the complete hydrogeology of the Great Artesian Basin (which seems to be a common criticism of the first edition), but represents a mapping exercise using the highest quality peer reviewed CSIRO and State Agency spatial data, as well as reviewing the latest peer reviewed and published reports on recharge and connectivity in the GAB. The technical information from these sources is the culmination of hundreds of person years of patient and thorough research on the GAB by well qualified and recognised scientists. The report draws conclusions based purely on the mapping and the review material.



Executive Summary

The Great Artesian Basin (GAB) of Australia extends over 22% of the Australian continent where it is the only reliable groundwater or surface water source. The GAB contains 65 000 km³ (or **115 658** Sydney Harbours) of groundwater which is released under pressure to the surface through natural springs and artesian bores across its extent (QDNRM 2012).

Much of the groundwater held in the GAB is very old, having taken thousands to many hundreds of thousands of years to reach its current position in the basin from the recharge beds which are predominantly around the margins of the basin. Modern recharge is not thought to add significantly to the volume stored in the basin however it provides the crucial pressure head to keep the artesian waters flowing to the surface across this massive expanse of land. In most areas, the bulk of the GAB has a recharge value of less than 0.1 mm/yr.

This report is not an exhaustive review of GAB hydrogeology, yet uses the findings of the most recent and valuable recharge measurement and modeling of recharge. State held data on gas, coal seam gas (CSG), and petroleum production and exploration leases are combined to create a GAB wide data set. This report shows that 80% of the GAB currently has a gas, petroleum or CSG exploration or production license over it.

Modern recharge concepts are summarised into maps and overlain with the extent of gas and petroleum production and exploration license areas. 9% of the GAB has recharge greater than 0.1 mm/yr. Less than 6% of the GAB provides recharge which pressurises most of the remainder of the basin with recharge greater than 1 mm/yr. Approximately 2.1% of the total area of the GAB provides than 5 – 30 mm/yr recharge to the basin, and only 0.2% of the GAB provides greater 30 - 80 mm/yr of recharge. These recharge values are recognised as very low, despite being the highest in the basin. These very critical recharge areas are rare and widely separated. The main recharge area in NSW is in the East Pilliga Forest between Narrabri and Coonabarabran.

Using a simple spatial overlay, the main recharge zones (> 1mm/yr) of the GAB which provide pressure to the remainder of the GAB are 68% covered with gas, coal seam gas (CSG) leases. Typically CSG production involves dewatering (pumping) of coal seams to allow methane gas to be extracted (the water is a waste product of production called produced water). There is proven downwards connection between sub basins of the GAB and many of its underlying petrochemical rich basins (Surat has 10% connection; Eromanga has up to 50% connection). It follows that dewatering of aquifers under the GAB where proven connectivity exists can ultimately reduce pressure heads in the critical recharge areas of the GAB and reduce or halt water flow at its numerous bores and springs.

This report shows that the proliferation of gas exploration and production licenses on recharge zones appears to have progressed without much consideration of a GAB wide impact on artesian groundwater resources and pressures. Regulation which is GAB wide and transgresses state boundaries should be considered particularly with regard to protection and management of the few and critical recharge areas of the GAB.

Clearly, there are other wide ranging risks to the water supply of the GAB, with many free flowing bores still in existence (which causes local water and pressure depletion), as well as large scale uranium mining in South Australia. None of these other risks have the potential to stop the water flowing across entire sub basins within the GAB, which removal of hydraulic head pressure can.



The following description of the Great Artesian Basin (GAB) is given in Ransley and Smerdon (2012).

The GAB contains an extensive and complex groundwater system. It encompasses several geological basins that were deposited at different times in Earth's history, from 200 to 65 million years ago in the Jurassic and Cretaceous periods. These geological basins sit on top of deeper, older geological basins and in turn, have newer surface drainage divisions situated on top of them (e.g. the Lake Eyre and Murray-Darling river basins). In this context – as a groundwater basin – the GAB is a vast groundwater entity underlying one-fifth of Australia.

Discharge from the GAB aquifers occurs naturally in the form of concentrated outflow from artesian springs, vertical diffuse leakage from the Lower Cretaceous-Jurassic aquifers towards the Cretaceous aquifers and upwards to the regional watertable and as artificial discharge by means of free or controlled artesian flow and pumped abstraction from water bores drilled into the aquifers.

For the GAB, like many other semi-arid to arid zone aquifers around the world, the current rate of recharge is significantly less than discharge. Groundwater currently stored in the Cadna-owie – Hooray Aquifer and equivalents is a legacy from higher recharge rates that occurred during much wetter periods in the early Holocene and Pleistocene age (essentially the last 2.6 million years).

The significance of the recharge zones to the GAB is not so much as an immediate water supply to central parts of the basin and natural discharge areas, but that they provide the pressure head (or weight of water) required to drive the water to the surface. Removal of this pressure through water abstraction associated particularly with Coal Seam Gas (where local drawdown of in excess of 1000 m can be experienced around gas fields) risks removing the driving force of many of the free flowing artesian bores and springs in the GAB.

1.2 Brief for this report

The brief provided to SoilFutures Consulting for this report was to undertake the following work;

- 1. Map known recharge areas of the Great Artesian Basin (GAB) using published and as 'up-to-date' as possible information; and*
- 2. to comment on the extent of Gas and petroleum activities within the GAB, particularly with respect to positioning on recharge areas.*

2. Materials and Methods

2.1 Great Artesian Basin Spatial Data Collection

Spatial data for the Great artesian Basin was obtained from the following sources.

Up to date boundary information, historical recharge zone information, and modern raster grid modelling recharge was sourced from Ransley and Smerdon (2012) and downloaded from www.ga.gov.au (Catalogue numbers 75904, 75842 and 76932 respectively).



