The Rewan Formation Connectivity Research Plan to meet EPBC Approval Condition 27 for the Adani Carmichael Coal Mine Project

November 2019
## Document Control & Version Control

**Document Title:** Adani Mining - Rewan Formation Connectivity Research Plan  
**Document Type:** Report  
**First Issue Date:** 02/08/2018

<table>
<thead>
<tr>
<th>Rev Code</th>
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<th>Description of Revisions Made</th>
<th>Signatures</th>
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<td>Rev B</td>
<td>30/05/2015</td>
<td>Amendments</td>
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<td>Rev C</td>
<td>02/06/2015</td>
<td>Incorporation of above amendments</td>
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<tr>
<td>CCP</td>
<td>Carmichael Coal Mine project</td>
</tr>
<tr>
<td>DNRM</td>
<td>Department of Natural Resources and Mines, Queensland</td>
</tr>
<tr>
<td>DoE</td>
<td>Department of environment and Energy</td>
</tr>
<tr>
<td>DSC</td>
<td>Doongmabulla Spring Complex</td>
</tr>
<tr>
<td>EIS</td>
<td>Environmental Impact Statement</td>
</tr>
<tr>
<td>EPBC</td>
<td>Environmental Protection and Biodiversity Conservation</td>
</tr>
<tr>
<td>GABSRP</td>
<td>Great Artesian Basin Spring research Plan</td>
</tr>
<tr>
<td>GDEMP</td>
<td>Groundwater Dependent Ecosystem Management Plan</td>
</tr>
<tr>
<td>GMMP</td>
<td>Groundwater Management and Monitoring Plan</td>
</tr>
<tr>
<td>IESC</td>
<td>Independent Expert Scientific Committee</td>
</tr>
<tr>
<td>JORC</td>
<td>Joint Ore Reserves Committee</td>
</tr>
<tr>
<td>MNES</td>
<td>Matters of National Environmental Significance</td>
</tr>
<tr>
<td>SEIS</td>
<td>Supplementary Environmental Impact Statement</td>
</tr>
<tr>
<td>SMP</td>
<td>Subsidence Management Plan</td>
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1. Introduction

During the EIS/SEIS/AEIS various studies carried out for conceptualisation of the geology, hydrogeological setting and development of ground water model for prediction of project impacts were scrutinised by the Coordinator General. The approval document “Carmichael Coal Mine and rail project” Coordinator General Evaluation report on the Environmental Impact Statement has identified certain areas where further information needs to be collected and additional studies need to be conducted to negate uncertainties, especially with effect of faulting and potential subsidence induced fracturing in the Rewan Formation strata. With respect to the Rewan formation, the Coordinator-General’s report states that “DNRM agreed with the IESC’s advice that the integrity of the Rewan Formation as an aquitard is critical to the impacts of mining and dewatering activities in this area. DNRM advised that it would therefore support the requirement for the development of a Rewan Formation Connectivity Research Plan for the Carmichael project as was required of Kevin’s Corner in the approval by the Commonwealth Minister for the Environment.”

The Rewan Formation Connectivity Research Plan (‘the Plan’) has been developed to meet the requirements of EPBC Approval Condition 27 for the Adani Carmichael coal mine complements as outlined below. The Plan combines existing monitoring and modelling programs with an initial period of intensive desktop research primarily focussed on characterising the Rewan Formation and the contribution of fracturing, faulting and preferential pathways to connectivity within the area impacted by the mine. This will be followed by ongoing monitoring and further validation as operations commence.
2. Conditions

Adani’s Carmichael Coal Mine Project (CCP) has received conditional EPBC Approval. The EPBC approval conditions include the following:

Condition 27. At least three months prior to commencing excavation of the first box cut, the approval holder must submit for the approval of the Minister a Rewan Formation Connectivity Research Plan (‘Rewan Research Plan’) that characterises the Rewan Formation within the area impacted by the mine. The Research Plan must be informed by the results of the groundwater flow model re-run (condition 23) and include but not be limited to the following:

a) research aims;

b) personnel responsible for conducting research and their qualifications;

c) time frames for research and reporting;

d) methods, including, but not limited to, seismic surveys to determine the type, extent and location of fracturing, faulting and preferential pathways (including any fracturing induced by longwall mining subsidence, including any fracturing impacting on the Doongmabulla Springs Complex) and an examination of the hydraulic properties (including but not limited to petrophysical analysis and facies mapping) of the Rewan Formation, to better characterise the Rewan Formation and the contribution of fracturing, faulting and preferential pathways to connectivity, including a description of how research will be undertaken in a manner that does not cause impacts on Matters of National Environmental Significance (unless the activities will be undertaken in accordance with a plan approved pursuant to conditions of this approval);

e) an explanation of how research will inform the GMMP (Groundwater Monitoring and Management Plan), any regional groundwater and surface water monitoring and assessment program, or Bioregional Assessment for the Galilee Basin sub-region and the Lake Eyre Basin and any subsequent iterations; and,

f) a peer review of the Rewan Research Plan, by a suitably qualified independent expert, approved by the Minister in writing, and a table of changes made in response to the peer review.

The Plan is prepared to meet Condition 27 of EPBC Approval. The structure of the report and compliance with each of the above mentioned condition is furnished in Table 1.
### Table 1 Structure of report and compliance with Approval conditions

<table>
<thead>
<tr>
<th>Sl No</th>
<th>EPBC Approval Condition 27</th>
<th>Reference to report and compliance statement to meet condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>Condition 27. At least three months prior to commencing excavation of the first box cut, the approval holder must submit for the approval of the Minister a Rewa Formation Connectivity Research Plan ('Rewan Research Plan') that characterises the Rewan Formation within the area impacted by the mine.</td>
<td>The Plan was first lodged to the Department on 7 August 2018. This report is “version N” updated to meet the review and comments received from DoEE on 5 June 2019.</td>
</tr>
<tr>
<td></td>
<td>The Research Plan must be informed by the results of the groundwater flow model re-run (condition 23) and include but not be limited to the following:</td>
<td></td>
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<tr>
<td></td>
<td>(a) research aims</td>
<td>See section 3 and section 4.5 of this report</td>
</tr>
<tr>
<td></td>
<td>(b) personnel responsible for conducting research and their qualifications</td>
<td>See sections 4.5 and Table 3 and section 6 of this report</td>
</tr>
<tr>
<td></td>
<td>(c) time frames for research and reporting</td>
<td>See sections 4.5 and Table 3 of this report.</td>
</tr>
<tr>
<td></td>
<td>(d) methods, including, but not limited to, seismic surveys to determine the type, extent and location of fracturing, faulting and preferential pathways (including any fracturing induced by longwall mining subsidence, including any fracturing impacting on the Doongmabulla Springs Complex) and an examination of the hydraulic properties (including but not limited to petrophysical analysis and facies mapping) of the Rewan Formation, to better characterise the Rewan Formation and the contribution of fracturing, faulting and preferential pathways to connectivity, including a description of how research will be undertaken in a manner that does not cause impacts on Matters of National Environmental Significance (unless the activities will be undertaken in accordance with a plan approved pursuant to conditions of this approval);</td>
<td>Sections 5.1 to 5.13.</td>
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<tr>
<td></td>
<td>(e) an explanation of how research will inform the GMMP (Groundwater Monitoring and Management Plan), any regional groundwater and surface water monitoring and assessment program, or Bioregional Assessment for the Galilee Basin sub-region and the Lake Eyre Basin and any subsequent iterations; and</td>
<td>See section 5.14</td>
</tr>
<tr>
<td></td>
<td>(f) a peer review of the Rewan Research Plan, by a suitably qualified independent expert, approved by the Minister in writing, and a table of changes made in response to the peer review.</td>
<td>A peer review has been conducted by and included in section 7.</td>
</tr>
</tbody>
</table>
3. Purpose and objectives of the Plan

The main purpose of the Plan is to outline research aims and objectives, with a description of the rationale applied and justification of approaches, methods and strategies that shall be adopted to meet EPBC Condition 27 as defined above. The Plan concentrates on an eighteen month intensive period of desktop research to meet specific conditions and provide outcomes which would then be validated and assessed once the mining process provides actual data that can be compared to predicted responses.

On examining the impact predictions from the SEIS predictive groundwater model and re-run model scenarios (using differing model boundaries under EPBC condition 23) at important receptors it is evident that the impacts are similar but higher in case of SEIS model. While developing this research plan a conservative approach has been adapted to use the SEIS model which predicts the highest magnitude of impacts which also has been used for all assessments and development of other management and research plans on groundwater.

Given the broad scope of the research, Adani have identified a number of key independent researchers and organisations (area content experts) who will make contributions to meet specific conditions. The selection of key personnel followed a mapping process to identify suitable researchers with the required industry standing, qualifications and capability to complete research for discreet specified conditions and subject areas. The approach is outlined as follows:

1) Key work packages and deliverables will be separated out for completion by area content experts; this will enable the researchers to provide confirmation of the availability of resources to meet key milestones and deliverables as outlined in the Plan;

2) Individual lead researchers will be tasked with specific work scopes and deliverables within their own area of expertise and capability. This will provide for a focussed approach for the individuals to meet the objectives and deliverables required for each specific condition, without requiring individuals to pass judgement on areas which may be beyond their scope or area of defined responsibility and capability;

3) As Project Manager and logistical coordinator will project manage inputs to the Plan to ensure the most effective utilisation of combined external independent and internal resources;

4) All external work scope packages will require an independent report formally documenting methods used and the outcomes of the research relating to each of the specific work packages;

5) It is proposed that a work shop will be conducted after individual research package reports are available; and

6) The research outcomes will subsequently be compiled in the form of a final report that will reflect the outcomes of the intensive first year of planned research.

The Plan provides details on how the research outcomes will directly inform the GMMP, any regional groundwater and surface water monitoring and assessment program, or Bioregional Assessment for the Galilee Basin sub-region and the Lake Eyre Basin and any subsequent iterations. The Plan also identifies ongoing measurement, monitoring and controls measures that will be required to validate outcomes of targeted research areas.

The Plan identifies timeframes and / or milestones for research and reporting and also provides relevant experience and qualifications of personnel responsible for conducting research in each of the areas identified to meet the required conditions.
4. **Background**

4.1. **The Rewan formation in the area of the Carmichael project**

Adani’s Carmichael Coal mine lease is situated in the northern Galilee Basin (Figure 1). Open cut and underground pits are planned with an operational life span of about 60 years. The location and layout of the mine are shown in Figure 3.

The overall geological stratigraphy is shown in Fig. 2, which is a SW-NE cross-section representative of the full NW-SE length of the mine lease area. The geological features relevant to the groundwater impacts assessment are described in Appendix K1 - Mine Hydrogeology Report (Nov 2014) of the Supplementary Environmental Impact Statement (SEIS) and in the Draft Groundwater Monitoring Program (March 2014) as supplementary information submitted post SEIS.

The Carmichael Coal Mine Project lies within the Galilee Basin which covers an area estimated at 247,000 km² of Central Queensland. Figure 1 shows the extent of the Galilee Basin and its relative position to the other major coal basins in Queensland. This basin is entirely intra-cratonic and is comprised of Late Carboniferous to Permian sediments. These rocks are predominantly fluvial in origin with minor glacial material developed at the base of the succession.

The principal tectonic elements of the basin include the east-west trending Barcaldine Ridge which subdivides the basin into northern and southern components. The northern component of the basin is subdivided by the Maneroo Platform and the Beryl Ridge which resulted in the development of the western depression termed the Lovelle Depression and the eastern depression termed the Koburra Trough. The Carmichael Coal Mine Project lies within the Koburra Trough. The southern part of the basin is divided into the western Powell Depression and the Springsure Shelf by the Pleasant Creek Arch.

The stratigraphy of the Galilee Basin and its coal measures is shown in Figure 2 and follows the most recent scheme from Allen & Fielding (2007). Mineable targets occur in the Bandanna Formation (A and B seam) and the Colinlea Sandstone (C and D seams underlain by E and F seams), that are separated by strata belonging to condensed Black Alley Shale and Peawaddy formations. These seams vary in thickness from 1 to 13m, and across the lease they converge and diverge or split to distances varying between 5 to 70m. Together, these Late Permian coal measures are also referred to as the Betts Creek Beds, and they unconformably overlay the Early Permian Aramac Coal measures and older strata. The Aramac Coal Measures do not occur in the Adani lease. A regional section illustrating the Galilee Basin Stratigraphy is shown in Figure 4.
Figure 1: Galilee Coal Basin Extent
Figure 2: Stratigraphy of the Galilee Basin and its coal measures. Modified from Allen & Fielding, 2007
Figure 3: Mine location and layout (From: Carmichael Coal Mine and Rail Project SEIS Report for Updated Mine Project Description, 18 October 2013, Section 1.1.)
Figure 4: SW-NE geological transect showing conceptual hydrogeological model

The Permian coal-bearing units of the Colinlea Sandstone and Bandanna Formation are overlain by (in ascending stratigraphic order) the Triassic Rewan Formation, the Dunda Beds, the Clematis Sandstone (which is also equivalent to the Warang Sandstone) and the Moolayember Formation, which occurs at surface to the west of the mine lease area. The Dunda Beds have been logged in boreholes along the western edge of the Adani Lease. The nearest recognised Great Artesian Basin (GAB) aquifer unit to the Adani Lease is the Clematis Sandstone, which is identified from geological mapping to crop approximately 2km to the west of Mining Lease and does therefore not stratigraphically overlie planned mine operations within the Adani lease. This is reflected in the existing hydrogeological modelling and conceptualisation.

