Water resource management plan

Hydraulic connectivity characterisation AE-A

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Santos
GLNG Project

Gas Field Development Project
Environmental Impact Statement

Appendix AE-A: 2014 Program of hydraulic connectivity studies to meet requirements of the EPBC Act (1999)

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1 Introduction

1.1 Report objectives

This report has been prepared as supporting document to the Santos GLNG Gas Field Development Project (GFD Project) environmental impact statement (EIS) and aims to provide the Independent Expert Scientific Committee (IESC) with the required information on studies undertaken and currently ongoing for the assessment of hydraulic connectivity relating to the Santos GLNG Project. It provides detail regarding the implementation of the hydraulic connectivity studies defined in Santos GLNG Stage 2 Coal seam Water Management and Monitoring Plan (Stage 2 CWMMP).

1.2 Legislative framework for existing regulatory approvals

In May 2010, the Queensland Coordinator-General approved the GLNG Project under the *State Development and Public Works Organisation Act 1971* (Qld) (SDPWO Act). In October 2010, the Minister of Sustainability, Environment, Water, Population and Communities (SEWPaC) (now the Department of the Environment) granted approval under the *Environment Protection and Biodiversity Conservation Act 1999* (Cth) (EPBC Act), with conditions.

Under the EPBC Act, approval conditions the GLNG Project is required to define and implement activities that investigate hydraulic connectivity in the context of understanding the potential impact of the GLNG Project on Matters of National Environmental Significance (MNES). The relevant conditions are listed in Table 1.

Table 1 Conditions relating to hydraulic connectivity studies

Condition Number	Condition
49	Within 6 months from the date of the project approval, the proponent must submit for the approval of the Minister a Stage 1 Coal Seam Gas Water Monitoring and Management Plan (Stage 1 CSG WMMP) which includes at least:
49. b)	a program and schedule for aquifer connectivity studies and monitoring of relevant aquifers to determine hydraulic connectivity.

The Santos GLNG Stage 2 CWMMP (revision 2) was approved by the Department of the Environment in November 2013.

1.3 Legislative framework for the Gas Field Development Project

On 16 November 2012, the GLNG GFD Project was deemed a 'significant project' in accordance with requirements of Section 26 of the SDPWO Act and therefore requires an EIS. The GFD Project EIS has been prepared and will be assessed in accordance with the Bilateral Agreement between the Commonwealth Government and the Queensland Government as a Class 2 Action under Part 4 of the SDPWO Act and the *State Development and Public Works Organisation Regulation 1999* (Qld) (SDPWO Regulation). The Commonwealth Government has accredited the SDPWO Act process coordinated by the Queensland Coordinator-General for the purpose of assessment. In addition to state approval, the GFD Project requires assessment and approval under Part 9 of the EPBC Act before it can proceed.

The EPBC Act was amended in June 2013, to provide that water resources are a MNES and a controlling provision in relation to the impact of coal seam gas development on water resources. The GFD Project was subsequently nominated water resources as an additional controlling provision under the EPBC Act.

1.4 Queensland Office of Groundwater Impact Assessment hydraulic connectivity studies

In addition to the EPBC required hydraulic connectivity studies and programs, the Queensland Department of Natural Resources and Mines (DNRM) is investigating and seeking support to characterise the level of connectivity between the target coal seams and the formations directly below and above the target coal seams. The studies are the responsibility of the DNRM's Office of Groundwater Impact Assessment (OGIA). The aim of the studies is to provide input towards characterising and managing cumulative impact associated with the coal seam gas projects of the Surat and southern Bowen basins.

The Surat Underground Water Impact Report (Surat UWIR[1]) defines ongoing management measures and responsibilities of coal seam gas industry in respect of impacts to environmental values such as groundwater users and environmental receptors associated with springs. The adequacy of the UWIR is reported upon annually and revised, if appropriate, every three years by the OGIA. Assessment of Surat UWIR adequacy and potential need for revision is dependent upon gaining an increasingly accurate understanding of hydraulic connectivity of the groundwater systems of the Surat and Bowen basins.