State data for gas and petroleum exploration licenses and production licenses were obtained from the following sources which are acknowledged as per the download license agreement for each state below:

1. NSW Trade & Investment, Resources & Energy (2014). Petroleum Titles (almost exclusively natural gas and coal seam gas) including production leases and Exploration leases and Applications. Downloaded from <http://minview.minerals.nsw.gov.au/mv2web/mv2>
2. Northern Territory Government (2014). Petroleum Applications (Including natural gas and petroleum) and Granted Exploration licences. Downloaded from http://geoscience.nt.gov.au/GeosambaU/strike_gs_webclient/default.aspx
3. Queensland Department of Natural Resources and Mines (2014). Exploration license leases, production license leases (Predominantly coal seam gas and natural gas). Downloaded from <http://dds.information.qld.gov.au/dds>
4. South Australian Department for Manufacturing, Innovation, Trade Resources and Energy (2014). Exploration license leases, production license leases for both natural gas and petroleum (oil). <http://sarig.pir.sa.gov.au/Map>

2.2 Manipulation of spatial data

The GAB wide datasets for recharge and boundary information were compiled in ArcView 3.3 (A Geographic Information System) as a base layer for an analysis of other mapped data. As the new recharge information was presented essentially as an image, it was categorised into recharge increments and then transformed into a shape file, so that area statistics of different recharge areas could be calculated.

Gas and petroleum lease data for each state was transformed to a common datum (WGS84) and a common projection (Albers Equal Area Conic). The data for each state was then merged into a single shapefile for ease of use.

2.3 Review of Recent Publications

This review is only a brief summary of select, up to date publications relating to recharge and discharge mechanisms and mapping in the GAB. The review helps to establish a model for how to process spatial data later in the report. It is important to note that the recharge calculations undertaken in this report do not include the Carpentaria Basin within the GAB, as this area has its own high recharge areas from overlying regional aquifers which do not affect the rest of the basin.



Ransley and Smerdon (2012) provide a thorough overview of recent research and conceptualization of the GAB. Figure 2 summarises recharge zones and their significance to the GAB. The eastern NSW section of the basin (The Surat Basin) and the Surat Basin extending into Queensland has some horizontal connectivity with the adjacent Eromanga Basin (the largest sub basin of the GAB) to the west.

The Surat Basin has about 10% connection with underlying aquifers. In addition to this, the Surat Basin has minor known discharge into the Gunnedah and Cubaroo formations which form the Namoi River Paleochannel at the northern end of the Pilliga outwash which bounds the Namoi Alluvium. These waters are still relatively fresh and augment irrigation aquifers and probably surface flows in the Namoi between Narrabri and Walgett.

Concern regarding CSG extraction is raised in Ransley and Smerdon (2012) in the following quote. *“CSG production in the Surat Basin targets the Jurassic Walloon Coal Measures. The main CSG producing fields are located in the northern Surat Basin in a broad arc extending from Dalby to Roma. For gas to be harvested, the coal seams need to be depressurised by pumping groundwater from tens of thousands of wells intersecting the Walloon Coal Measures. Drawdowns of several hundred metres will be generated by the depressurisation and significant volumes of groundwater are to be pumped from the Walloon Coal Measures – averaging about 75 to 98 GL/year over the next 60 years (RPS Australia East Pty Ltd, 2011). This process will induce drawdown in overlying and underlying GAB aquifers, the amount of which will depend on the leakiness of the system.”*

Ransley and Smerdon (2012) summarise recharge in the following: *“Wohling et al (2013b) recently mapped recharge. Across the majority of the Surat Basin, recharge is estimated to be less than 5 mm/year, with the exception of portions of the Hutton Sandstone, which have values greater than 20 mm/year in the north part of the region. Similarly, recharge values of up to 45 mm/year were estimated for a localised region on the east side of the Coonamble Embayment. For the remainder of the eastern margin of the GAB, the spatial distribution and values are similar to those reported previously by Kellett et al (2003), less than 5 mm/year, with a trend for increasing recharge in the north of the region, with values up to 45 mm/year. Across the western margin of the GAB, recharge was effectively zero (mean of 0.15 mm/year).”*

Smerdon, Ransley, Radke and Kellett (2012) updated the geological knowledge base for the GAB and also revised the boundary of the GAB. This revised boundary is used in all of the below analyses of recharge and gas and petroleum related activities. They provide detailed information about the geological formations which contribute to recharge of the greater basin.

Recharge mechanisms are discussed in Herczeg and Love (2007) and fall into the following categories:

1. Via direct infiltration to the soil into the outcropping regions of the Jurassic Aquifers
2. Direct recharge through ephemeral creeks and rivers and mountain block alluvial fan systems (very important within the East Pilliga section of the Coonamble Embayment of the Surat Basin)
3. Downward hydraulic movement through aquifers above the GAB aquifers, where conditions permit



- Upward hydraulic movement from aquifers underlying the GAB aquifers. This is thought to be happening in the Winton Sandstones in the central part of the wider GAB.