The Rewan Formation is a heterogeneous unit of green lithic sandstone, pebble conglomerate and red and green mudstones (Bashari 1996) and is generally regarded as an aquitard. The Rewan Formation within the Galilee Basin is characterised by generally fine grained siltstone and mudstone with intercalated sandstones that contain labile minerals and abundant clay matrix (Vine 1976, Grigorescu 2012). The Rewan Formation subcrops beneath Tertiary/Quaternary alluvium within the mine lease area (Figure 5); the typical thickness in the area immediately west of the mine is approximately 200 meters (m), increasing to a thickness of 275 m further west from the mining lease boundary. Although the Dunda beds also lie between the coal seams and the overlying aquifers, the Rewan is the principal control on vertical hydraulic connectivity due to its generally low vertical hydraulic conductivity. In general terms the Rewan Formation it is a very distinctive unit that is
easily recognisable in drill core and chips. The typical lithological characteristics for all sequences are illustrated in Table 2.
Figure 5: Map of Adani leases overlaying mapped geology, also showing the location of available groundwater monitoring and test locations available to the project.
<table>
<thead>
<tr>
<th>Period</th>
<th>Stratigraphic Unit</th>
<th>Mineralogy</th>
<th>Sorting</th>
<th>Grainsize (lithologies)</th>
<th>Lateral Continuity</th>
<th>Paleo-environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triassic</td>
<td>Moolayember Formation</td>
<td>Scattered aggregates of brown carbonates. Mid-high quartz content. Dominant clay mineral is kaolinite. Rare siderite, calcite and hematite.</td>
<td>Poorly to moderately sorted.</td>
<td>Abundant mudstone with interbedded lithic and quartz sandstones.</td>
<td>Located in the centre of the Galilee Basin running north to south. Extends into the north western limb. Also observed in the Bowen Basin.</td>
<td>Low energy, westerly flowing fluvial system. Lacustrine facies also observed.</td>
</tr>
<tr>
<td></td>
<td>Clematis Sandstone</td>
<td>Abundant quartzose. Dominant clay mineral is kaolinite. Rare illite and haematitic particles.</td>
<td>No data.</td>
<td>Fine to very coarse grained sandstone with rare silt and mudstone. Angular to subrounded grains.</td>
<td>Located in the eastern and central parts of the Galilee Basin. Extends into the Bowen Basin over the Springsure Shelf.</td>
<td>Deposited by a braided river system travelling from the east of the basin.</td>
</tr>
<tr>
<td></td>
<td>Dunda Beds</td>
<td>Abundant quartzose. Dominant clay mineral is kaolinite.</td>
<td>Moderately sorted.</td>
<td>Medium grained quartzose and liable sandstone with silt and mudstone.</td>
<td>Located in the central part of the Galilee Basin.</td>
<td>Thought to be a facies variation of the Rewan Formation.</td>
</tr>
<tr>
<td></td>
<td>Rewan Formation</td>
<td>Common hematite and kaolinite matrix</td>
<td>Well to moderately sorted.</td>
<td>Labile sandstone, siltstone and multi coloured mudstone. Generally fine grained</td>
<td>Located in the central and south eastern part of the Galilee Basin. Extends into the Bowen Basin over the Springsure Shelf.</td>
<td>Deposited in a fluvio-lacustrine environment.</td>
</tr>
<tr>
<td></td>
<td>Bandanna Formation</td>
<td>Quartz abundant with rare hematite and chlorite. Dominant clay mineral is kaolinite. Feldspars range up to 30% in samples.</td>
<td>No data.</td>
<td>Laminated to massively bedded labile sandstone, interbedded with mudstones and siltstones. Contains major coal seams.</td>
<td>Located in the southern and north eastern part of the Galilee Basin. Extends into the Bowen Basin over the Springsure and Nebine Ridge.</td>
<td>Deposited on a coastal alluvial plain by a fluvio-deltaic system.</td>
</tr>
</tbody>
</table>
Kaolinite is dominant clay mineral. Hematite and chlorite have been detected. Significant feldspars.

Black Alley Shale

- Kaolinite is dominant clay mineral. Hematite and chlorite have been detected. Significant feldspars.
- Black mudstones interbedded with light grey siltstones in parts. Common tuffaceous layers.
- Located in the southern part of the basin and extends northwards along the eastern margin.
- Deposited in brackish-marine conditions.

<table>
<thead>
<tr>
<th>Stratigraphic Unit</th>
<th>Mineralogy</th>
<th>Sorting</th>
<th>Grainsize (lithologies)</th>
<th>Lateral Continuity</th>
<th>Paleo-environment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peawaddy Formation</td>
<td>Quartz content is variable, higher in sandstone than in mudstone. Feldspar is abundant across all lithologies. Dominant kaolinite and mica in mudstone. Significant pyrite in mudstones.</td>
<td>Well sorted.</td>
<td>Fine grained to interbedded siltstone. Some massive mudstone.</td>
<td>Located in the southern part of the basin and extending along the eastern margin of the basin.</td>
<td>Marine influence.</td>
</tr>
<tr>
<td>Colinlea Sandstone</td>
<td>Abundant quartz observed. The dominant clay mineral is kaolinite with rare illite and minor chlorite.</td>
<td>Well sorted</td>
<td>Predominantly sandstone with minor mudstone, siltstone and coal. Angular to sub angular grains.</td>
<td>Located to the central and eastern part of the Galilee Basin. Extends into the Bowen Basin over the Springsure Shelf and Nebine Ridge.</td>
<td>Deposited in an alluvial plain by southerly and easterly flowing rivers.</td>
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Table 2 Triassic and Permian Strata found in the Galilee Basin
4.2. Overview of information to support the Plan

The Plan has been written based on the following sources of information:

- Internal Adani knowledge and reports relating to exploration carried out to characterise geology, geotechnical conditions and properties and hydrogeology;
- Review of the relevant scientific literature;
- The EIS and supplementary documents;
- The Draft Groundwater Monitoring Plan, including available groundwater level and chemistry data;
- Previous and current investigations in the Galilee basin into the geology and hydrogeology of the Rewan Formation; and,
- Workshops and meetings with Adani staff and other consultants and proposed research staff.

The main items of relevant available information in the context of Rewan research conditions provided by the EIS and supplementary documents are:

- Existing Adani geological models and reports outlining the strata interpretation of the Permian Bandanna Formation and Colinlea Sandstone as well as the overlying Triassic units (Rewan Formation, Dunda beds, Clematis Sandstone and Moolayember Formation);
- Hydrogeological modelling reports as well as peer review reports and responses relating to hydrogeological modelling reports, including the results of groundwater flow model re-run (condition 23);
- Logs and data from approximately 90 hydrogeology exploration bores in and around the lease;
- Logs and data from approximately 830 geological exploration and geotechnical bores in and around the lease;
- In-situ hydraulic conductivity test results (from packer tests and slug tests) in interpreted Rewan strata units from boreholes located within the lease;
- A summary regional and site data set consisting of approximately 800 samples of hydraulic conductivity from various sources;
- Calibrated values of hydraulic conductivity from the groundwater modelling process;
- Bore logs showing the extent of weathering, stratigraphy and, where apparent, evidence of faults in and near the mine lease;
- 2-D seismic lines and seismic interpretation reports from acquisition and processing of lines within the mine area and in particular in the vicinity of the Doongmabulla Springs;
- The location of known faults from geological modelling, 2D seismic interpretation, JORC Resource reports and aeromagnetic surveys;
- Groundwater level data and inferred regional groundwater flow directions (horizontal and vertical) in strata above and below and Rewan;
- Geochemistry samples from the Rewan and over and under-lying formations;
- Underground longwall subsidence predictions, including potential for change in hydraulic conductivity and connectivity;
- Geotechnical analysis reports for underground longwall and opencut mining; and,
- Hydrogeological inflow modelling and associated reports.
4.3. Interpretation of Preferential Pathways

The key components of required research outlined in Condition 27 (as defined in section 2) are schematically illustrated in Figure 6. The key aspects to address the Plan within the area impacted by the mine are summarised as follows:

- The nature and extent of fractures and the extent to which fractures could provide preferential pathways;
- The type, extent and location of faults and the extent to which faults could act as conduits for groundwater flow (via cross-fault leakage and/or along-fault leakage);
- The potential impacts of fault throw (i.e. vertical displacement of hydro stratigraphic units) on groundwater flow;
- The potential for lithologic connectivity (i.e. lateral/vertical connection of sandy horizons, both within competent Rewan Formation and also across faults); and,
- The vertical and lateral impacts of mine-induced subsidence on the hydraulic properties of the Rewan Formation and on groundwater flow.

Aspects relating specifically to better characterise the Rewan Formation and the contribution of fracturing, faulting and preferential pathways to connectivity are illustrated schematically in Figure 6.

Figure 6: Schematic illustration of the Rewan Formation and the possible connectivity mechanisms that the Plan will research
With reference to Figure 6, the following research packages will be used to determine the type, extent and location of the preferential pathways in the Rewan Formation as illustrated schematically in Figure 6:

- Research package 5.3 will be used to remodel the main stratigraphic units, including the stratigraphic location of the Rewan Formation through the CCP area, based on existing data and additional exploration and field work to be conducted;
- Research package 5.4 will provide for the conceptualisation of the groundwater resources associated with the Rewan Formation and over- and under-lying strata and will be undertaken with the aid of north-south and east-west cross-sections through representative bore logs;
- Research package 5.5 (reprocessing and interpretation of existing historical regional 2D petroleum seismic lines) will provide a determination of the anticipated strike and displacement of interpreted displacement faults, and their assessed permeability characteristics acting as conduits and other preferential pathways through the Rewan Formation;
- The information and outcomes from the above research packages, will be utilised in Research package 5.6 to map fault styles, orientations, displacements and densities over the CCP;
- Research package 5.7 will utilise juxtaposition analysis to construct Allen diagrams that provide a sense of horizontal connectivity on each fault plane;
- Research package 5.8 will utilise Shale Gouge Analysis and Fault membrane seal analysis to assess the permeability of interpreted fault zones including a specific focus on interpreted structural regime in the area of the DSC;
- Research package 5.9 will provide an assessment of fault leakage potential including the potential for along or up-fault seal breach. This will be undertaken through geometric analysis of kinematically correct fault interpretations within a three-dimensional anisotropic stress field.
- Research package 5.10 will assess longwall Mining Subsidence on hydraulic connectivity, including an assessment of the impacts or increased likelihood of hydraulic connectivity within the or across the Rewan Formation due to longwall mining and the impact of hydraulic connectivity associated with predicted subsidence. This will include the assessment of any potential impacts associated with longwall mining subsidence on the DSC.
- Research package 5.11 will complete fault zone analysis to determine hydraulic properties that may influence the Rewan Formation connectivity, taking into consideration all prior research packages and analysis.
- Research package 5.12 will provide for a review of literature and benchmarking studies, assessing the typical CCP case outcomes be assessed against available literature relating particularly with respect to benchmarking permeability across faults and strata in similar environments.
- Research package 5.13 will provide for a compilation of preferential pathway outcomes as illustrated schematically in Figure 6. The primary deliverable from this research package will be to compile all the relevant outcomes of the prior research packages to provide a succinct definitive position on all potential preferential pathways.

4.4. Existing Knowledge Base and Position

The understanding of the geology of the region of the Carmichael mine indicates that geological strata dip from east to west – that is, that each stratum as detailed in Table 2 is closer to surface level in the east than it is in the west as previously illustrated in Figure 4.
Coal for the Carmichael mine will be extracted from the strata below the Rewan Formation, being the Bandanna Formation and the Colinlea Sandstone. The coal-bearing seams below the Rewan Formation will be dewatered.

Figure 7 shows the current number and distribution of exploration holes across the Carmichael Coal Mine project together with boreholes locates to the west of the area, with the corresponding logged units of Rewan and underlying/overlying strata. Adani have recently completed the drilling of four holes (Figure 7, C14200VWP, C14201VWP, C14204VWP and C14207VWP) to fulfil the requirement for supplementary field investigation, which includes geophysical and geological logging of all four holes and collection of core samples from two holes. The data obtained from field investigations and laboratory results from these four holes has been summarised in the report “Seer, H, Stewart, M. “Geological and Groundwater Assessment of the Rewan Formation”. URS Australia Pty Ltd. January 2016” and will form the basis of data analysis and interpretation and will be further used to feed into the developing and/or updating the models for this research plan.

It has been concluded, based on accepted regional geology interpretation, borehole logs and regional data (including 2D seismic lines), that the Rewan Formation as shown in Figure 2 forms a thick sequence of very low permeability strata (i.e. an aquitard) that separates recognised aquifers of the Great Artesian Basin (GAB) from underlying Galilee Basin sediments, which include the Permian coal-bearing sequences of the Bandanna Formation and Colinlea Sandstone. The nearest borehole to the Doongmabulla springs (the petroleum exploration bore Shoemaker 1) is located 600m from the Joshua spring and records the Rewan Formation as being 279.2 metres thick, commencing at 246.8 metres below ground level (mbgl) and extending to 526.0 mbgl.