Post 2014, it is Santos GLNG's understanding that the OGIA will take full responsibility for the direction and implementation of any future hydraulic connectivity studies, with technical support (e.g. data collection, data interpretation) provided by industry. It is expected that technical support from Santos GLNG will only be required to focus on OGIA hydraulic connectivity work programs relevant to production activities. OGIA hydraulic connectivity studies are described in Section 3 of this report. Studies completed by OGIA prior to this are reported in full by the Surat UWIR.

The findings of these hydraulic connectivity studies are publically reported by the OGIA annually and are being carried out in collaboration with CSIRO; Geoscience Australia; universities; and petroleum tenure holders.

[1] Underground Water Impact Report for the Surat Cumulative Management Area, Queensland Water Commission. December 2012.

2 Review of GLNG hydraulic connectivity studies

2.1 Previous and current studies

In the Stage 2 CWMMP, Santos GLNG reported on the outcome of completed hydraulic connectivity studies and further described a program of additional hydraulic connectivity studies proposed to be completed prior to 2015. This program has subsequently been refined to account for increasing the role of OGIA and associated hydraulic connectivity programs being undertaken by the OGIA. Table 2 provides a status update on progress of each of the current Santos GLNG hydraulic connectivity programs.

Table 2 Progress on Santos GLNG activities and studies

Hydraulic connectivity study	Current status
Hutton - Wallumbilla Fault Program- Roma	In progress. Expected completion end of 2014.
Contact Zone Program - Fairview	In progress. Program to be defined in August 2014 in view of field results for activities carried out Q1 and Q2 2014
Construction of deep monitoring bores	As per Surat UWIR requirements.
Multi-level groundwater pressure monitoring	All monitoring wells expected to be completed by end 2014
Aquifer geochemical and isotopic signature	To be updated 2014-2015
Aquifer response – private bores	Expected completion by end 2014
Aquifer response – monitoring bores	Ongoing, and undertake as required, as events occur

The 2013 hydraulic connectivity studies report (provided as an appendix of the Stage 2 CWMMP) will be updated and consolidated with the results of the 2014 hydraulic connectivity studies and included in the next update of the CWMMP (prior to first cargo of Santos GLNG). With this report, Santos GLNG will have delivered on the requirements under conditions 49. and 49. b) of the approval conditions.

Geological knowledge acquired throughout 2013 has resulted in amendment to the Hutton-Wallumbilla Fault Program and Contact Zone Program. The following sections provide a summary of the findings and intended remaining study scope and objectives.

2.2 Update of the forward hydraulic connectivity studies program

2.2.1 Hutton-Wallumbilla Fault Roma

The Hutton-Wallumbilla Fault (also called the Wallumbilla Fault) is a regional fault. The fault is orientated through the Roma gas field in a south-east to north-west direction (see Figure 1). The Hutton-Wallumbilla Fault is defined as a complex faulting system. The fault system consists of a main fault to which are associated a number of secondary significant faults. The fault system spreads in width of approximately two kilometres. The main fault is not a straight box offset fault type and its characteristics vary along the fault profile. The main fault offset can be made of a number of offsets with varying displacements. The amplitude of the displacement varies from a few metres to the south to about 50 m to the north of the Roma gas field.

The fracturing and the displacement do not affect the full stratigraphic profile. The main faulting occurred during a compressive phase during the mid-Triassic. The faults were reactivated during the mid-Cretaceous causing minor faulting throughout the secondary sequences or causing folding. Fractures affecting the secondary could also result from differential sediments compaction and as such be tension fractures.

Using the Boxgrove Ironstone Member (a very good reflector of seismic lines and used as a marker) found at the top of the Boxvale Sandstone, seismic sections show that the formations above the Evergreen Formation are continuous across the fault. Therefore it is now interpreted that the coal beds of the Walloon Coal Measures and all the aquifers above them are continuous across the fault zone. The Precipice Sandstone underneath would not be continuous as it would have been deposited on a heterogeneous structure.