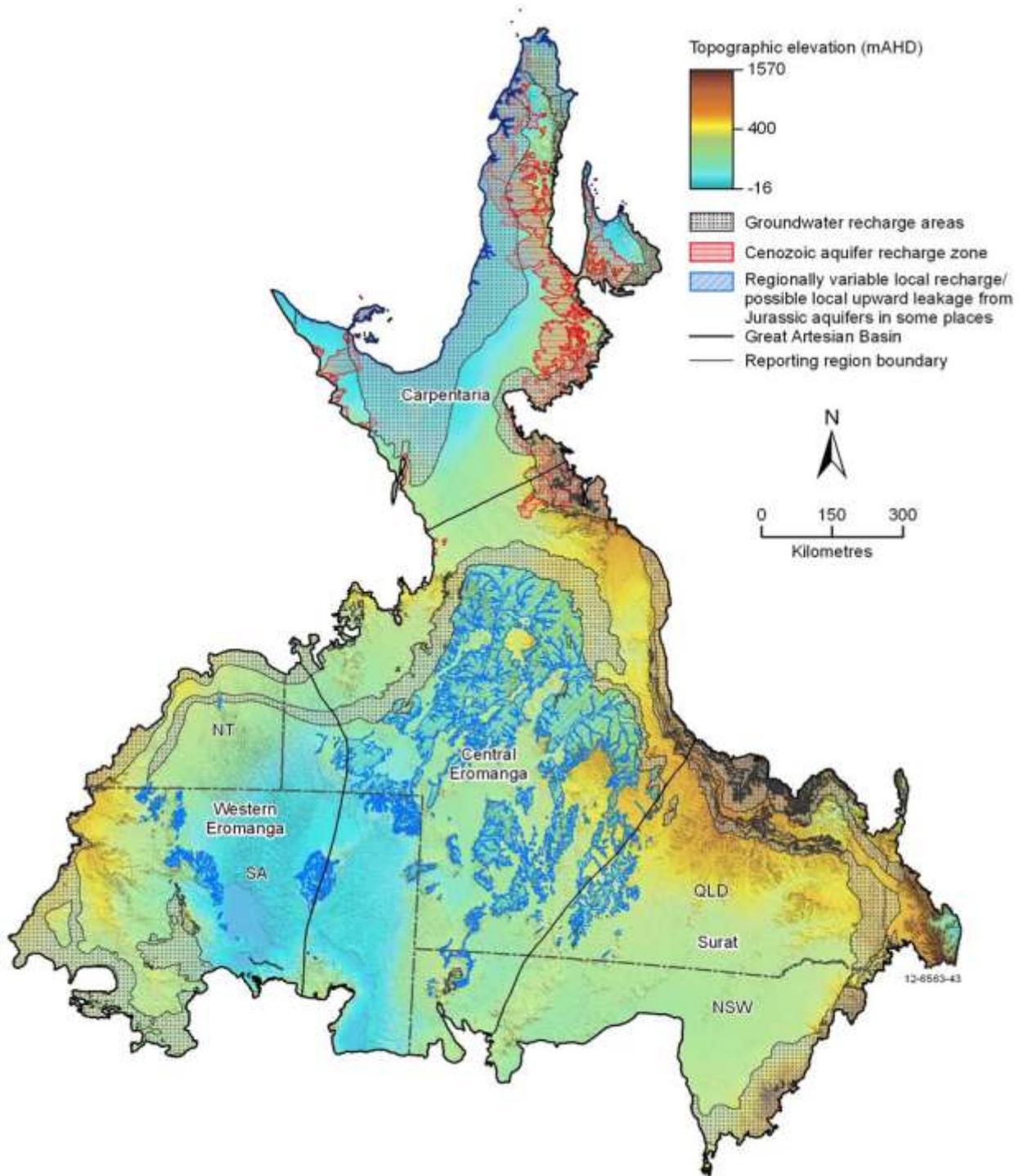


Figure 2: © CSIRO 2012 Hydrostratigraphy, hydrogeology and system conceptualisation of the Great Artesian Basin ▪ 17 Figure 2.2 Digital elevation model with Great Artesian Basin boundary and aquifer recharge zones.



3. Results of Analysis of Spatial Data

This section of the report provides a stepwise analysis of high quality modern spatial data relevant to recharge in the GAB. It shows the process by which areas were modeled and spatial statistics generated.

3.1 Recharge areas

Known mapped recharge areas for the GAB are separated into the Carpentaria basin recharge (not considered in this report), broad recharge associated with the Winton Block (in central QLD) which is thought to be recharged from underlying geology rather than from the surface), and the eastern and western margins of the GAB, which are generally considered to be the main recharge areas.

Figure 3 includes the Winton block recharge area (the central red area of the map), where water is thought to enter the GAB from pressurized aquifers underlying the main GAB aquifer. Surface recharge here is reported as poor (<0.1 mm/yr) No further consideration of these areas is given in this report.