There are 4 petroleum exploration bores located west of the CCP lease; Carmichael-1, Montani-1, Shoemaker-1 and Lake Gallilee-1. These bores are located from 6.5 km up to 36.5 km from the western border of the CCP lease and provide information on the sub-surface stratigraphy from surface to the underlying Joe Joe Group sediments (via interpretation of lithological logs, geophysical logs and palynological analysis).

The geological stratigraphy west of the CCP lease is comprised of (from surface to depth): Tertiary or surficial materials, Moolayember Formation, Clematis Sandstone, Dunda beds, Rewan Formation, Betts Creek beds and the Joe Joe Formation. No bore holes in the area have penetrated material below the Joe Joe Group.

The thickness of the Moolayember Formation ranges from 77 to 282 metres, the Clematis Sandstone ranges from 120 to 205 metres, the Rewan Formation/Dunda beds ranges from 312 to 342 metres and the Betts Creek beds ranges from 123 to 198 metres.

The regional stratigraphy west of the CCP lease, correlated by the interpreted lithology logs of the petroleum bores drilled, demonstrates that the stratigraphy is dipping westwards at approximately 0.5 degrees and has stable thickness. Progressing west from the lease boundary the thickness of the Clematis Sandstone and then Moolayember Formation increases.

There have been a number of independent studies and analyses completed to date from available data, information and interpretations. These sources have provided for the current interpretation of the stratigraphical position, thickness and hydrogeological characterisation. A number of these independent studies and analyses were provided as supporting evidence in the Land Court proceedings (Adani Mining Pty Ltd v Land Services of Coast and Country Inc & Ors [2015] QLC 48), delivered on 15th December 2015). However, a number of studies and analyses have been completed since the 2015 Land Court verdict was
delivered and these provide further information and data sources that will support the research aims and future outcomes of this plan.

Relevant studies, analyses and interpretations that were completed prior to the Land Court judgement in 2015 include the following:

- Turner, T. “Adani Mining Pty Ltd JORC Coal Resource Estimate - Carmichael Coal Project” Completed by Xenith Consultants Pty Ltd. For Adani Mining Pty Ltd. April 2013;

Relevant studies, analyses and interpretations that were completed following the Land Court judgement in 2015, but provide relevant material to support this plan include the following:

- Seer, H, Stewart, M. “Geological and Groundwater Assessment of the Rewan Formation”. URS Australia Pty Ltd. January 2016.; and

The following provides a general summary of the current knowledge base and position in relation to geological and hydrogeological understanding of connectivity through the Rewan Formation based on independent studies, analyses and reports completed to date:

- Whilst the Coordinator General’s evaluation report supported the conceptualisation that the source aquifer for the Doongmabulla Springs is likely to be above the Rewan Formation, uncertainty was to be addressed through further investigative, monitoring and research studies;
- A number of independent hydrogeologists have, following consideration of the regional geology, borehole data and hydrogeological modelling, reached the following conclusions (and it is on the basis of many of these findings that federal EPBC approval for the Mine Project has been granted subject to establishing and complying with approved conditions):
  - That coal extraction through planned opencut and underground mining of Permian coal seams to the east (the Carmichael Coal Mine Project) will not result in dewatering of the Doongmabulla springs due to the significant thickness of low-permeability Rewan Formation present in this area (it is acknowledged that groundwater modelling predicts a degree of groundwater drawdown at
the location of the Doongmabulla springs, though the extent of drawdown has been assessed to be within acceptable limits;

- That there is no indication of any significant displacement faulting in the vicinity of the Doongmabulla springs that could lead to mixing of aquifers (Biggs, 2014);
- That the potential for hydraulic connectivity through the entire Rewan sequence through fractured zones (vertical or horizontal) associated with possible faults with only zero or small levels of displacement is considered by Adani to be extremely low. There is currently no evidence of any fault through the Rewan Formation in the vicinity of the Doongmabulla springs that could act as a conduit for significant groundwater flow.

- A Report compiled by URS, 2016 based on site-specific data, from field and laboratory tests in boreholes assessed the geological and groundwater nature of the Rewan Formation, located to the west of the Carmichael Coal Project and examined the hydraulic properties of the Rewan Formation adjacent to the Carmichael mine lease.
- The current assessment of longwall mine subsidence (MSEC 2014) in relation to subsurface connectivity of overburden strata associated with longwall undermining.

A principle research aim of this plan is to further investigate the local stratigraphy, connectivity and hydrogeological conceptualisation/s. This will be achieved through:

1) Further assessing the presence of faults that may allow for continuous hydraulic connection. If a fault with sufficient ‘throw’ that may result in juxtaposition of Clematis Sandstone against the Permian coal bearing formations is interpreted, then appropriate hydraulic testing of the parameters associated with, and across, that fault will be completed to determine hydraulic conductivity (i.e. contribution to connectivity) across the structure.
2) Further assessing the lithological properties, material characteristics and “self-healing” nature of the Rewan Formation around any potential fault zones due to the presence of swelling clays, thereby to establish the effect of vertical permeability of the Rewan Formation.
3) Assessment of the conceptualisation in the project approval that the Clematis Sandstone is artesian in the vicinity of the Doongmabulla Springs and that it acts as a source aquifer feeding the Doongmabulla Springs, and alternative conceptualisation’s that there are other alternative source aquifers above and/or below the Rewan Formation.;
4) Further assessing as to whether or not the impact of mine subsidence from planned underground longwall mining could provide for continuous pathways through the entire Rewan Formation sequence (where the sequence is developed to full thickness and is not cut by the Base of Weathering), that could in turn compromise the overall permeability of the sequence and render it as a “leaky” aquitard;
5) Further assessment of the overall geology, lithology and properties of the Rewan Formation that have thus far characterised the unit as a thick, low-permeability aquitard sequence from additional field work and testing / analysis;
6) Further confirmation of the mapped sub crop location of the nearest GAB unit (Clematis Sandstone) relative to the Adani lease from additional field work / analysis.

The conditions as provided in Section 2 of this plan (EPBC Condition 27) will, when implemented, provide a high level of robustness and allow for validation or otherwise relating to the assessment of mining-induced impacts (i.e. comparison of measured impacts vs predicted impacts). The work program outlined in this plan, which has been prepared in consultation with independent experts in their respective fields, is to establish
with a higher level of certainty with respect to the properties of the Rewan Formation and the potential/ability for vertical transfer of groundwater via preferential flow paths within faults, fractures or connected lithological units.
Figure 7: Current Exploration and Stratigraphic Description in Boreholes West of the Carmichael Coal Mine Project
4.5. Summary of Plan Aims, Approach and Methods

Extensive investigations have been conducted as part of the Joint Ore Reserves Committee (JORC) and EIS processes, other targeted mining, geotechnical and hydrogeological studies. There has also been extensive investment in monitoring, which will continue into the operational phase of mining as part of the GMMP and other approval conditions.

As there is an extensive data set already in existence relating to geological and hydrogeological information the research plan focuses mainly on utilisation of the existing data sources, both internal Adani sources together with available regional geology and hydrogeological studies and interpretations.

The key field work elements including the reference of conditions being addressed, research packages and ongoing validation work that are planned to meet the requirements of this plan are outlined in Table 3.

The principal aims of this plan are as follows:

1) To characterise the stratigraphic location, thickness, material properties and hydrogeological characteristics of the Rewan Formation through further appropriate field testing and analysis work;

2) To use available data sources (including seismic data), to determine and quantify the level of risk associated with geological structures, in particular the type, extent and location of interpreted fault zones, in the context of their potential to act as conduits for connectivity through the Rewan Formation;

3) To use available data sources, including the results of geological and hydrogeological analyses from exploration drilling, to determine and quantify the level of risk associated with lithological connectivity through fracture zones in the Rewan Formation, including lateral and vertical connection of sandy horizons;

4) To further determine the vertical and lateral impacts of mine-induced subsidence on the hydraulic properties of the Rewan Formation and associated aquifers stratigraphically located above the Rewan Formation, including detailed geological assessment of the horizontal location and proximity of such aquifers to planned longwall operations, and to quantify the associated level of risk relating to groundwater flow associated with longwall subsidence; and

5) To utilise all available data and findings as outline above to assess the validity of the current hydrogeological model conceptualisation, or alternatively support alternative conceptualisations and to assess the level of risk specifically associated with connectivity through the Rewan Formation based on either current, or alternative conceptualisations.

The Rewan Research program will be directed on behalf of Adani Mining Pty Ltd, who is a role is primarily the logistical coordination of individual research packages and coordinating external correspondence related to this Plan. A number of key research personnel who are recognised experts in their fields and roles under this Plan have been identified to provide inputs into specific research packages as outlined in Table 3. The combination of recognised industry experts from various consulting companies and research bodies, all with significant experience in industry research in their areas of expertise, both enhances the strength of this Plan proposal and also provides for a level of balance in assessing the overall project risk.

Whilst due care has been exercised to ensure that identified and approved researchers are available in the time frames specified within this Plan, if a research lead becomes unavailable prior to, or during the course of
the approved research program, a suitably qualified research lead of equivalent status will be sourced and submitted in advance for approval to the relevant regulatory bodies.

This balance, based on a collective team of researchers, is an essential basis for any credible overall research and assessment process and is therefore favoured over an approach where the entire plan and risk assessed outcomes are undertaken by a single organisation. It also provides for a collective approach in determining outcomes for focused targeted research packages and avoids single point opinion dictating final outcomes. Importantly, this approach will provide for impartial research by defining and delivering specific work scopes based on scientific research with clear deliverable outcomes. Any requested opinions will be limited to interpretation of the available data relating explicitly to the scope of individual research work packages.

Timeframes as outlined in Table 3 are based on compiling the outcomes of all research packages and evaluating the overall potential for hydraulic connectivity through the Rewan, associated with faults and fractures and mining impacts including the impacts of subsidence.

The outcomes of all individual research packages are scheduled to be delivered within eighteen months following the start of this Research Plan which will commence on Federal approval of this Plan, and following completion of an initial stage of exploration drilling and associated data gathering. Any additional relevant research or data that becomes available during the life of the plan, where relevant to the research objectives, will be considered and incorporated into this plan.

An overall assessment will be conducted following completion of the work packages in month 18 following federal approval of this Plan. The main purpose of this assessment is to compile the outcomes of individual research packages, together with the supporting methodologies and approaches taken to deliver the outcomes, into an overall report reflecting the collective combined research efforts.

The links to the GMMP, any regional groundwater and surface water monitoring and assessment program, or Bioregional Assessment for the Galilee Basin sub-region and the Lake Eyre Basin and any subsequent iterations are also outlined in this Plan. It is also recognised that this Plan, as well as the conditions required to fulfil obligations under this Plan, will continue throughout the mine life. Any interpretations and predictions that are either validated or changed during mining operations will be used for future refinement of the outcomes of the Plan. Examples may include findings from future exploration activities, actual draw down as measured following mining linking in with the GMMP, actual measurements of surface and subsurface subsidence, and observations relating to any faults that are exposed during mining operations.

Groundwater and geological data collected and compiled under various management plans and research plans including the findings of research plans will be considered and included in future iterations of the GMMP and GDEMP, where appropriate. A Flow Chart (Figure 8) has been compiled indicating the interaction between the research plans and the management plans.
This section provides more detail on each of the research packages outlined in Table 3, specifically in relation to the detailed work program and objectives.