In terms of its hydraulic properties, the Hutton-Wallumbilla Fault is not considered to be a barrier to horizontal flow above the Evergreen Formation and as such the fault is not expected to play a major role in controlling drawdown resulting from coal seam depressurisation neither vertically (i.e. between formations) and horizontally (i.e. across formations).

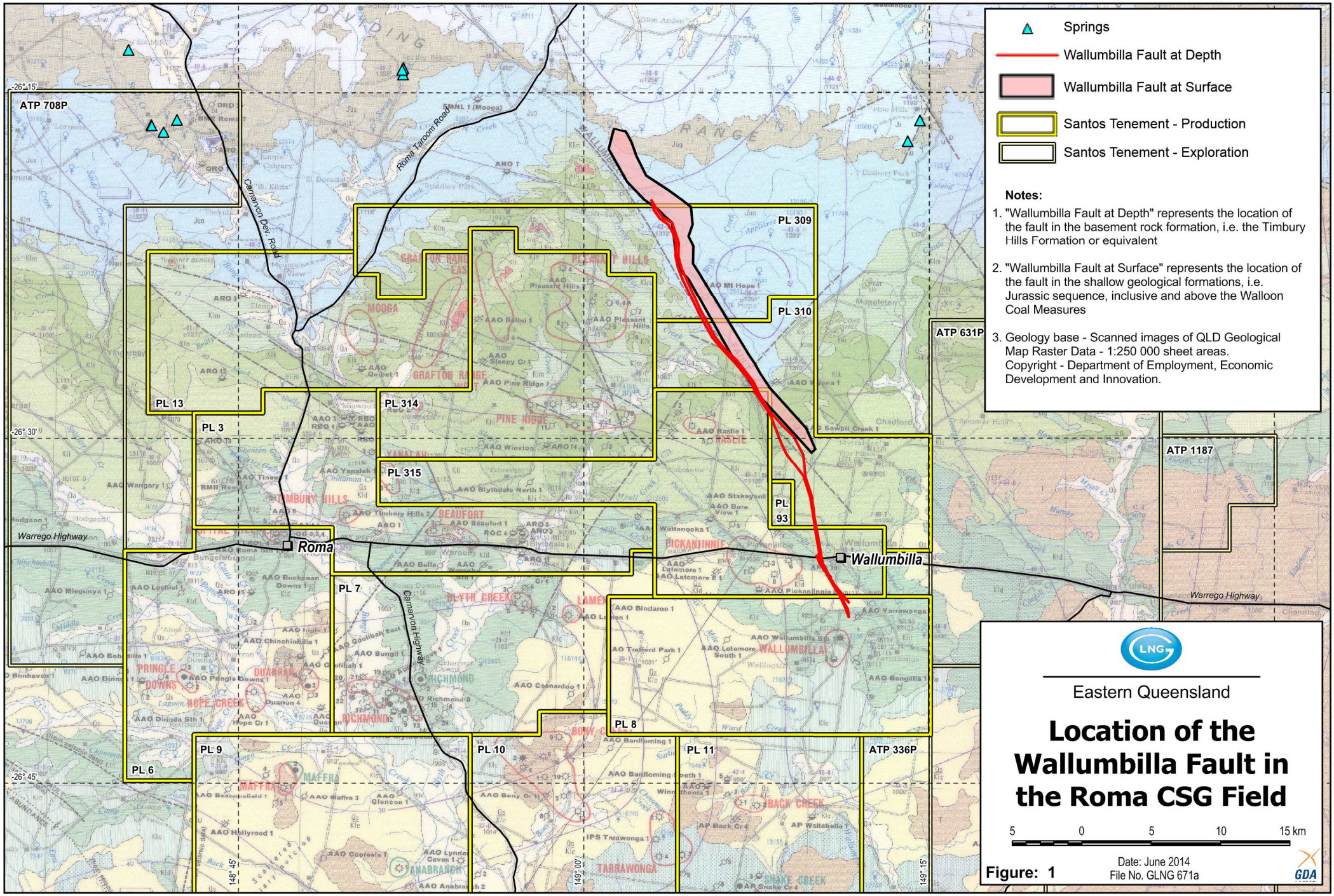
2.2.2 Precipice contact zone in Fairview