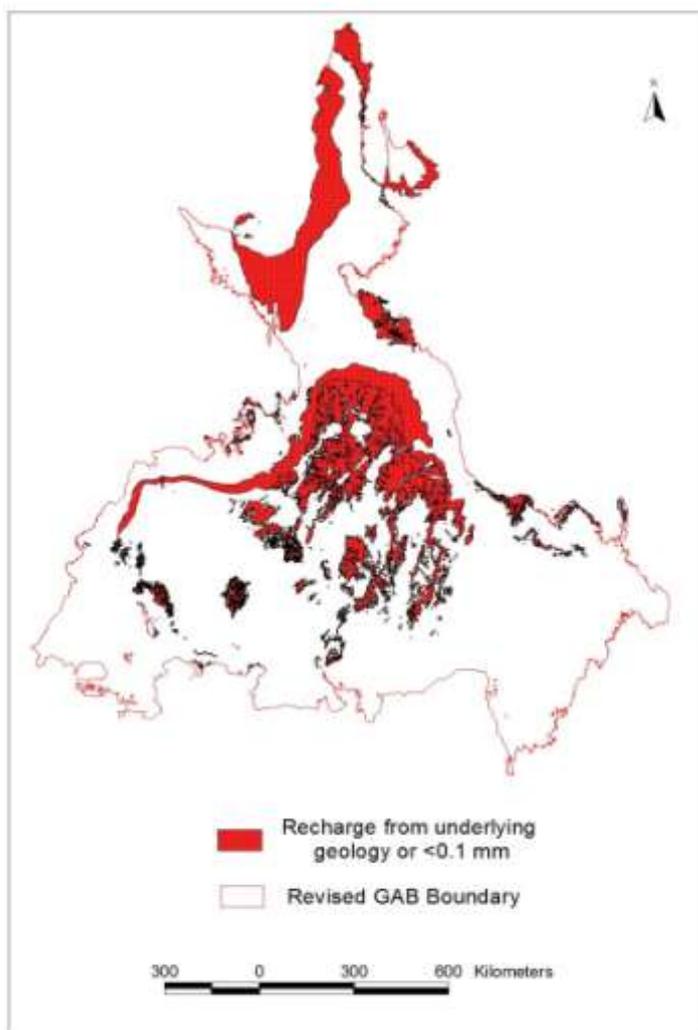


Figure 3. Poor recharge from surface yet likely recharge from underlying aquifers.



Figure 4 Shows known areas of recharge around the margins of the GAB, where recharge is through soil into underlying Cretaceous and Jurassic geologies or through alluvial fan systems which are prominent in the south eastern portion of the basin in the Pilliga Outwash. This figure shows that the total area of GAB marginal recharge (excluding Carpentaria) is 157 902 km² or 9% of the GAB.

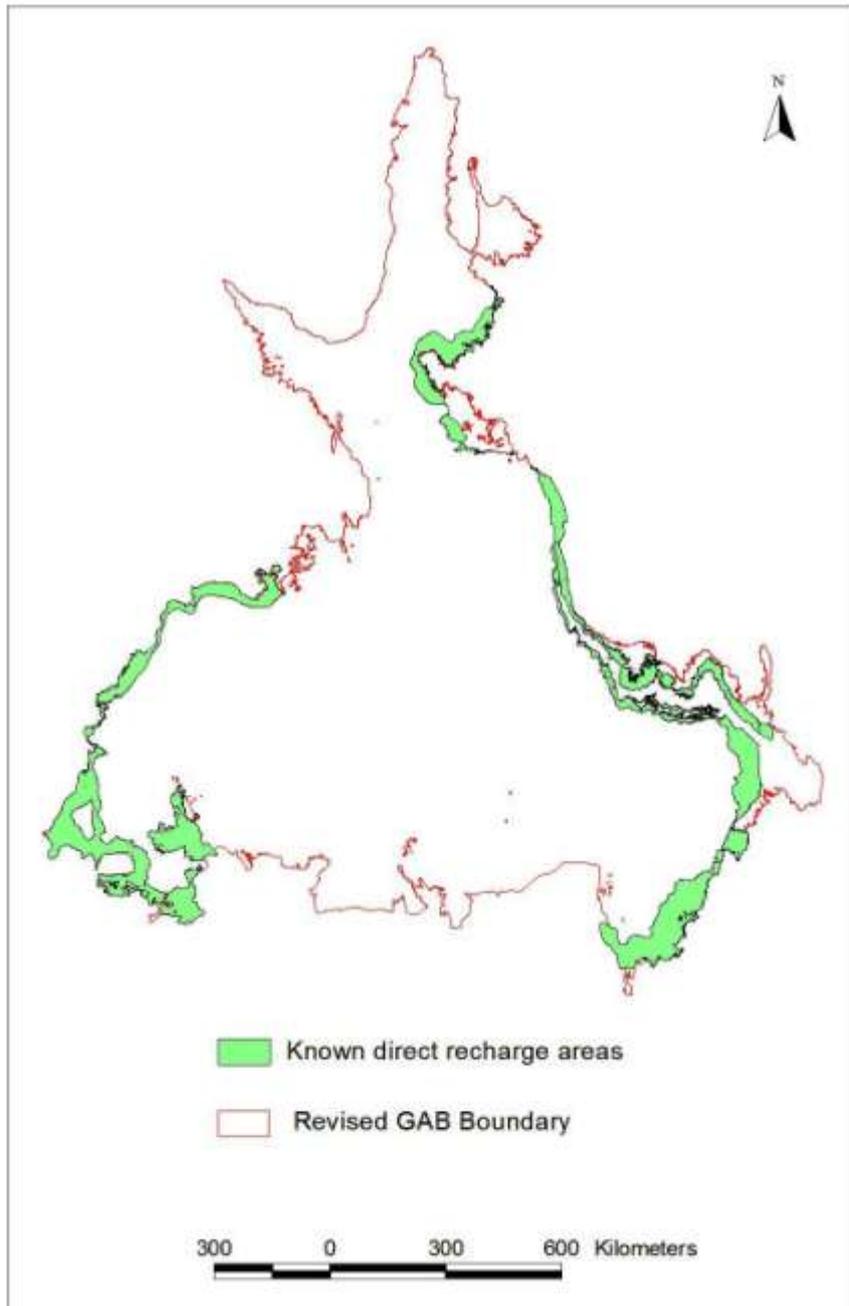


Figure 4: Direct recharge areas – margins of basin on Jurassic and Cretaceous Sandstones

Figure 5 shows the results of recharge measurement and modeling presented in Ransley and Smerdon (2012) and derived from Wohling *et al* (2012), Kellet and Ransley *et al* (2003) and Habermehl *et al* (2009) and are the most up to date assessment of GAB margin recharge available.