A timeframe for research and reporting of the above research packages and as required under Condition 27 e) of the Rewan Connectivity Management Plan is provided in Appendix 1.
### Table 3: Rewan Connectivity Research Plan Approach, Methods, Timelines and Personnel

<table>
<thead>
<tr>
<th>Condition 27 reference</th>
<th>Research Package</th>
<th>Approach</th>
<th>Main outcome</th>
<th>Link to GMMP and Bioregional Assessment (BA)</th>
<th>Timeframe (months from project start)</th>
<th>Personnel (leader of research package)</th>
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<tbody>
<tr>
<td>Examination of the hydraulic properties (including but not limited to petrophysical analysis and facies mapping) of the Rewan Formation</td>
<td>5.1 Review of Data from Supplementary field investigations.</td>
<td>Review data from hydrogeological bores drilled to the west of the mine lease in strategic locations in late 2014/early 2015 and information from additional nested bores to be drilled near to the existing bores near Doongmabulla Springs with the aim of providing additional data for this Plan.</td>
<td>Processed geophysical data extending through the Rewan formation, as well as additional data on Rewan Formation lithological and hydraulic properties, to support other topics in the Rewan Plan.</td>
<td>Drilling of additional monitoring bores as per commitment provided in GMMP within first year of commencement of Mining operations. Will contribute to the Groundwater Monitoring and Management Plan (GMMP) water level and chemistry data set, and allow verification of hydraulic parameters used in groundwater modelling. New data to inform the Bioregional Assessment (BA) regional groundwater model.</td>
<td>Months 7 - 10</td>
<td>Geological Research Lead,</td>
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<tr>
<td>5.2 Detailed geological interpretation of Rewan Lithofacies from Existing Data, including in the vicinity of the Doongmabulla Springs.</td>
<td>Analysis of new and existing exploration data to inform updating of the Rewan formation within a 3D stratigraphy model.</td>
<td>Stratigraphy model with lithofacies interpretation of Rewan aquitard and overlying/underlying sequences.</td>
<td>Will use data from additional nested monitoring bores to be drilled as per commitment in GMMP near Doongmabulla springs to extend the stratigraphic model and provide further confidence in the stratigraphic interpretation to the west of the Project Area.</td>
<td></td>
<td>Months 7-15</td>
<td>Geological Research Lead,</td>
</tr>
<tr>
<td>Examination of the hydraulic properties (including but not 5.3 Interpretation of groundwater</td>
<td>The interpretation of the groundwater resources associated with the</td>
<td>Determination of groundwater levels and vertical gradients to</td>
<td>Will contribute to the GMMP water level and chemistry data set, and verification of</td>
<td></td>
<td>Month 7</td>
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<td>Condition 27 reference</td>
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<td>limited to petrophysical analysis and facies mapping) of the Rewan Formation</td>
<td>resources associated with the Rewan Formation</td>
<td>Rewan Formation and over- and under-lying strata will be undertaken using north-south and east-west cross-sections through representative bore logs, with a particular focus on the area of the Doongmabulla Springs</td>
<td>illustrate the aquitard nature of the Rewan Formation and allow for accurate description of the multilayered aquifer and aquitard sequence.</td>
<td>hydraulic parameters used in groundwater modelling. New data to inform the BA regional groundwater model.</td>
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<td>5.4  Assignment of hydraulic properties from supplementary field work and existing data sources</td>
<td>Permeability data obtained from core samples, providing vertical and horizontal hydraulic conductivity data spatially and with depth, will be compiled and assessed. A particular focus will be on data collected in the area of the Doongmabulla Springs.</td>
<td>Horizontal and vertical hydraulic conductivity data to be used in other plan assessments.</td>
<td>Will contribute to the GMMP data set and allow verification of hydraulic parameters used in groundwater modelling. New data to inform the BA regional groundwater model. This will take into consideration and be informed by the groundwater flow model re-run (condition 23).</td>
<td></td>
<td>Month 7</td>
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<tr>
<td>methods, including, but not limited to, seismic surveys to determine the type, extent and location of fracturing, faulting and preferential pathways”</td>
<td>Existing historical petroleum 2D seismic lines will be reprocessed and interpreted. Interpretation will focus on Rewan aquitard and overlying / underlying sequences and fault structures. Particular focus will be given to high quality re-processing and re-interpretation of 2D</td>
<td>Improved resolution and definition of the strata sequences and any impacting fault zones.</td>
<td>Prioritising the new monitoring bore locations planned under the GMMP to areas with uncertainties in fracture and fault properties that affect hydraulic connectivity potential. Provide new information about degree and location of flow pathways to assist with interpretation of pressure and</td>
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<td>Condition 27 reference</td>
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<td>seismic line CAR 82-25 which is in close proximity to the Doongmabulla Springs, together with CAR 82-23, CAR 82-27 and CAR 85-4 to provide strong regional coverage over the area.</td>
<td>chemistry data collected under GMMP. Allen diagrams (juxtaposition of fault and stratigraphy models) to inform the development and updating of the BA regional groundwater model.</td>
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<td>5.6</td>
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<td>Mapping and modelling of fault styles, orientations, displacements and densities</td>
<td>Using seismic interpretation by construct a 3D fault model including specific focus on the area of the Doongmabulla Springs.</td>
<td>A 3D fault model and assessment of any associated high permeability zones.</td>
<td>Months 8 - 10</td>
<td>Geological Lead,</td>
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<tr>
<td>5.7</td>
<td>Juxtaposition analysis</td>
<td>Using outcomes of all of the above work to construct Allen diagrams</td>
<td>Allan Diagrams that provide a sense of horizontal connectivity on each fault plane</td>
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<td>Months 11-15</td>
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<tr>
<td>5.8</td>
<td>Shale Gouge Analysis and Fault membrane seal analysis</td>
<td>Shale Gouge Ratio and permeability analysis of fault zones</td>
<td>Estimates of fault zone permeability including a specific focus on interpreted structural regime in the area of the Doongmabulla Springs.</td>
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<td>Months 11-15</td>
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<td>5.9</td>
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<td>The potential for along or up-fault seal breach will be determined by</td>
<td>Geometric analysis of kinematically correct fault interpretations within a</td>
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<td>Months 11-15</td>
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<td>Assessment of fault leakage potential</td>
<td>analysing fault zone architecture and key leak points on fault systems</td>
<td>three-dimensional anisotropic stress field.</td>
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<td><em>the extent and location of fracturing, faulting and preferential pathways (including any fracturing induced by longwall mining subsidence)</em> to better characterise the Rewan Formation and the contribution of fracturing, faulting and preferential pathways to connectivity.</td>
<td>5.10 Assessment of Longwall Mining Subsidence on hydraulic connectivity</td>
<td>The impacts or increased likelihood of hydraulic connectivity within the or across the Rewan Formation due to longwall mining.</td>
<td>Determination of hydraulic connectivity associated with predicted subsidence. This will include the assessment of any potential impacts associated with longwall mining subsidence on the Doongmabulla Springs.</td>
<td>Months 15-17</td>
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<td>Fault Zone and Hydraulic Connectivity Analysis</td>
<td>Estimate fault zone hydraulic properties that may influence the Rewan connectivity, taking into consideration all prior studies and analysis.</td>
<td>The primary deliverable will be a summary of the possible extent and location of faulting plus the potential for preferential pathways as a result of longwall mining. A particular focus will be on any potential preferential pathways impacting on the Doongmabulla Springs.</td>
<td></td>
<td>Months 14 - 15</td>
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<tr>
<td><em>better characterise the Rewan Formation and the contribution of fracturing, faulting and preferential pathways to connectivity</em></td>
<td>5.12 Literature and Benchmarking Studies</td>
<td>Review of the typical Carmichael case outcomes will be assessed against available literature relating particularly with respect to benchmarking permeability across faults and strata in similar environments.</td>
<td>Preparation of a report detailing benchmarking outcomes as they apply in the context of the CCP Mine Project.</td>
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<td>Month 17</td>
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<td>5.13</td>
<td>Plan Workshop and Preparation of Report on Research Outcomes</td>
<td>The outcomes of the previous research packages detailed in sections 5 to 5.10 will supplement the existing evidence base about the potential degree and mechanisms of hydraulic connectivity across the Rewan and how interpreted faults and predicted subsidence will impact on permeability and hydraulic connectivity. Particular focus will be the overall assessed potential impacts on the Doongmabulla Springs.</td>
<td>An integrated and combined report for submission to Department outlining all the outcomes of research packages.</td>
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<td>Month 18</td>
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<td>5.14</td>
<td>Links to the Groundwater Management and Monitoring Plan (GMMP)</td>
<td>The GMMP will be updated to include compliance with all relevant approval conditions.</td>
<td>Will provide for: 1) The development of early warning triggers and sentinel monitoring points (with regards to identifying the potential impacts prior to reaching the targeted GAB units); 2) The establishment of groundwater level threshold levels (which if reached instigate</td>
<td>Linking to the GMMP as described left. Results from individual work packages 5.1 to 5.12 will be used for updating GMMP and revising conceptual hydrogeological model for groundwater numerical model rerun. (two years from commencement of mining operations). The results of Groundwater model rerun will be used for development of</td>
<td>Months 7 – 18</td>
<td>Months- 24</td>
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</tbody>
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### Condition 27 reference

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#### 3) The interaction of the Rewan Connectivity Research Plan (groundwater component) with the springs, subsidence assessment, offsets for and Groundwater Dependent Ecosystems (GDE) and updating revising various management plans related to groundwater; and

#### 4) Provide information from the outcomes of the research plan to the Geoscience Australia for Bioregional Assessment for the Gálilee Basin sub-region and the Lake Eyre Basin regional numerical groundwater model updates.

**Timeframe:** Months – 24

**Personnel:**

- **Months – 24**

**Personnel:**

- **Months – 24**

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**An explanation of how research will inform the GMMP, any regional**

5.15 Links to Bioregional

- The research and assessment results compiled during the Rewan Connectivity

- The results of the Rewan Formation connectivity research will allow for the more accurate assessment

- As described above

**Timeframe:** Months – 7-24

**Personnel:**

- **Months – 7-24**
<table>
<thead>
<tr>
<th>Condition 27 reference</th>
<th>Research Package</th>
<th>Approach</th>
<th>Main outcome</th>
<th>Link to GMMP and Bioregional Assessment (BA)</th>
<th>Timeframe (months from project start)</th>
<th>Personnel (leader of research package)</th>
</tr>
</thead>
<tbody>
<tr>
<td>groundwater and surface water monitoring and assessment program, or Bioregional Assessment for the Galilee Basin sub-region and the Lake Eyre Basin and any subsequent iterations</td>
<td>Assessment Program</td>
<td>Research Plan will thus link to the Galilee Basin regional water balance (an approval condition) and the Geoscience Australia regional Galilee Basin numerical groundwater model.</td>
<td>of potential for induced flow of groundwater from the Great Artesian Basin units (and possible subsequent reduction in water resources in the Galilee subregion).</td>
<td></td>
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5. Research Packages

5.1. Review of Data from Supplementary field investigations.

Following finalisation of EPBC condition 27, and pre-empting the further data requirements to support this Plan, an additional four hydrogeological investigation bores were drilled in late 2014/early 2015. These holes have been fully geotechnically logged, with a full suite of down-hole geophysical tools and acoustic scanner run to assess the nature and orientation of in situ fracturing. Other data obtained from these supplementary field investigations includes permeability data (from packer testing, core permeability testing), geotechnical testing, lithological logging and stratigraphic interpretation. Selected samples or core from these bores will also be tested to determine the "self-healing" nature of the Rewan Formation materials (i.e. the swell index of Rewan Formation clays); this being a critical aspect of the nature of faulting within the Rewan Formation. In addition limited further drilling in key strategic locations to confirm the occurrence of the Rewan Formation and associated overlying and underlying strata has been completed.

Further to the investigation bores drilled in 2014/early 2015 as explained in section 4.4, Adani will drill nested bores at three additional sites between the mine and the DSC and as close as possible to the DSC into the Triassic Rewan formation and Dunda Beds, as per the commitments provided in GMMP and GDEMP. The location of these additional bores is shown in Figure 9. These additional monitoring bores will be used for monitoring purpose and also to enable to obtain further data related to hydraulic properties, lithological logging and strata interpretation relating to the Rewan Formation. Adani will conduct necessary pre-clearance surveys to identify presence of MNES and will avoid any direct or indirect impacts to MNES while carrying out fieldworks related to installation of new nested bores at three sites (Figure 9) including any clearance required for acquisition of new 2D seismic data.

An initial work package involving detailed geological interpretation of Rewan lithofacies from existing data was completed in 2014 and this forms the starting point for independent confirmation of the lithological Rewan Formation conceptualisation. [Adani] will update their current lithological model based on this further data and information provided from the additional nested bores planned at three sites as per the work package in section 5.2 further below.

These hydraulic properties, lithological logging and strata interpretation data, will be combined with the existing database of groundwater pressure, quality and hydraulic parameters data and will be utilised to analyse and describe groundwater occurrence and flow within the Rewan Formation, as well as the stratigraphic units above and below. The detailed bore logs, geophysical logs, acoustic scans, photographs, and available geological history information will be compiled and presented to provide a description of the depositional system (Figure 10) and associated facies (Figure 11).

Knowledge from the groundwater chemistry and water level data (existing data as well as data analysed and compiled for these bores) will inform the revised Groundwater Management and Monitoring Program (GMMP). The GMMP will be updated as required during the program to reflect information from the supplementary drilling program and the revised geology, as identified by Adani. This research package will be led by [Adani].
Figure 9 Location of additional Monitoring bores near Doongmabulla Springs
Figure 10: Basin depositional systems example

Figure 11: Basin facies example
5.2. Detailed geological Interpretation of Rewan Lithofacies from Existing Data

This research package will involve an independent geological interpretation of available Rewan Formation data. This research package is an independent interpretation of existing data, as well as from additional nested bores, to:

- Confirm the material characteristics of the Rewan strata sequences;
- Characterise the spatial distribution of lithofacies within the Permian coal measures and overlying Triassic strata; and
- Identify areas of potential connectivity within the Rewan group and between the Rewan and adjacent formations.

Petrophysical analysis will be used to develop lithofacies schemes and a conceptual depositional model and a 3D interburden model for the Rewan.

The aim of this package is to confirm the material characteristics of the Rewan strata sequences and to characterise the spatial distribution of lithofacies that will influence the potential for aquifers and aquitards occurring within the Permian coal measures and overlying Triassic strata within the Adani lease area and in the vicinity of the Doongmabulla Springs. In addition, the exercise will identify areas of potential connectivity within the Rewan group and between the Rewan and adjacent formations.

An initial work package was completed in 2014. This work involved the lithological and geophysical interpretation of 626 boreholes to characterise the spatial distribution of lithofacies that will influence the potential for aquifers and aquitards occurring within the Permian coal measures and overlying Triassic strata within the Project area. The work will be updated with data from additional borehole data as proposed in section 5.1 to the west of the lease in the vicinity of the Doongmabulla Spring Complex (at three additional sites as shown in Figure 9, also taking into consideration the shallow high quality re-processing of 2D seismic lines focussing on the shallower Permian coal measures and overlying Triassic strata, as proposed for work package 5-5. The proposed additional work will also further focus on the presence and extent of any interpreted paleo channels both vertically and laterally.