The Precipice contact zone study in Fairview will characterise the unconformable contact between the Precipice Sandstone and the Bandanna Formation (the target coal seam in the Fairview area) where the Rewan Formation, which normally hydraulically isolates the Bandanna Formation from overlying aquifers, is absent.

In the Fairview gas field, the Precipice Sandstone can have a thickness of more than 70 m and outcrops along some parts of the Dawson River and Hutton Creek. The lower Triassic aged Rewan Formation separates the Precipice Sandstone from the underlying Bandanna Formation. In the Fairview area, the thickness of the Rewan Formation reaches 400 m. The Rewan Formation is made of lithic sandstones, green to reddish brown mudstone and minor volcanilithic pebble conglomerate found at its base. It has low hydraulic conductivity and as such is seen as a major confining bed.

Erosion of the Rewan Formation in the south-western corner of Fairview prior to deposition of the Precipice Sandstone has resulted in an unconformable contact where the Precipice Sandstone directly overlies the Bandanna Formation (Figure 2). This area is referred to as a contact zone. The study seeks to better understand the location and extent of this contact zone.

The Santos GLNG Project plan was to monitor the contact zone through a number of bores as defined in Table 3. Two vibrating wire piezometers were installed in 2009 (VWP0902 and VWP0903), and one monitoring bore was installed in 2013 (QWC129, also referred to as MTGWP01 or the Mount Hutton bore). Critically, and given the revised location of the contact zone, the Mount Hutton bore, VWP0902 and VWP0903 are no longer interpreted to be in the contact zone (although VWP0902 is not far away).


Springs
Wallumbilla Fault at Depth
Wallumbilla Fault at Surface
Santos Tenement - Production
Santos Tenement - Exploration
Notes:
1. "Wallumbilla Fault at Depth" represents the location of the fault in the basement rock formation, i.e. the Timbury Hills Formation or equivalent
2. "Wallumbilla Fault at Surface" represents the location of the fault in the shallow geological formations, i.e. Jurassic sequence, inclusive and above the Walloon Coal Measures
3. Geology base - Scanned images of QLD Geological Map Raster Data - 1:250 000 sheet areas. Copyright - Department of Employment, Economic Development and Innovation.
ATP 708P
PL 309
PL 310
ATP 631P
PL 13
PL 314
PL 3
PL 315
PL 93
ATP 1187
PL 7
PL 8
PL 9
PL 10
PL 11
PL 6
ATP 336P
Roma
Wallumbilla
Warrego Highway
Roma Taroom Road
Carnarvon Dev. Road
Carnarvon Highway
MOOGA
GRAFTON RANGE
PLEASANT HILLS
PINE RIDGE
TIMBURY HILLS
BEAUFORT
PICKANJINNIE
BLYTH CREEK
RICHMOND
WALLUMBILLA
PRINGLE DOWNS
DUARRAH
HOPE CREEK
MAFFRA
BACK CREEK
SNAKE CREEK
TARRAWONGA
ANABRANCH
-26° 15'
-26° 30'
-26° 45'
148° 45'
149° 00'
149° 15'
5 0 5 10 15 km
Eastern Queensland
Location of the Wallumbilla Fault in the Roma CSG Field
Figure: 1
Date: June 2014
File No. GLNG 671a
GDA