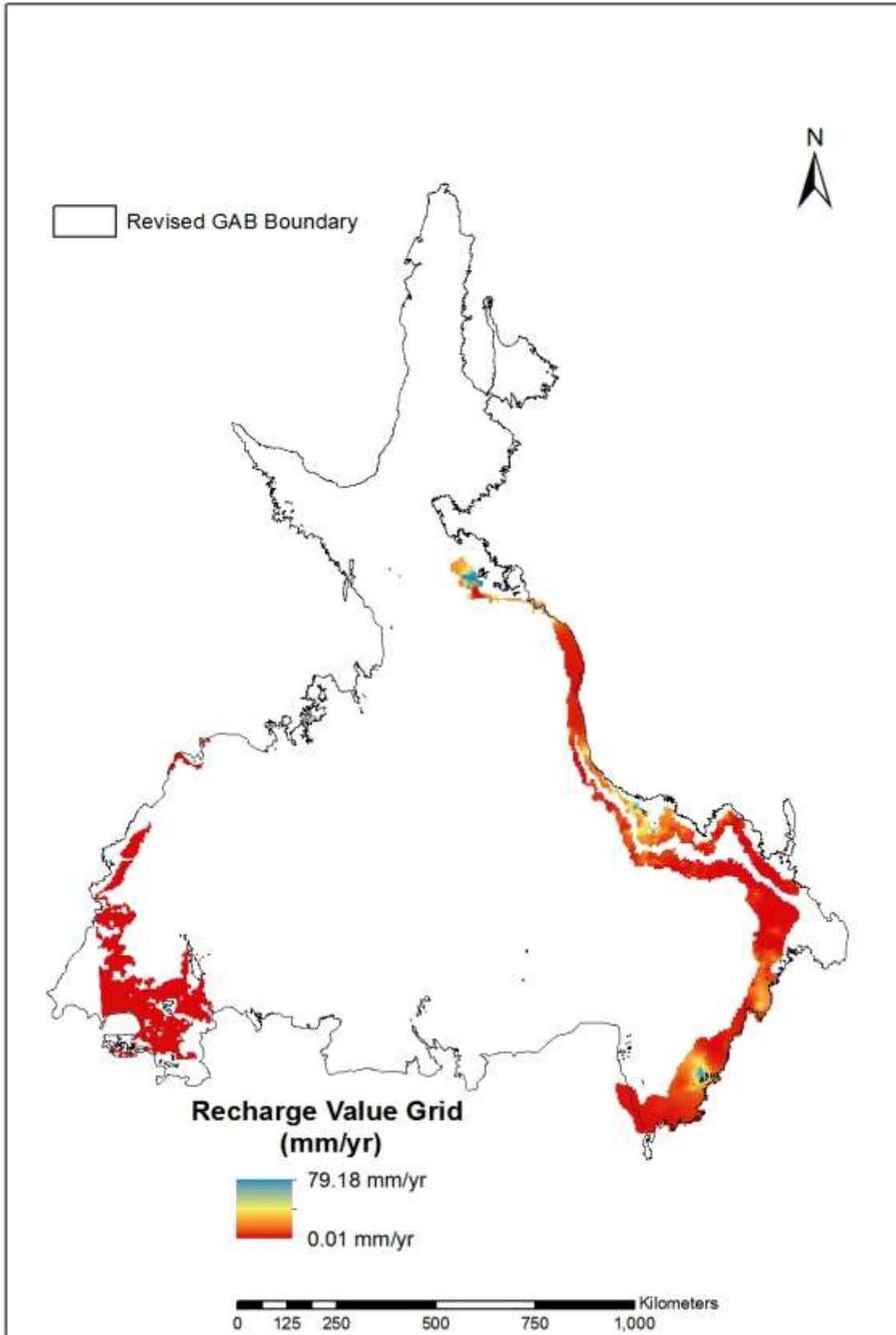


Figure 5: Modern recharge values for the GAB margins (from Ransley and Smerdon (2012))



The recharge categories presented in Figure 5 were machine digitized into the three zones which are presented in Figure 6 below.

Figure 6 shows the following. The area with 1 – 5 mm/yr recharge is 65 064 km², or 3.8% of the GAB. The area with 5 – 30 mm/yr recharge is 37 775 km² (2.1% of the GAB). The area with recharge greater than 30 mm/yr recharge is 2 847 km² (0.2% of the GAB). In NSW the recharge areas of higher than 5 mm/yr and >30 mm are almost entirely contained within the east Pilliga area. The total area with recharge > 1 mm/yr is 102 826 km², or 6% of the GAB.