This exercise (in part) addresses the required condition relating to “examination of the hydraulic properties (including but not limited to petrophysical analysis and facies mapping) of the Rewan Formation, to better characterise the Rewan Formation and the contribution of fracturing, faulting and preferential pathways to connectivity”.

The hydraulic connectivity through a rock mass is determined by the spatial distribution of permeable and impermeable strata. The nature and integrity of the impermeable strata act to compartmentalise the vertical and lateral flow pathways through the stratigraphy; however, material properties may not be uniform and the starting character of the basic lithologies can be overprinted by diagenesis and/or weathering and fracturing during the history of the rock mass. Therefore the rock mass needs to be considered in its entirety, in particular the spatial juxtaposition of the different lithologies, their hydraulic and geomechanical properties, the nature of contacts within and between units of similar properties, and their response to changing stress conditions.
The starting point for understanding hydraulic connectivity across a rock mass is developing a stratigraphic or sedimentary depositional model. Although coal and coal seam gas companies develop detailed models of the coal seams and their quality distributions, the character of the inter- and overburden to the coals is commonly only modelled at the formation level (Chase et al., 2005). In the case of the Rewan Formation, there is potential to develop more sophisticated sedimentary models utilising the abundance of geophysical wireline data available from the existing and new bores, coupled with information from the seismic data. The research under this topic will feed into the assignment of hydraulic properties to rock mass and will also assist in improving geotechnical and hydrodynamic models of the strata response to mining.

Petrophysical analysis will be used to develop lithofacies schemes from a combination of existing and new exploration borehole core, wireline geophysics and acoustic scanner data. This would entail analysis of boreholes from representative cross sections down the length of the mining lease / resource based on:

- Borehole wireline logs (as digital LAS files);
- Borehole location data;
- Seam pick files;
- Digital core and chip descriptions;
- Digital acoustic scanner data;
- Available geotechnical and hydrogeological (permeability) data;
- Stratigraphic Surfaces; and,
- Topographic surface data.

Litho- and sedimentary facies recognition will use simple cut off values based on correlations with core or rock chips, and more sophisticated geostatistical analysis (clustering techniques) of multiple wireline logs to develop electrofacies (McNally, 1988; Fullagar et al., 2006; Hatherly et al., 2008; Pell et al., 2014; Ye and Rabiller, 2006).

Results will be validated against data from existing cores, and in consultation with Adani geologists and geo-technicians.

Correlation of lithofacies between boreholes will be used to develop a conceptual depositional model for the Rewan, using manual correlation of visibly correlated units (deterministic) in 2D or 3D space from a combination of core and wireline logs; and also developing static and dynamic geocellular (block) models to which properties are assigned through geostatistical approaches (Steel and Milliken, 2013).

will liaise with Adani geology staff to develop an interburden model within their software (Minescape and or Vulcan 3D modelling software) that illustrates lateral heterogeneity of the Rewan group (e.g. stochastic block modelling, or correlation of major sandstone bodies for stratigraphic modelling)

Cores will be used to investigate post depositional weathering and effect on mineralogy and texture which impact on porosity and hydrological properties within the Rewan. This will involve sampling the different lithofacies for thin section analysis of mineralogy and texture, to determine if there are differences in the primary grains and cements between weathered and unweathered Rewan, and if this would change the porosity. XRD analysis can identify the different minerals and clays, and determine whether these will be reactive, i.e. self-sealing with water movement, or not. This study also contributes to the depositional environment and subsequent diagenesis interpretation of the Rewan Group.
5.3. Interpretation of groundwater resources associated with the Rewan

The conceptualisation of the groundwater resources associated with the Rewan Formation and over- and under-lying strata will be undertaken with the aid of north-south and east-west cross-sections through representative bore logs. This conceptualisation, which will include analysis of groundwater levels and vertical gradients, will illustrate the hydrostratigraphic relationship (i.e. the relationship between aquifer and aquitard units) of the Rewan Formation and the overlying/underlying strata. The inclusion of groundwater level data for each hydrostratigraphic unit will allow evaluation of the relative potential for groundwater flow between units (through identification of the presence and magnitude of upward/downward flow potential between adjacent units).

The conceptualisation will include information regarding groundwater occurrence, hydraulic parameters of all hydrostratigraphic units, and groundwater flow potential. These data will be summarised from the available groundwater models compiled for the eastern edge of the Galilee Basin, which include Kevin’s Corner Project, Alpha Coal Project, Carmichael Coal Project, South Galilee Coal Project, and Galilee Coal Project. In addition, modelling and Underground Water Impact Reports (UWIR) within the Eromanga Basin will be assessed to obtain additional hydraulic property data for the Rewan Formation for inclusion within this conceptualisation research package.

The work package with existing and supplementary data obtained from additional drilling on permeability, geotechnical data and packer tests to provide a range of information, including permeability ratios, swell indices, hydraulic conductivities, zones of connectivity and composition of the Rewan Formation. The information, including the results of aquifer testing, will be included in an updated database to inform the effective radius or radius of influence and updates to groundwater and subsidence modelling.

The updated geological modelling process outlined in Section 5.2 will be based on the independent interpretation of data to confirm the material characteristics of the Rewan strata sequences; characterise the spatial distribution of lithofacies within the Permian coal measures and overlying Triassic strata; and identify areas of potential connectivity within the Rewan group and between the Rewan and adjacent formations. This interpretation, together with additional hydrogeological data including supplementary (additional bore sites) permeability data, geotechnical data and packer tests will provide sufficient high confidence data to support a valid conceptualisation of groundwater resources associated with the Rewan Formation.

This work will be completed primarily by . The data will be summarised and provided to the for input into their assignment of hydraulic properties as outlined below.
5.4. Assignment of hydraulic properties from supplementary field work and existing data sources

This work will be conducted primarily by .

This work involves analysis of filed data collected during studies conducted during the supplementary drilling program from 2014/15 and data to be collected form additional nested bores at three sites to be drilled as per the commitments provided by ADANI in GMMP and GDEMP.

Permeability data obtained from the core samples of additional bores, providing vertical and horizontal hydraulic conductivity data spatially and with depth, will be compiled and assessed. These data sources will be evaluated to provide information on:

- Horizontal and vertical permeability ratios (allowing for assessment of the potential for preferential pathways);
- The assessment of stratigraphic connectivity across zones of increased horizontal permeability (sandstone layers within the claystone);
- Composition of the Rewan Formation (percentage argillaceous and arenaceous units); i.e., the thickness of various layers within Rewan formation for studies related to prediction of longwall subsidence (section 5.10);
- Swell index information and comments on clays;
- Hydraulic conductivity of overlying units and vertical conductance potential; and
- An assessment of the strata alteration as a result of longwall mining (extent of fracturing, depth of target coal, overlying strata) based on geotechnical reports.

The information on above parameters will be used for assessment of strata alteration as a result of longwall mining (extent of fracturing, depth of target coal, overlying strata) based on geotechnical reports.

Analysis of the packer (Lugeon) tests will also be conducted to provide additional information regarding:

- Aquifer hydraulic properties (permeability and transmissivity); and
- Evaluation of higher permeability zones.

The aquifer hydraulic properties (permeability and transmissivity and k values including kV/kH ratios) will be used for studies related to prediction of longwall subsidence (section 5.10) and updating groundwater numerical model in the next scheduled re-run.

The groundwater level data and hydrogeological properties from other Galilee basin projects and regional studies (from section 5.1) and site specific information collected from studies conducted at site during 2014/15 and proposed drilling program for nested bores at three sites will be compiled and included in the existing data base used for groundwater numerical model. This updated data base will assist in selection of wide range of local and regional hydraulic parameters to conduct variability and parametrisation studies during next groundwater model re-run.

The evaluation of these higher permeability zones will allow for the assessment of the effective radius or radius of influence of the zone, which will aid in assessing interconnectivity of fractures, stratigraphic
connectivity (extent of sandstone zones within the claystone of the Rewan Formation), and evaluation of connectivity across the Rewan Formation.

The assessment of permeability and connectivity will also be informed by the results of the groundwater flow model re-run (condition 23).

This exercise (in part) addresses the required condition relating to “examination of the hydraulic properties (including but not limited to petrophysical analysis and facies mapping) of the Rewan Formation, to better characterise the Rewan Formation and the contribution of fracturing, faulting and preferential pathways to connectivity”.
5.5. Reprocessing and interpretation of existing historical regional 2D petroleum seismic lines

Modern state of the art high resolution 2D seismic line acquisition and processing, when used in combination with other data sources and studies, provides base data for the validation of the roof, floor and thickness of stratigraphical units, and the location, style, persistence, dip and displacement of fault zones in as they are interpreted along the 2D seismic lines.

In the process of developing this plan it has been established that, whilst high quality seismic interpretation will provide for a high confidence assessment of the above fault style and displacement characteristics at the location 2D seismic lines, the relevant experts (in this instance have concluded that seismic interpretation in isolation is very limited in its ability to provide and practically achieve adequate resolution and relevant information on localised fracturing that may or may not be associated with fault zones. On this basis, and following consultation with appropriate research content matter experts, a number of industry established methods, including empirical approaches, modelling and benchmarking case studies examining precedence in similar geological environments will be adopted to determine the likely characteristics of fracturing and the associated impacts and risks of fracturing and preferential pathways in the context of this plan.

Specific empirical approaches, modelling and benchmarking case studies will be used to provide further confidence on the extent and magnitude of interpreted fault zones and their potential influence and impact as preferential pathways. The reference research and case studies will include (but not be limited to):

- Department of Science, Information Technology and Innovation 2015, Lake Eyre Basin Springs Assessment Project: Groundwater Dependent Ecosystem Mapping Report, Department of Science, Information Technology and Innovation, Brisbane.
- Fallon, G. “Empirical Assessment of Fault throw and Maximum Possible Fault Strike based on Australian Coal Measures”. Propriety GRS analysis; and
Referencing the research publications above, and where relevant other additional information, the following process sequence will be adopted to assess the permeability of interpreted faults for the Carmichael Coal Project against international research and case studies:

1) Establishing the key definitions, terminology, approaches, concepts and principles related to permeability across and within fault zones;

2) Positioning the anticipated fault and associated host rock interpretations against empirical datasets presented in the research papers; and

3) Assessing the permeability characteristics likely preferential pathways and impacts for interpreted faults in the Carmichael Coal Project based on benchmarking these interpreted fault zones against empirical datasets and comparable cases from international literature, referencing as a minimum the above research and case studies.

The initial approach will be to identify the likely maximum displacement characteristics and density of displacement fault structures through the project area, and then utilise both international and Australian studies to assess fault scaling relationships as they are relevant to the CCP. Cowrie and others (various studies as referenced above, has demonstrated that fault scaling relationships are a statistical distribution of the fault attributes (length, displacements etc.). (proprietary analysis) has applied a similar statistical distribution presenting a strike versus throw summary for published data and various coal deposits within eastern Australia. This approach also clearly identifies that the length of displacement faults in Eastern Australian coal measure strata has a strong statistical relationship with the observed maximum displacements within clear boundaries. For example and with reference to Figure 12, a fault with an average displacement of greater than 30m would be represented by a strike length of at least 10 km to be within the normal boundaries of Australia eastern seaboard coal measure basin experience.

The 2D seismic line stratigraphic and structural interpretations will form the base data for site specific work packages to be undertaken as follows:

- As part of the seismic reprocessing and interpretation exercise, an empirical exercise will be undertaken to assess the likely fault density and strike vs. throw characteristics for the area. This will determine the likely maximum displacements of faults that may exist between existing 2D seismic lines based on precedence of measured faulting characteristics in different Eastern Australian deposits, as shown in Figure 12 (Fallon, 2015).
- Content experts will construct a 3D fault model (including a specific focus on the DSC) and analyse fault zone architecture, including assessments of fault zone permeability associated with fracturing, shale gouge, fault sealing analysis in three dimensions and fault leakage potential, also taking into consideration regional stress field (refer research packages 5.6 to 5.9).
- The interpretation of fault displacements on relevant 2D seismic lines will be empirically assessed against relevant industry literature and benchmarking studies. This will assist in establishing the likely permeability associated with fracturing along or in the vicinity of fault structures within the Rewan Formation, also taking into consideration shale gauge analysis.
- On completion of all the above work, a workshop will be undertaken, coordinated by the appointed peer reviewer.
It is also acknowledged by the research team that seismic interpretation cannot provide any relevant information on the type, extent and location of fracturing induced by subsidence in advance of mining and subsidence being initiated. To gain an appropriate level of confidence and understanding and to quantify the height and nature of subsurface fracturing above longwall mine goafs, it is proposed to conduct specific subsidence modelling studies as detailed in section 5.10.

![Figure 12 Strike Versus Throw summary for published data and various coal deposits within Eastern Australia (GRS Proprietary Analysis).](image)

A number of regional petroleum 2D seismic lines exist that run across and within the Carmichael lease area (labelled CAR as shown in Figure 13). There is a relatively high density of regional 2D seismic lines (CANSO 1982) in the general Carmichael mine project area, many of which run across the Carmichael mine site. Whilst these lines currently have relatively low to average data quality in their current published form, the existing raw data is publicly available and can therefore be re-processed.