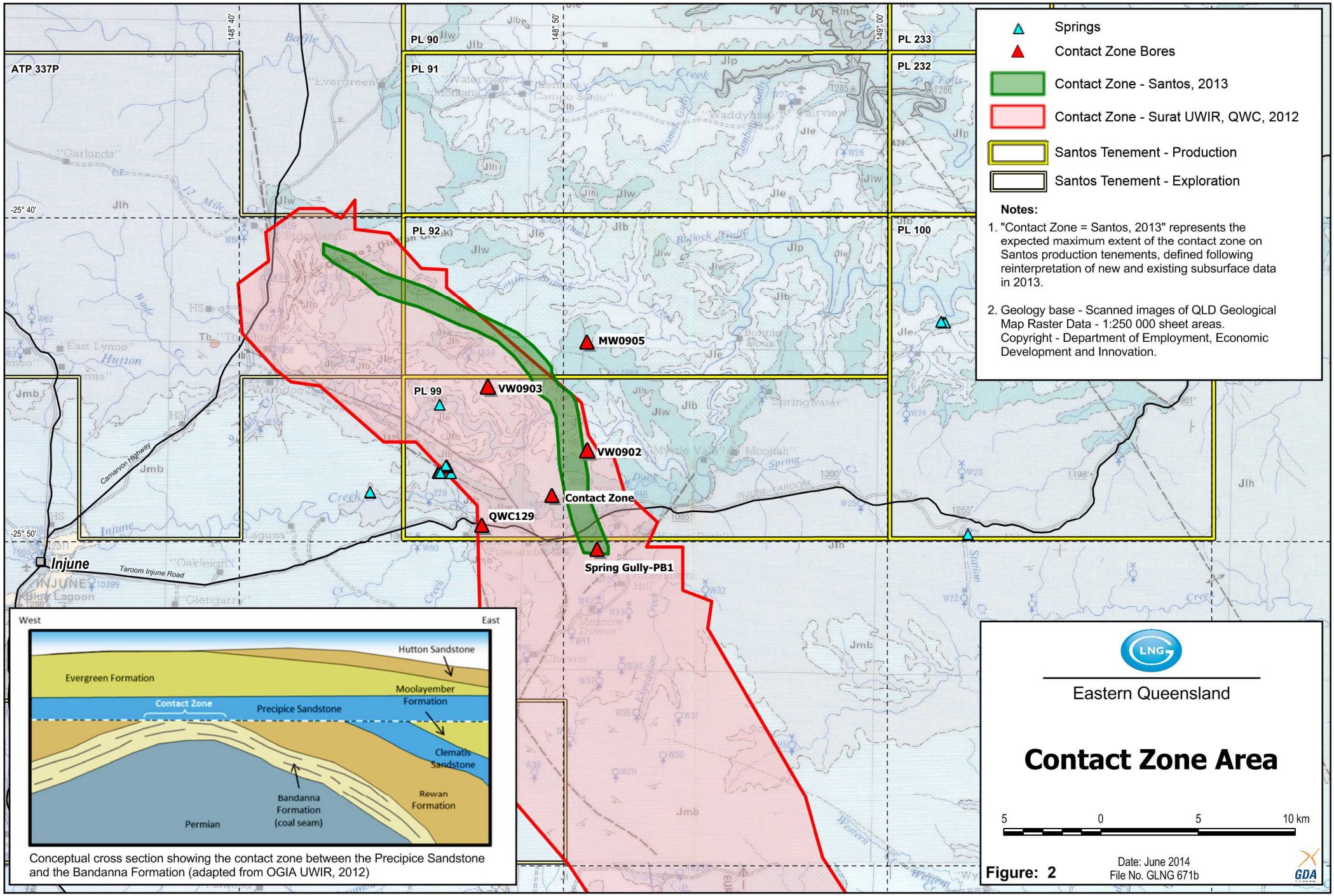

Springs
Contact Zone Bores
Contact Zone - Santos, 2013
Contact Zone - Surat UWIR, QWC, 2012
Santos Tenement - Production
Santos Tenement - Exploration
Notes:
1. "Contact Zone = Santos, 2013" represents the expected maximum extent of the contact zone on Santos production tenements, defined following reinterpretation of new and existing subsurface data in 2013.
2. Geology base - Scanned images of QLD Geological Map Raster Data - 1:250 000 sheet areas. Copyright - Department of Employment, Economic Development and Innovation.
ATP 337P
PL 90
PL 91
PL 92
PL 99
PL 100
PL 232
PL 233
MW0905
VW0903
VW0902
Contact Zone
QWC129
Spring Gully-PB1
Injune
Carnarvon Highway
Taroom Injune Road
West
East
Hutton Sandstone
Evergreen Formation
Moolayember Formation
Contact Zone
Precipice Sandstone
Clematis Sandstone
Rewan Formation
Bandanna Formation (coal seam)
Permian
Conceptual cross section showing the contact zone between the Precipice Sandstone and the Bandanna Formation (adapted from OGIA UWIR, 2012)
Eastern Queensland
Contact Zone Area
5 0 5 10 km
Figure: 2
Date: June 2014
File No. GLNG 671b

Table 3 Hydraulic connectivity monitoring bores at contact zone (2013 study program)

Bore Name	Longitude	Latitude	Monitored Formations	Status of installation
VW0902	148.8459	-25.7863	Precipice Sandstone	Completed
VW0903	148.7948	-25.7538	Precipice Sandstone	Completed
Contact Zone	148.8276	-25.8098	Precipice Sandstone	Planned 2014
			Hutton Sandstone (if present)	Planned 2014
QWC 129 – Mount Hutton	148.7916	-25.8250	Hutton Sandstone	Planned 2014
			Precipice Sandstone	Completed
Spring Gully – PB1*	148.8510	-25.8375	Hutton Sandstone	Not known*
			Precipice Sandstone	Completed

* PB1 is located on a tenement operated by the Australia Pacific LNG Project (APLNG), on the southern part of the contact zone area. PB1 is therefore not the responsibility of the Santos GLNG Project.

2.2.3 Multi-Level monitoring bores data

The Santos GLNG monitoring network includes single-level and a number of multi-level piezometers of varying types. These piezometers target aquifers and specific monitoring zone depths to pre-defined data acquisition objectives.

Multi-level monitoring bores have been and continue to be drilled, completed and equipped in 2013-2014. Where sufficient data is available for valid interpretation relating to aquifer connectivity, Santos GLNG will review the water level data and discuss inter-formation connectivity observations.