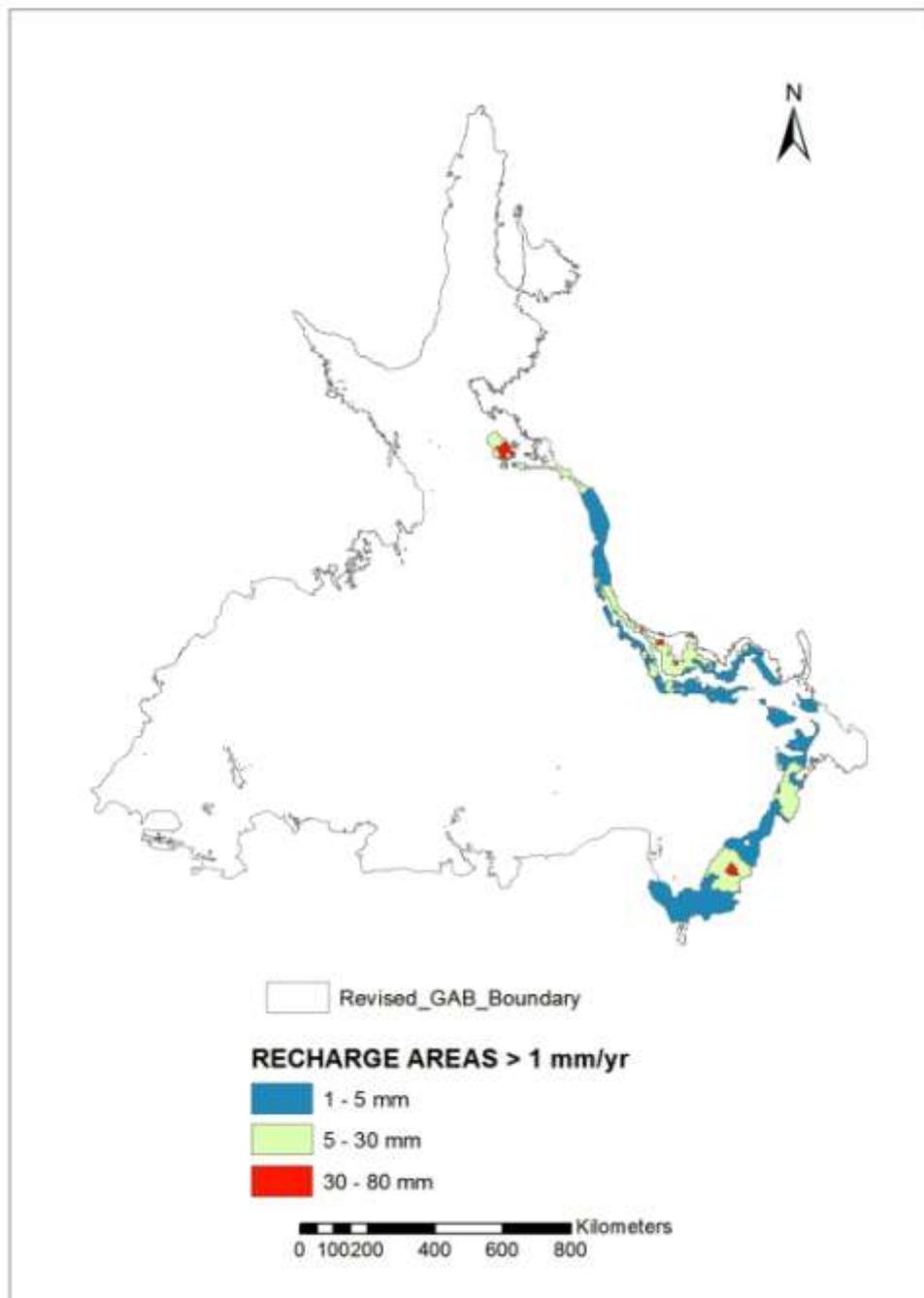


Figure 6: Machine digitised recharge zones from grid data provided in Figure 5.



3.2 Gas and petroleum data

Owing to the complex nature of the gas and petroleum data from the four differing states, it was decided to present both exploration license areas and production license areas on the same map. The data in Figure 7, show that 1.38 million km² (or 80% of the GAB) is taken up with exploration or production licenses associated with gas or petroleum.