An original work scope completed by ![Original work scope completed by](image) in August 2015, provided a first pass assessment of 2D seismic lines CAR 82-23, CAR 82-25, and CAR 82-27. It was recognised at the time and recommended that the resolution of the seismic interpretations could be improved with higher quality re-processing, publicly available from existing seismic acquisition data, targeting the shallower Permian coal measures and overlying Triassic strata. An additional work scope is therefore proposed taking into consideration this recommendation.
Reprocessing and reinterpretation of these petroleum CASNO 2D seismic lines will lead to provide higher resolution and more accurate seismic imaging. The study will be undertaken at regional scale but will also focus on available data and in particular 2D seismic line CAR 82-25, shown in Figure 13 which is located closest to the Doongmabulla Springs. The study will also focus on high quality re-processing and interpretation of CAR 82-23, CAR 82-27 and CAR 85-4 to gain further understanding and confirmation of the strata sequences and nature and displacement of geological structures both across the overall Project area and in the vicinity of the Doongmabulla Spring Complex.

It is recognised that the three seismic lines CAR 82-23, CAR 82-25 and CAR 82-27 are in the same orientation. However, re-processing of line CAR 85-4 which is in a perpendicular orientation to the above three lines with high quality resolution will assist in resolving orientation issues associated with interpreting structural geometries for the shallower stratigraphy.

The study will provide for the following deliverables:

1) Confirmation of the Colinlea, Betts Creek coal beds, Rewan, Clematis and overlying strata thicknesses and boundaries through detailed interpretation of reprocessed seismic lines (correlated with borehole data and other regional geology information).
2) Confirmation of the thicknesses and strata dips of the above strata units.
3) Interpretation of any faults that exist within the above strata units, including their style, orientation in section view, and displacement characteristics.

4) In combination with other research and data, an assessment of the fracturing associated with interpreted fault zones.

The reprocessed 2D seismic line data will be interpreted and considered in conjunction with other regional geological assessment data including magnetics and borehole data.

These seismic lines will be reprocessed. The reprocessing of these seismic lines will allow for improved resolution and definition of the strata sequences and any impacting fault zones. Further to this, will conduct an interpretation of the reprocessed historical 2D seismic lines to confirm Rewan and associated strata sequences as they are apparent in the general area within and beyond the Carmichael lease. This interpretation will take into consideration available borehole data to correlate and confirm strata units and regional magnetics to interpret the location of fault zones and other relevant structural features. It is anticipated that the interpretation of high quality reprocessing of 2D line seismic data, focussed on increasing resolution of the shallower Permian and Triassic strata, also considering and correlated with additional borehole data lithological interpretation and regional geophysical airborne survey interpretation, will provide very high level confidence in required deliverables as outlined above, without the need for further seismic acquisition and interpretation.

It has been confirmed by both reprocessing will enable identification of structures within the Rewan Formation through the shallower depths and up to the surface. If not, Adani will acquire 2D seismic data along CAR 82-23, CAR 82-25, CAR 82-27 and CAR 85-4, within an agreed and practically reasonable timeframe to be agreed with the Department, following the outcomes of reprocessing and to allow for clearance activities, regulatory approvals, securing of services providers and acquisition activities to be completed. In such case, Adani will conduct necessary pre-clearance surveys to identify presence of MNES and will avoid any direct or indirect impacts to MNES while carrying out fieldworks related to acquisition of new 2D seismic data, including specific management plans that will developed and implemented for the purpose.

In particular the interpretation exercise from reprocessed 2D historical lines will seek to define any fault structures that may be apparent through the Betts Creek beds (Colinlea Sandstone and Bandanna Formation), Rewan Formation, Dunda beds, Clematis Sandstone and overlying sequences in the vicinity of the Doongmabulla Springs. Fault displacements will be interpreted from the seismic lines, and the extent and spatial orientation of any identified faults will be interpreted in plan view from seismic lines and other data sources including boreholes, geological models and existing regional magnetic data. This exercise (in part) addresses the required condition relating to “methods, including, but not limited to, seismic surveys to determine the type, extent and location of fracturing, faulting and preferential pathways”.

Note that it is considered that further seismic acquisition work, particularly off lease, is not necessary in the context of all other research work being proposed unless the research under the Plan identifies a need for these data. The acquisition of additional seismic data is considered unnecessary given that:

- There is an existing high level of understanding and confidence relating to the location of the Rewan Formation and surrounding strata;
• High quality reprocessing and re-interpretation of existing seismic data, targeting the shallower Permian and overlying Triassic strata, will increase the understanding of fault style, density, orientation and displacement to a level of high confidence;
• The reprocessed data will be interpreted in conjunction with other regional geological assessment data including magnetics and borehole data; and,
• Other work is being conducted within this Plan specifically to examine and assess fault shale gauge impacts and water flow leakage within and across any interpreted faults.

The assessment and modelling of the anticipated strike and displacement characteristics of interpreted fault zones in addition to further interpretation of the main stratigraphic will provide further inputs feeding into research packages described in 5.6 to 5.12 culminating in a workshop as outlined in 5.13. These subsequent research packages will utilise the outcomes of this 2D seismic interpretation exercise (including the research and case study benchmarking) to determine the associated relevant impacts on connectivity within and around the Rewan Formation based in part on the interpretation of fault displacement, strike and other characteristics from this 2D seismic interpretation exercise.
5.6. Mapping and modelling of fault styles, orientations, displacements and densities

Following on from the exercise of 2D seismic line reprocessing and interpretation there is a further requirement to build a representative 3 dimensional structural fault model based on all available sources of information. This model will supplement the existing structural models and interpretations within the mine project area and verified by competent persons as defined under JORC (Xenith Consultants 2013 and ROM Resources 2015). The model will apply in a spatially continuous manner across the mine area extending to at least 5 km west of the mine project area and incorporate the area of the Doongmabulla Springs. This model will be used to assess the potential for preferential flow pathways along fault planes and associated fracture zones.

In particular the fault model will take into further consideration the seismic reprocessing and interpretation work conducted by as described in section 5.5 above and will extend to at least 5 kilometres west of the mine project area and incorporate the area of the Doongmabulla Springs.

The building of a 3 dimensional fault model from the above fault interpretations is required to assess the potential for preferential flow pathways along fault planes and associated fracture zones. This research component will be undertaken with inputs and assistance from Adani geological staff.

This exercise (in part) addresses the required condition relating to “methods, including, but not limited to, seismic surveys to determine the type, extent and location of fracturing, faulting and preferential pathways”.
5.7. Juxtaposition analysis

This research package will use the fault modelling described in Section 5.6 and construct Allen Diagrams for individual mapped fault surfaces using software. These diagrams will allow for an assessment of the distribution/occurrence of horizontal hydraulic connectivity or isolation on each fault plane.

Juxtaposition diagrams (Allan Diagrams) utilise information of the lithology either side of a particular fault plane. If the facies distributions and associated rock properties are known, a geometrical analysis will create a map of the fault surfaces that show which rock types are juxtaposed across the fault (e.g. sand on sand, sand on shale, shale on mud, mud on mud etc.). The nature of the rock type juxtaposition provides an estimate of the across fault leakage potential based simply from the lithologic properties of the host rock. For example, juxtaposition of sand on sand contacts across a fault would provide an opportunity for across fault hydraulic continuity.

Case studies such as Bailey et al. (2006) show that juxtaposition alone does not describe the seal potential of a fault. Hydrodynamic and geochemical analysis in faulted strata (Underschultz et al. 2005, and Underschultz et al. 2003) can be combined with juxtaposition diagrams and this can help to determine if additional fault seal analysis is required for adequate assessment of seal capacity.

The juxtaposition analysis will consist of:

- Using the output of the stratigraphic and fault modelling as detailed in Section 5.6 in the form of a 3D static model; and,
- Construction of Allen Diagrams for individual mapped fault surfaces using software such as Petrel, Fault Risk, or TrapTester.

The outcomes will include:

- Allen Diagrams showing where sand on sand, shale on shale, or sand on shale contacts occur across each fault plane; and,
- An assessment of the distribution/occurrence of horizontal hydraulic communication or isolation on each fault plane.

Juxtaposition analysis as described above will be completed by

The above addresses in part the conditions relating to “the contribution of fracturing, faulting and preferential pathways to connectivity”.
5.8. Shale Gouge Analysis and Fault membrane seal analysis

This research package involves Shale Gouge Analysis and Fault membrane seal analysis to determine the permeability / hydraulic properties of fault zones. Interpreted faults, if any, as identified by the study conducted in Section 5.5 through geological modelling and re-processing of 2D seismic data, will be used for SGR analysis. The data obtained from the SGR analysis leads to an estimate of the fault zone permeability distribution across the area and a particular focus will be on calculated SGRs from data obtained from boreholes that were drilled in 2014/15 and new nested bores that will be installed at three sites.

The Shale Gouge Ratio (SGR) is an algorithm used to predict the sealing capacity along a fault by calculating the net shale/clay content (VShale) of rock that has slipped past a given point on the fault plane.

Several not entirely independent precursors to Shale Gouge Ratio (SGR) have been proposed such as CSP (Clay Smear Potential, Bouvier et al. 1989, Fulljames et al. 1997) and SSF (Shale Smear factor, Lindsay et al. 1993). However, the SGR method has become standard, largely due to the robustness of the algorithm which will estimate a SGR irrespective of data quality, making it ideal for operation with indescrete data such as a Vshale log. Shale Gouge Ratio calculations can be conducted according to Yielding et al. (1977), and these can be related to fault zone permeability (Sperrevik et al. 2002 and Gibson et al. 1998). The standard approach for calculating across fault pressure difference is to use the pressure profile on either side of the fault as described by Underschultz (2007). Bense (2004) demonstrated how fault zone parameterisation such as SGR had application in understanding fault zone hydraulic properties even at shallow depths where faults come to surface.

Membrane seal capacity will be estimated with the following inputs:

- Stratigraphic heterogeneity characterisation: the different sedimentary facies within the Rewan are important to know for SGR calculation as these relate to the volume of shale on either side of a fault. There is a correlation between this and the amount of shale gouge at any location on the fault plane;
- Fault zone architecture: the geometry of the fault zone and the orientation of the various fault segments forms a key input to understanding the SGR. The distribution of throw on the fault plane needs to be mapped and this forms an input parameter to the SGR calculation;
- Shale Gouge Ratio maps: The SGR distribution on the fault plane will be calculated as a function of the shale volume distribution and the throw distribution;
- Pore pressure distribution (hydrogeology bores): the detailed pore pressure in the strata on either side of the fault forms the important calibration parameter of across fault pressure difference. This distribution will be mapped and plotted against SGR in order to obtain a permeability estimates for a given SGR values;
- Mapping the across fault pressure difference sustainable prior to membrane seal failure and estimate the fault zone permeability distribution; and,
- Development of SGR data for individual mapped fault surfaces will be done using software such as Petrel, FaultRisk, or TrapTester.

The data obtained from the SGR analysis leads to an estimate of the fault zone permeability distribution across the area and a particular focus will be on calculated SGRs from data obtained from boreholes that were drilled in 2014/15 (see Figure 7 and section 4.4) and new nested bores that will be installed at three sites. Interpreted faults if any, that may exist within the strata units, including their style, orientation in section view, and displacement characteristics in the vicinity of the DSC (from the nested bores at three sites
mentioned in Figure 9) as identified by the study conducted in section 5.5 through re-processing of 2D seismic data, will be used for SGR analysis.

The research package as described above will be completed by

The above addresses in part the conditions relating to “the contribution of fracturing, faulting and preferential pathways to connectivity”.
5.9. Assessment of fault leakage potential

This research package will use geometric analysis of faults to determine locations of tension, compression or shear, which relate to the potential for the fault to transmit water, particularly in the area of DSC. This work will be conducted by using the fault plane statistics from the seismic interpretation from section and in-situ stress analysis.

The potential for along or up-fault seal breach can be determined by analysing fault zone architecture and key leak points on fault systems (e.g. Gartrell et al 2006). These often occur at the intersection of high angle steeply dipping faults (Craw 2000) or at relay zones (Underschultz et al. 2003) where the continuity of the fault plane is interrupted (Gartrell et al., 2004; Cowley and O’Brien, 2000). These leak points have characteristic signatures, often identifiable with hydrodynamic analysis (Underschultz et al. 2005), where they form anomalies in the pressure, water chemistry and temperature distributions. The following analysis method will be used, drawing on fault zone architecture and in-situ stress inputs:

- Geometric analysis of kinematically correct fault interpretations within a three-dimensional anisotropic stress field. This determines the locations along the fault zone and on various fault segments where the fault geometry is in tension, compression or shear. This related to the dilatant tendency of the fault, which relates to the potential for the fault to transmit water. This work will be conducted by using the fault plane statistics from the seismic interpretation from section and in-situ stress analysis. A particular focus will be on any interpreted faults if any, that may exist within the strata units, in the vicinity of the DSC (from the nested bores at three sites mentioned in Figure 9) as identified by the study conducted in section 5.5 through re-processing of 2D seismic data.