2.2.4 Hydraulic characterisation of monitored private bores (telemetry bores)

The Santos GLNG Project monitors 65 landholder bores, out of planned total of 85, with groundwater pressure monitoring equipment. Data collection at these sites is installed with telemetry and therefore all groundwater pressure data is recorded 'live', being automatically uploaded to a central data holding repository as it is collected. These bores are generally active water supply bores and are therefore periodically pumped by the landholder.

An assessment has been carried out to select data collected from these pumped bores to determine if they are suitable for hydraulic analysis to estimate hydrogeological parameters (e.g. transmissivity and hydraulic conductivity). The intent is to analyse only those groundwater pressure data that exhibits a clear response to bore pumping, where the bore completion is known and a reasonable estimate of water production can be made.

Where data are deemed suitable and bore completions are well known, groundwater pressure data from monitored private bores will also be used to determine long term non-pumped groundwater pressure trends.

3 OGIA's current and future hydraulic connectivity studies

In 2014 and 2015, OGIA is developing and implementing a number of research projects to improve knowledge about the interconnectivity between the target coal seam formations and the underlying and overlying aquifers. The primary objective of this work is to improve the Surat UWIR conceptual hydrogeological model and therefore to reduce the uncertainty of the numerical groundwater model which is used to predict potential groundwater impacts in the Surat and Bowen basins. The projects investigate the connectivity between the aquifers of the Surat and Bowen basins and the influence of geological structures on aquifer connectivity.

This work has and will continue to incorporate the best available data, interpreted in the context of actual observed changes in groundwater pressures that have resulted from coal seam gas production activities and other anthropogenic and natural influences. The findings of this work will guide the requirements of current and future hydraulic connectivity studies and ongoing advice and policy development with respect to management of the groundwater resource.