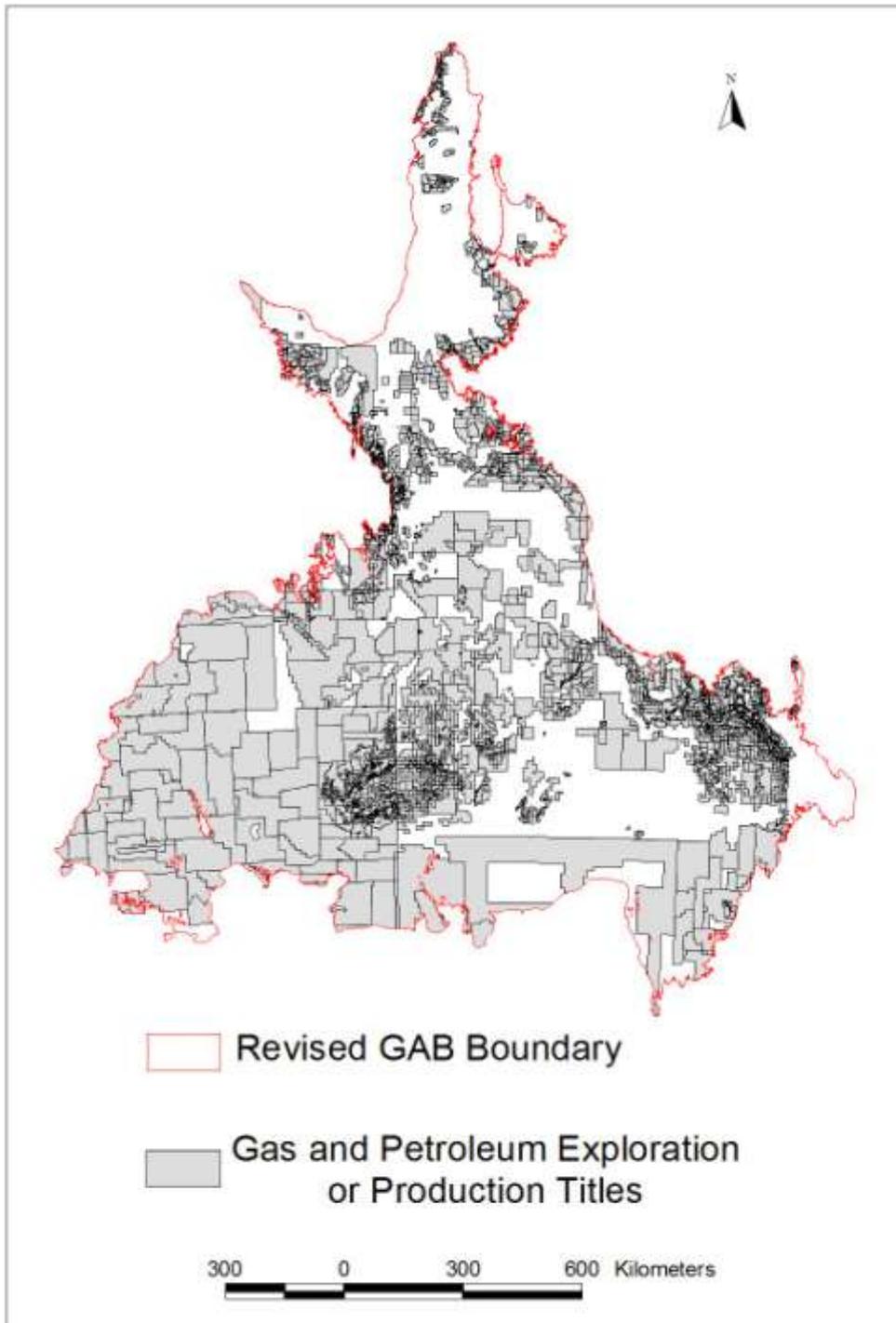


Figure 7: Extent of Gas or petroleum production and exploration licenses in the GAB



3.3 Gas/Petroleum license areas and Recharge

The data from Figure 7 were overlain with the digitised (polygon) version of the Cretaceous and Jurassic recharge zones on the margins of the GAB (Figure 6). Figure 8 shows the extent of gas and petroleum related license areas within the critical recharge zones (>1 mm/yr).

32 326 km² (or 31%) of the critical recharge zone is not covered by any license. 70 590 km² (or 69%) of the critical recharge zone is taken up with either production or exploration leases.

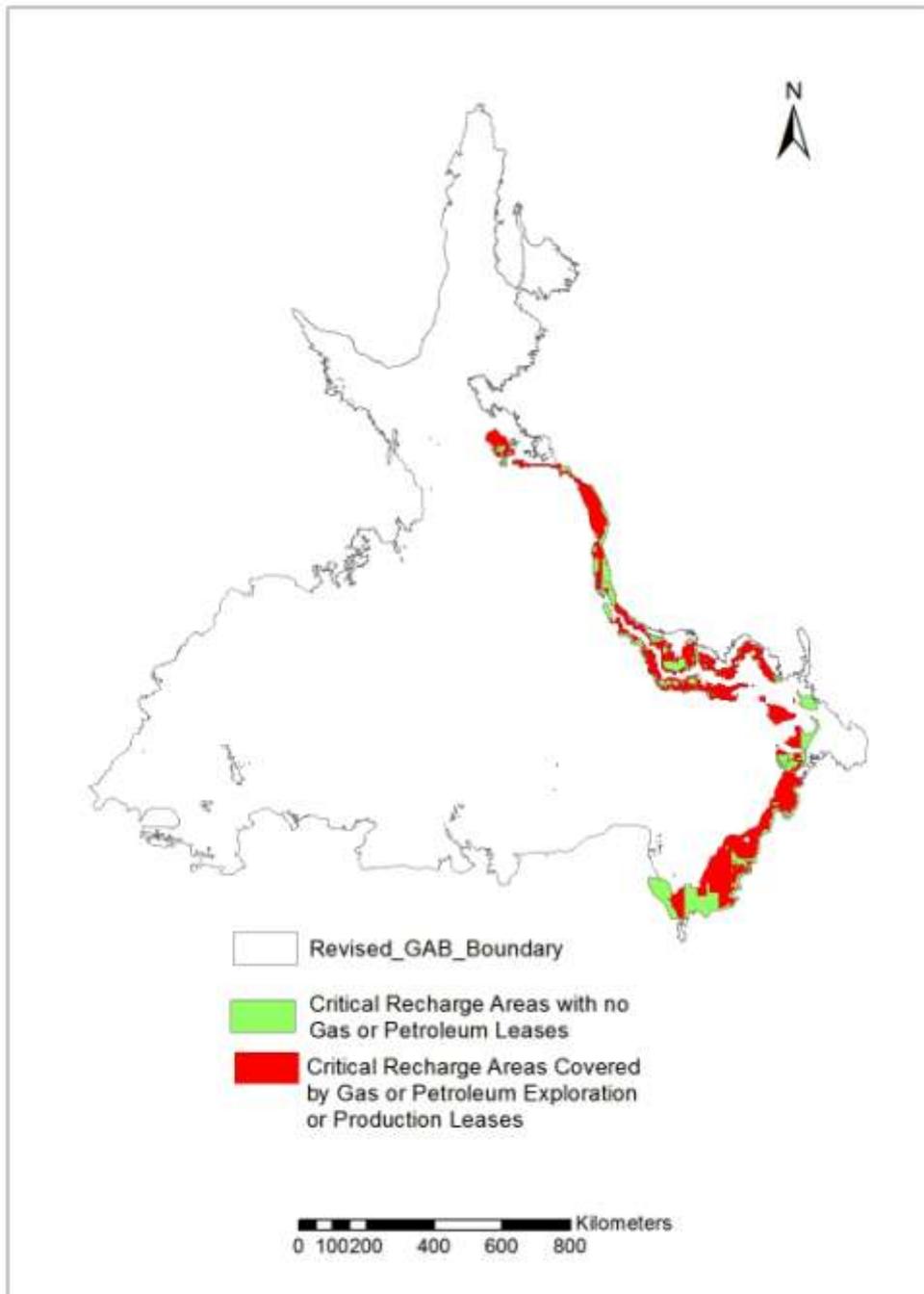


Figure 8: Extent of Gas/Petroleum production and exploration licenses within critical recharge zone (>1 mm/yr) of GAB



4. Discussion of results

The above results show that:

- Recharge along the Jurassic to Cretaceous margins of the GAB is crucial to providing hydraulic head which drives the whole system.
- Significant recharge to the bulk of the GAB is much more limited in area than previously thought with only 6% of its area providing more than 1 mm /yr.
- Although approximately 30% of the GAB is mapped as recharge, only 6% of the GAB is effective recharge which maintains the pressure head on the bulk of the GAB (excluding the Carpentaria basin).
- Only 2.3% of the GAB has effective recharge of greater than 5 mm/yr.
- Only 0.2% of the GAB has effective recharge of 30 – 79 mm/yr.
- In NSW, the main occurrence of recharge >30 mm is in the east Pilliga between Coonabarabran and Narrabri.
- Draw down of many hundreds of metres is reported in Ransley and Smerdon (2012) for the northern Surat basin coal seam gas fields where coal seams are being dewatered to release gas.
- Draw down of in excess of 1000 m is proposed in the Pilliga in the south eastern Surat Basin (ICSG Forum, 2014).
- Both of the Pilliga and the northern Surat gas fields or license areas occur in the very limited critical recharge (>30 mm) areas of the GAB.
- Excessive draw down of pressure heads in the recharge zone of the GAB associated with gas extraction, has the potential to reduced pressure heads on artesian waters across much of the GAB, and potentially stopping the free flow of waters to the surface at springs and bores.
- Gas and petroleum exploration and production licenses cover 80% of the entire GAB.
- Gas and petroleum exploration and production licenses cover 79% of the critical highest and most critical recharge areas of the GAB.

5. Concluding Remarks and Recommendations

This report clearly demonstrates that a very large percentage of the critical recharge areas of the GAB are covered with gas or petroleum exploration or production licenses. Although individual impact studies may have been carried out or may be carried out for each license on the impact of gas or petroleum extraction from beneath the GAB sediments, it is unlikely that an impact on the whole of the GAB can be assessed in this way.

The GAB covers large areas of Australia's two largest surface catchments, the Murray Darling Basin, and the Lake Ayre Basin and comprises a substantial portion of Australia's agricultural production.



Clearly the area of highest recharge (>5 mm/yr) within NSW is in the Pilliga Sandstones and associated colluvial fans of the East Pilliga. This area is almost completely covered with exploration licenses at this time. Most of the highest recharge areas within QLD are also substantially covered by gas or petroleum licenses for exploration and production.

The GAB is administered from four states which place differing values on its mineral and natural resources. Given that the four states within the GAB have different criteria by which to judge the suitability of a proposal for development, it seems that there is as yet no standard approach to gas and petroleum extraction approvals which cover the whole of the GAB. The current approval or issuing of licenses for both exploration and production in the GAB appears without coordination or regard to recharge. CSG extraction may significantly affect groundwater resources and groundwater resource access within the GAB if bores or springs begin to fail as a result of depressurisation caused by dewatering of recharge zones.

Consideration should be given to a basin wide approach to the management of the GAB with respect to minerals and natural resources, particularly with respect to potentially wide ranging activities such as gas and petroleum production where groundwater from below the GAB is drawn down and produced as an excess or waste byproduct of such development. In particular, serious thought needs to be given to the management of the few critical recharge zones within the GAB and how these might interact with future water supplies.

Recognition of CSG as a water user needs to be given parity with groundwater irrigation users. It needs to be monitored stringently to ensure that the overlying water resource (the GAB) is not affected and the recharge resource is properly managed to maintain hydraulic head.

The concept of the value of land in making development decisions with regard to CSG and mining in NSW has been developed significantly in the past few years. Biophysical Strategic Agricultural Lands (BSAL) were defined to place more rigorous consideration on extractive industry applications in areas of high agricultural productivity, or near special agricultural industry clusters (NSW Government 2013). BSAL areas address the agricultural potential of land only, and do not relate to other landscape functions. Landscape functions such as critical recharge zones to the GAB or other aquifer systems are not considered. A similar approach to delineating high value agricultural lands in Queensland is given in DERM (2012).

The East Pilliga area between Narrabri and Coonabarabran in NSW has Soil and Land Capability Classification (SLC) of between 4 and 6, meaning that there are no contiguous areas of Biophysical Agricultural Land (BSAL) in the area. BSAL is defined as Classes 1 to 3. This means that currently no special consideration which includes landscape function is given with regard to CSG and Mining applications in the critical recharge zone areas of the GAB within the East Pilliga.

A regulative approach which is applied in Germany on a regional scale to manage potential impacts on groundwater is the concept of “*Wasserschutzgebiet*”, or clean recharge water protection area. Despite having relatively high rainfall and low evaporation, Germany predominantly sources its drinking waters and waters for agricultural or industrial applications through groundwater. These legislated groundwater protection zones are in



place to protect both water quality and quantity and all land uses are highly regulated with respect to groundwater and surface activities within sensitive zones. The sensitive zones include recharge areas and areas in proximity to water bores. This approach to recharge has now been taken across the European Union (EU 2014)

This report establishes that the landscape function of critical recharge is an important consideration community and national land value that is generally not taken into account with regard to mining and CSG activities across the whole GAB. The landscape function of critical recharge to the GAB should be taken into account with regard to these activities. Prolonged deep draw down of aquifers under the GAB (associated with CSG) may eventually lead to a permanent loss of head to large areas of the GAB and as such this needs to be considered a very high risk activity extending far beyond the bounds of an individual gas field or mining activity.

Clearly an approach such as the German one, which controls all land use with regard to important recharge zones and other areas within the GAB, needs to be adopted so that potential catastrophic pressure losses can be avoided. A nationwide management stratagem which includes critical recharge protection and regulates these industries within the GAB may prevent potential degradation of this essential groundwater resource which provides water to 22% of Australia.



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