The research package as described above will be completed by

The above addresses in part the conditions relating to “the contribution of fracturing, faulting and preferential pathways to connectivity”.
5.10. Assessment of Longwall Mining Subsidence on hydraulic connectivity

The impacts or increased likelihood of hydraulic connectivity within the or across the Rewan Formation due to longwall mining will be addressed based on the following:

1) Numerical modelling studies conducted by These studies use FLAC 2D, a finite element geotechnical modelling software tool to simulate the subsidence profiles, caving and fracturing propagation following longwall goafing and hydraulic connectivity associated with goafing of planned longwall panels. The modelling will explicitly assess fracturing and hydraulic conductivity through the Rewan formation where it exists above planned longwall mines.

2) A literature review of available subsidence prediction reports for the proposed mines within the eastern edge of the Galilee Basin, including Kevin's Corner Project, Alpha Coal Project, Carmichael Coal Project, South Galilee Coal Project, and Galilee Coal Project.

3) Available subsidence research (ACARP reports, etc.) and monitoring data from Bowen Basin (as the Galilee Basin has no existing longwall mining), will be reviewed and summarised to allow for consideration of possible alteration due to controlled collapse after coal extraction.

4) Review recent research documents relating to new findings that have arisen since the publication of the EIS that provide broad industry outcomes relating to the prediction and behaviour of subsidence and subsurface fracturing as a result underground longwall mine local seam extraction and goafing above mined longwall panels based on case studies. In particular the following research document will be reviewed and any relevant conclusions, outcomes and / or predictive analysis will be incorporated in the assessment and updated modelling of mining subsidence on hydraulic connectivity:


An updated and appropriately calibrated subsidence model will be constructed and processed with outcomes based on the following:

- Mine plans and stratigraphy (overlying units underlying and overlying the target coal seams). The definition and lithological and hydrogeological characterisation of the Rewan Formation and overlying and underlying stratigraphical units will be based on updated lithofacies characterisation and 3D geological modelling to be completed by . In particular the subsidence research modelling analysis work will incorporate any updates to the interpreted Rewan thickness, the interpreted Base of Weathering thickness, and the occurrence and hydrogeological characterisation of any overlying aquifer units, including the Clematis Sandstone (should it be interpreted), and interpreted geological structures in areas overlying planned longwall operations;
- The depth and thickness of target coal seams to be extracted through underground longwall mining;
- The nature of the overlying hydrogeologic units (aquitard or aquifer), and the impact of modelled continuous and discontinuous fracturing driving hydraulic connectivity and permeability changes within identified hydrogeological units as a result of longwall mine subsidence. This will include assessment and incorporation of the detailed lithological characterisation of the Longwall mining details (panel width, thickness, super-critical width extraction, etc.);
- Surface ground movement resulting from coal extraction (subsidence, tilt, curvature, strain, and horizontal shear deformation);
- Vertical and horizontal subsidence movement;
- Far-field movements (beyond the longwall panel edges);
- Possibility of irregular subsidence movement (sudden or abrupt changes in geological conditions for example);
- Predictions of sub-surface alteration (fracture height, deformation zones, etc.);
- Continuous and discontinuous fracturing (as illustrated below in Figure 14); and
- Potential subsidence impacts on the area of the Doongmabulla Springs.

New data from field investigations underpinning the work scopes to construct a comprehensive 3D geological model will provide for improved definition of the spatial and vertical stratigraphic compartmentalisation of broad relevant lithological units. These units include Tertiary, Moolayember, Clematis Sandstone, Dunda beds, Rewan Formation and the Bandanna Formation as they may occur over the underground mine operations and extending to the west beyond the DSC. Completion of other relevant work scopes as detailed in this plan will provide for increased definition and hydrogeological characterisation of interpreted individual units within these broad lithological units, including subdividing the Rewan Formation into discreet hydrogeological units.

The Comprehensive subsidence modelling as planned and based on updated data, analysis and interpretation and taking into consideration latest longwall subsidence case studies and research, will improve on existing subsidence modelling used to underpin the EIS (MSEC, 2013). The subsidence modelling will assess a range of possible reasonable practical outcomes based on sensitivity analyses associated with fracturing, permeability and drainage predictions above longwall goaf areas. Numerical geotechnical modelling sensitivity / uncertainty analysis utilising updated hydraulic connectivity values as established from planned exploration field work and testing, will incorporate spatial heterogeneity of permeability (K) values within the subsidence modelling process and this will feed into hydrogeological model updates/re-run as required under separate commitments and conditions required for GMMP, GDEMP and GABSRP as per schedule provided in table-3 in section 4. This parameterisation will ultimately enable the reporting of confidence intervals relating to drawdown to be established based on probability assessment.

Whilst subsidence analysis and geotechnical numerical modelling will facilitate the best possible subsurface and surface subsidence and fracturing / connectivity predictions, a Subsidence Management Plan (SMP) will be developed to validate model predictions and, importantly, provide controls through Trigger Action Responses (TARPS), should actual subsidence measurements and / or impacts exceed predictions.

Underground longwall panels are sequenced in a manner whereby the initial panels are located well to the east of recognised Great Artesian Basin (GAB) aquifer units and do not underlie and will not therefore directly subside upper Rewan Formation (including Dunda beds), or overlying Clematis Sandstone or Moolayember formations. As such the early, shallower longwall panels may be subsided and monitored without any connectivity impacts associated with subsidence fracturing of sensitive overlying aquifers.

Monitoring and surveyed measurement of subsidence over shallower longwall panels, sequenced early in the underground mining operations and utilising cross line and centreline subsidence surveys and impact assessments will provide an appropriate assessment of the level of risk and associated consequences of deeper longwall panels to the west of the Adani lease located closer to, or directly underlying sensitive overlying aquifers. The process of monitoring, measurement and trigger control under a SMP is a standard and regulated coal mine industry process which is used to progressively check and calibrate subsidence predictions and impacts. The process may, or may not, result in a decision not to mine progressively deeper longwall panels located to the west of the Adani lease, depending on the level of risk and if it is deemed that
the associated consequences of impacting connectivity, permeability and potentially drainage of sensitive nearby or overlying aquifers are unacceptable. Ongoing progressive collection of actual baseline subsidence monitoring and measurement data will provide for ongoing subsidence model calibration and subsidence impact predictions for progressive longwall panels, which will be required following the completion of each longwall panel.

A SMP is a regulatory requirement that will be finalised and approved in advance of mining commencing. The SMP will details the roles, responsibilities and obligations of responsible persons and will ultimately require authorisation and approval by both the operational management team in place at the time (including the Site Senior Executive), and by the relevant government regulatory authorities. The key elements of the SMP include planning and hazard prediction, monitoring and measurement, trigger action response based on established thresholds, mandatory reporting, and continuous improvement including calibrating the geotechnical numerical subsidence model with real time measurements.

Whilst the SMP will be developed in advance of mining with an appropriate cross section of the in place workforce and based on consultation and interaction with appropriate regulatory authorities, based on experience at other longwall mines the SMP will include as a minimum:

General planning components including:

- Compilation of subsidence hazard plans;
- inspection regimes;
- layout of monitoring points;
- parameters to be measured;
- monitoring methods and accuracy;
- timing and frequencies of surveys and inspections; and
- recording and reporting of monitoring results.

Environmental management typically entailing:

- A detailed monitoring programme;
- Trigger levels for subsidence impacts that require actions and responses;
- Procedures that would be followed in the event that the monitoring indicates an exceedance of trigger levels;
- Measures to mitigate, remediate and / or compensate any identified impacts;
- A protocol for the notification of identified exceedances of the trigger levels; and
- A contingency plan.

Incident and ongoing management reporting including:

- Any significant unpredicted and/or higher-than-predicted subsidence and/or abnormalities in the development of subsidence;
- Any exceedance of predicted impacts on groundwater resources and/or the natural environment that may have been caused (whether partly or wholly) by subsidence;
- Any observed subsidence impacts adverse to the serviceability and/or safety of infrastructure and other built structures that may be affected by longwall mining;
- Any significant subsidence-induced cracking and/or ground deformations observed in surface areas within the SMP application area; and
• Any buildings, structures and infrastructure, which have become or are likely to become hazardous as a result of subsidence.

Regulated status reporting including but not limited to:

• The current face position of the panel being extracted;
• A summary of any subsidence management actions undertaken by the Leaseholder in the period subsequent to the last regular submission of the Status Report;
• A summary of any comments, advice and feedback from consultation with stakeholders in relation to the implementation of the approved SMP (including the preparation, implementation and review of plans, programmes, reports or strategies required by this approval) undertaken or received in the period subsequent to the last regular submission of the Status Report and a summary of the Leaseholder's response to the comments, advice and feedback given by the stakeholders;
• A summary of the observed and/or reported subsidence impacts, incidents, service difficulties, community complaints, and any other relevant information reported to the Leaseholder in the period subsequent to the last regular submission of the Status Report and a summary of the Leaseholder's response to these impacts, incidents, service difficulties and complaints;
• A summary of subsidence development based on monitoring information compared with any defined triggers and/or the predicted subsidence to facilitate early detection of potential subsidence impacts;
• A summary of the adequacy, quality and effectiveness of the implemented management processes based on the monitoring and consultation information summarised above; and
• A statement regarding any additional and/or outstanding management actions to be undertaken or the need for early responses or emergency procedures to ensure adequate management of any potential subsidence impacts due to longwall mining.

Model updates and continuous improvement and lessons learned, including:

• Updating and calibrating the geotechnical numerical subsidence geotechnical model with surveyed accurate measurements and observations following the completion of each successive longwall; and
• Updating subsidence predictions and impacts for future longwall panels based on the results of model updates as described above.

The research package for the Assessment of Longwall Mining Subsidence on hydraulic connectivity will be coordinated... The SMP will be developed and implemented as required under the appropriate regulatory process.

This research package addresses conditions relating to “the extent and location of fracturing, faulting and preferential pathways (including any fracturing induced by longwall mining subsidence)….. to better characterise the Rewan Formation and the contribution of fracturing, faulting and preferential pathways to connectivity”.  

Figure 14: Fracturing associated with longwall extraction example
5.11. Fault Zone and Hydraulic Connectivity Analysis

The overarching goal of the fault zone analysis is to correctly estimate fault zone hydraulic properties that may enhance hydraulic conductivity within the Rewan Formation, taking into consideration all prior studies and analysis. Fault seal capacity is the term used to describe the capacity of the fault to limit / reduce secondary hydraulic connectivity as a result of alteration. State of the art fault seal capacity analysis requires an evaluation of the internal stratigraphic heterogeneity linked with associated rock properties; and many of the techniques for evaluating fault seal capacity require accurate information on the stratigraphy either side of the fault.

Fault zones may either compartmentalise strata horizontally or cause localised vertical hydraulic connectivity between stratigraphic levels. There are several aspects of fault zones that can either allow for this hydraulic communication or prevent it. These require different assessment methods which generally rely on similar underpinning data sets. Integration of these analytical processes, supported by hydrodynamic and geochemistry data, is required to assess the fault seal capacity and assign hydraulic properties to the rock mass and groundwater models.

The research package will provide a summary of the possible extent and location of faulting plus the potential for preferential pathways as a result of longwall mining. This will include consideration of other preferential flow pathways including connected (more permeable) sandstone bodies, small offset faults and fractures around fold hinges, or combinations of these as illustrated in Figure 6. The range of possibilities will allow for further refinement of the existing numerical groundwater model.

Fault zone and hydraulic connectivity analysis will draw on all the prior Research Packages (RPs), and consider all potential preferential pathways as described in Section 4.3 and illustrated in Figure 6, to provide the base data and interpretations underpinning fault zone and hydraulic connectivity analysis:

- **RP 5.2:** Detailed geological interpretation of Rewan lithofacies from existing data will provide the interpretation of host rock material;
- **RP 5.3:** Interpretation of groundwater resources associated with the Rewan group will provide base information and data on the occurrence of groundwater potentially enhanced by faulting or other preferential pathways; affecting fault zone analysis and hydraulic connectivity;
- **RP 5.4:** Estimation of hydraulic properties from supplementary field work and existing data sources will provide the base data for the assessment of hydraulic connectivity between stratigraphic units, sandstone bodies and within and around fault zones;
- **RP 5.5** Reprocessing and interpretation of existing historical regional 2D petroleum seismic lines will provide base interpretation information on the on the anticipated fault style and displacement characteristics;
- **RP 5.6:** Mapping and modelling of fault styles, orientations, displacements and densities using information and interpretations from the 2D seismic interpretation exercise (and other geological interpretation) to provide fault architecture inputs to conduct high confidence fault zone analysis and hydraulic connectivity assessment;
- **RP 5.7, RP 5.8, and RP 5.9** are independent studies that collectively provide the input parameters relating to juxtaposition analysis, shale gauge and fault membrane seal analysis, ands fault leakage potential that feed into the overall assessment of fault zone and hydraulic connectivity analysis; and
- **RP 5.10:** Assessment of potential Longwall Mining Subsidence impacts on hydraulic connectivity will provide the base analysis and conclusions relating to predicted changes in hydraulic connectivity as a
function of subsidence, including the impacts of subsidence associated with interpreted fault zones (and their assessed permeability characteristics).

will provide analysis of fault zone and hydraulic connectivity data based on subsidence over longwall panel predictive modelling, considering rock mass permeability alteration, rock mass porosity changes, and strain dependent permeability and porosity analysis. This RP will incorporate analysis of hydraulic connectivity associated with fault zones and all other preferential pathways as described in Section 4.3 and illustrated schematically in Figure 6.