A summary of the groundwater impact assessment process that has been followed to date is presented in Section 3.1, and a summary of the investigations and research that OGIA intend to progress over the next year is provided in Section 3.2.

3.1 OGIA groundwater impact assessment process

In 2011, the OGIA implemented a range of technical investigations and assessments to support the development of the current Surat UWIR. A summary of the progress of these investigations has been referenced from the OGIA's annual report (Annual Report 2013 for the Surat Underground Impact Report, OGIA, December 2013).

The investigations included:

- Compiling a current understanding of the hydrogeology of the area in and around the Surat CMA
- Developing a regional groundwater flow model (the regional model) for making predictions of groundwater impacts from the petroleum and gas activities
- Analysing uncertainty in model predictions
- Undertaking a comprehensive survey of the relevant springs in the Surat CMA for their hydrogeological and ecological attributes
- Compiling an inventory of all existing and proposed monitoring bores and activities in the Surat CMA.

The Surat UWIR was approved by the Department of Environment and Heritage Protection (formerly DERM) and the approved report took effect on 1 December 2012. The Surat UWIR will be revised every three years (with the next revision due in 2015) to incorporate new knowledge. Annual implementation reports will be prepared on monitoring results and emerging knowledge.

OGIA is carrying out research to build new knowledge about the groundwater flow system to support the revision of the UWIR in December 2015. The research projects are being carried out in collaboration with: CSIRO; Geoscience Australia; universities; and petroleum tenure holders.

3.2 OGIA research projects

The following sections provide a summary of OGIA research projects being developed and implemented by the OGIA.

3.2.1 Condamine connectivity project

The current cumulative groundwater model for the CMA predicts relative small impacts on the Condamine Alluvium as a result of depressurisation of the underlying Walloon Coal Measures (WCM). However, the alluvium formation is extensively used by the local community and this project was deemed necessary to identify the level of connectivity between the WCM and the alluvium formation and reassess the risk to private bores.

OGIA has analysed the water quality over the study area to identify the character and origin of the water. OGIA has reviewed all geological information and created a detailed geological model. The project consisted then in a number of aquifer pumping tests with monitoring of responses in multi-level monitoring bores.

3.2.2 Walloon Coal Measures connectivity project

OGIA has developed two hydraulic connectivity projects relating to the Walloon Coal Measures (in addition to the Condamine Connectivity Project). The aim is to cover different areas of the Surat Basin to account for different geological settings and expected level of hydraulic connectivity. The hydraulic connectivity of the Walloon Coal Measures are being investigated by OGIA because their depressurisation is expected to have the greatest contribution of potential impact on GAB aquifers and springs and groundwater users. OGIA states that a similar approach is being used to that used for the Condamine Connectivity Project and that it aims at focussing both at a regional and local scale with local scale investigations being carried out in collaboration with tenure holders.

The GLNG Project is supporting OGIA's investigation by providing data over its Roma gas field. Geologic Modelling Project.

A new geological model is being prepared as a basis for the construction of a new groundwater flow model for the update of the Surat UWIR due in 2015. The work comprises a stratigraphic reinterpretation of geophysical wireline log data, as well as a general review of more recently acquired and interpreted geological data such as seismic survey interpretations.

The GLNG Project is assisting by providing OGIA with data.

3.2.3 Geological structures project

OGIA's geological structure project aims at documenting and understanding the role of faults on the propagation of depressurisation and as such the connectivity between potentially affected aquifers.

The GLNG Project is contributing information to the OGIA on the major fault systems.

4 Reporting

Santos GLNG currently reports annually connectivity studies as detailed in the Stage 2 CWMMP.

It is expected that after 2014, the annual reports submitted to the DOE, and the new CWMMP that is required to be submitted for approval by DOE at the time Santos GLNG's first cargo of LNG is delivered (which is expected to be some time in 2015) reporting on the status of hydraulic connectivity studies will focus on the research in relation to the UWIR being implemented by the OGIA.