The RP will allow for the compilation of comments for inclusion in the Rewan Connectivity workshop, including:

- The height of fracture zones and development of constrained/dilated zones;
- Height of fracturing does not imply that hydraulic connectivity will extend to the same height due to overlying aquitards;
- Extent and self-sealing potential of clay-rich overburden;
- Uncertainty and sensitivity analysis regarding the influence of fracture height with regards to aquifer enhancement and groundwater ingress predictions; and
- Uncertainty and sensitivity analysis regarding the influence of increased vertical hydraulic conductivity within overlying units on groundwater ingress predications.

This research component will be led by .

The research package addresses conditions relating to “the extent and location of fracturing, faulting and preferential pathways (including any fracturing induced by longwall mining subsidence)..... to better characterise the Rewan Formation and the contribution of fracturing, faulting and preferential pathways to connectivity”.

It is planned that the range of alteration predictions (fracture height, increase in vertical hydraulic conductivity, etc.) will, at the end of the research study, be included in the approval condition predictive modelling. Adani will use results of studies carried out for subsidence prediction study (section 5.10) and fault zone analysis (this section) to update the conceptual hydrogeological model which underpins the groundwater numerical model used for predictions of impacts on MNES including DSC. Adani has given commitment in GMMP and GDEMP, to undertake this work during the next groundwater model review and re-run within two years of commencement of mining operations related to first box cut. This will allow for further refinement of the groundwater numerical model and assessment of potential impacts of the proposed mining activities on the GAB groundwater resources to the west of the Rewan Formation.
5.12. Literature and Benchmarking Studies

This research package will compare outcomes from previous research packages with international literature on (i) structural fault permeability studies, (ii) subsidence effects and (iii) permeability and flow path case studies through similar materials / strata. The outcome of this research package will be the preparation of a report using benchmarking of case studies where there is empirical evidence of the connectivity risks under comparable geological and hydrogeological conditions.

A review of available international literature on structural fault permeability studies and subsidence effects will be completed by , with the Carmichael project benchmarked against available industry case studies. Similarly prior to the workshop review a review of available international literature on permeability and flow path case studies through similar materials / strata will be completed by , with the Carmichael project benchmarked against available industry case studies.

Importantly, the evidence including outputs from the benchmarking will be discussed (and tested / critiqued) by an expert panel. The expert panel will include the lead researchers who have implemented relevant research packages for the Plan, the independent expert peer reviewer ), Adani experts and Government officers from DoE will also be invited to participate if available. The workshop will be convened and Chaired by the independent expert peer reviewer ( ).

The outcome of this workshop will be the preparation of a report using national and international benchmarking of case studies where there is empirical evidence of the connectivity risks under comparable geological and hydrogeological conditions.
5.13. Plan Workshop and Preparation of Report on Research Outcomes

Relevant outcomes from all the prior research packages will be compiled to provide a succinct definitive position on all potential preferential pathways as illustrated in Figure 6 and outlined in Section 4.3. This will be compiled to provide an accurate representative summary report of key findings and outcomes based on assessed data, interpretations and conclusions from all the relevant research completed. The summary report will provide the necessary information and relevant factual, analytical and interpretive information to be used for a workshop and preparation of a report on research outcomes as detailed in Section 5.14. This will include identifying any knowledge gaps/areas of inconsistent results and agreeing on recommendations as required for further analysis/study.

This report and workshop preparation will be compiled and issued by the RFCMP coordinator.

The outcomes of the previous research packages detailed above in sections 5.1 to 5.12 will supplement the existing evidence base with respect to the potential degree of hydraulic connectivity across the Rewan, the mechanisms at work, and the impact that the interpreted faults and predicted subsidence will have on permeability and hydraulic connectivity, with a particular focus on the area of the Doongmabulla Springs. A joint workshop will be held between all the research leads after completion of their respective research packages, to produce a combined report for submission to Department. This workshop will be chaired and coordinated by the Independent Peer Reviewer.

These outcomes will be compiled into a final report following delivery of all research packages outlined in Sections 5.1 to 5.12.

A workshop will be conducted as follows:

- The attendees at the workshop will include all Research Package Study leaders, the appointed external peer reviewer for the Plan, Adani staff involved in the research plan and representatives from Department of Environment and other persons related to Bioregional Assessment programs in Galilee basin will also be invited to participate;
- The findings/outcomes of all research packages (which will have been made available to all workshop participants at least one week prior to the workshop to allow the opportunity for consideration of the research package findings and outcomes) will be presented via a short presentation to the workshop by the task leader for each research package;
- The overall findings/outcomes of the Plan will be discussed and a coherent, coordinated set of final findings/outcomes will be agreed (this process may extend beyond the workshop). This process will be chaired and coordinated by the external peer reviewer;
- Identify if any areas exist where the results of individual research packages have provided results that contradict the findings of other research packages (i.e. confirm (or otherwise) whether the overall results/outcomes of the individual work packages provide results that are consistent with each other);
- Identify any knowledge gaps/areas of inconsistent results that have been identified during the course of the Plan process and agree on recommendations as required for further analysis/study;
- The workshop will also examine the outcomes of each individual research component and make recommendations on the necessity to extend these studies into future or alternatively recommend for additional studies if required;
The process for compiling and integrating the deliverables of all research packages (as well as the existing knowledge base) into a single integrated report will be discussed. The objective will be the preparation of a final report that:

- Presents each research package in a comprehensive and consistent format (e.g. description, methodology, discussion, conclusions and recommendations);
- Incorporates the existing knowledge base as appropriate to support/augment the study findings;
- Presents an integrated set of findings, outcomes, conclusions and recommendations for the overall Plan; and,
- Makes use of appendices as appropriate, e.g. to present full detail of each research package while allowing preparation of a main report that presents/discusses the findings/outcomes of each research package in a clear and concise manner and in a consistent format.

- Makes recommendations (from the results/findings from individual packages of this research plan) that must be used for updating hydrogeological conceptualisation used for groundwater numerical model during the re-run exercise and revise groundwater drawdown impacts. GMMP and GDEMP will be updated as per revised predicted impacts which includes updating of early warning triggers for MNES including DSC and groundwater drawdown thresholds.

This process will be chaired and coordinated by the external peer reviewer;

- The timing of the report writing process will be discussed and agreed; and,
- Subsequent to the workshop, a final report template and style guide will be prepared and distributed to each Research Study leader. This process will be coordinated by in consultation with the external peer reviewer.
5.14. **Links to the Groundwater Management and Monitoring Plan (GMMP)**

A Groundwater Management and Monitoring Program (GMMP) is prepared and approved by the Minister on 8 April 2019 as per the approval condition of the Carmichael Coal Project. The GMMP includes details of groundwater monitoring network plus recommendations for groundwater monitoring during all phases of the project including baseline, operations, and post-closure. The GMMP also includes additional commitments with respect to acquisition of new data by installing nested bores at three sites near to DSC.

The GMMP has been prepared to ensure all geological units, potentially impacted by mining activities (including the Rewan Formation), are adequately monitored. The existing groundwater monitoring network is being reviewed to confirm monitoring in line with the revised geology.

The Rewan research, once completed, will make recommendations as to:

- The properties that should be used for the Rewan Formation as relevant to future refinement of the groundwater model;
- The associated behaviour of fractured Rewan Formation following longwall mining subsidence as relevant to the groundwater model;
- The associated behaviour of other structures and conduits as relevant to the groundwater model;
- A revised 3D geological model will be made available for all future groundwater model revisions, with current data and information at the time of the groundwater model revisions.

Adani commits to update the GMMP through a suitably Qualified Person to ensure compliance with all relevant approval conditions, including the recommendations from the Plan during the next review of GMMP within two years of commencement of mining operations related to first box cut.

In section 5.11, Adani commits to use results of studies carried out for subsidence prediction study (section 5.10) and fault zone analysis (5.11) to update the conceptual hydrogeological model which underpins the groundwater numerical model used for predictions of impacts on MNES including DSC. Adani has given commitment in GMMP and GDEMP to undertake this work during the next groundwater model review and re-run within two years of commencement of mining operations related to first box cut. This will allow for further refinement of the groundwater numerical model and assessment of potential impacts of the approved mining activities on the GAB groundwater resources to the west of the Rewan Formation.

Section 5.13 commits that the GDEMP and GMMP will be updated based on revised impacts from the model re-run, which includes updating of early warning triggers for MNES including DSC and groundwater drawdown thresholds.

Details have been included in the GMMP regarding how the Rewan Formation monitoring allows for:

- The development of early warning monitoring points (with regards to potential impacts on the GAB units);
- The establishment of groundwater level threshold levels (which if reached instigate investigation into potential for environmental harm);
- The interaction of the Plan (groundwater component) with the springs, offset, subsidence, and GDEMP; and
- Links to the Geoscience Australia regional Galilee Basin numerical groundwater model.
In addition, any further data and information collected subsequently from exploration and mining relevant to the above will be utilised in the periodic model reviews and revisions of the groundwater model, and future updates to the GDMEP, GMMP, and GABSRP.
5.15. **Links to Bioregional Assessment program**

As it is considered that as the Galilee Basin is a subregion of the Lake Eyre Bioregion (Figure 15), the Rewan Formation assessment forms part of the Lake Eyre Bioregion Assessment.

The results of the Rewan Formation connectivity research will allow for the more accurate assessment of potential for induced flow of groundwater from the Great Artesian Basin units (and possible subsequent reduction in water resources in the Galilee subregion).

The research and assessment results compiled during the Plan will be made available to the Galilee Basin regional water balance (an approval condition for development and implementation of GMMP) and the Geoscience Australia regional Galilee Basin numerical groundwater model. Mark Stewart of AECOM will assist Adani in their discussions with the relevant stakeholders and provide required reporting / up-date correspondence. Adani will also make available the outcomes of the Plan and data obtained through implementation of GMMP to any regional groundwater and surface water monitoring and assessment program, or Bioregional Assessment for the Galilee Basin sub-region and the Lake Eyre Basin and any subsequent iterations.

![Figure 15: Lake Eyre Basin and Galilee subregion (source: DoTE, 2014)](image-url)
6. **Key research personnel**

This chapter outlines key research personnel and their roles in the Plan as required under Condition 27 “b) personnel responsible for conducting research and their qualifications”. It should be noted that with the passage of time since the first edition of this Plan the following researchers are now unavailable:

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The work scopes originally proposed to be coordinated by will be coordinated by a researcher of appropriate and equal status as elected by the

The role of , who is recognised as a suitably qualified and experienced replacement.

; however his work scope deliverables will now be led by who has been confirmed by as a suitably qualified and experienced replacement.

6.1.

years’ experience in the mining industry, with specifically in the Australian coal industry. has significant experience in project managing all aspects of exploration, geological data management and modelling, geotechnical and hydrogeological field activities, studies and analysis to support mine planning and environmental approvals.

completed a number of JORC Resource Estimates as Competent Person for a number of resources in Australia and internationally and also coordinated numerous consulting and research assignments on geological and geotechnical areas during this time including:
6.2.

6.3. Researcher leading Research Package No 5.2 and 5.6 Geology Research Lead -

An appropriately experienced and qualified geological lead will be elected by ... lead these research packages

6.4. Geology Research Lead: Role in the Plan

The Geology Research Lead will coordinate and deliver the following research packages under this Plan: 5.2: Detailed geological Interpretation of Rewan Lithofacies from Existing Data - Stratigraphy model with Lithofacies interpretation of Rewan aquitard and overlying / underlying sequences. 5.6: Mapping and modelling of fault styles, orientations, displacements and densities – This work involves using seismic interpretation by ... to construct a 3D fault model to assess any associated potential high permeability zones.

6.5.
Experience in the mining industry includes turnkey drilling projects, design and construction of groundwater monitoring bores, management of groundwater monitoring programs, aquifer assessments, bore surveys, compliance and due diligence audits, and Environmental Impacts Statement reporting. Additional experience includes groundwater resource evaluation and impact assessment due to land use change within the Cape York, North West Mineral Province, and central areas of Queensland, including the Great Artesian Basin and Burdekin alluvium aquifers.

6.6. Role in the Plan

The role in this plan is to coordinate and deliver the following research packages all of which will link into the GMMP:

The conceptualisation of the groundwater resources associated with the Rewan Formation and over- and under-lying strata will be produced using north-south and east-west cross-sections through representative bore logs. This work will provide for the determination of groundwater levels and vertical gradients to illustrate the aquitard nature of the Rewan Formation and allow for accurate description of the multilayered aquifer and aquitard sequence.

Permeability data obtained from the core samples will be used to determine vertical and horizontal hydraulic conductivity both spatially and with depth. The permeability and other hydraulic properties to be used in other plan assessments.

This work involves reviewing results of subsidence predictions, carried out by FLAC 2D numerical modelling of subsidence, fracturing and hydraulic connectivity and cross checking against regional experience.

The work will provide for determining the potential for preferential pathways as a result of longwall mining and subsidence, including the contribution of interpreted faulting. This work involves validation and assessment of existing baseline groundwater level and quality data and the development of a conceptual model to assess potential hydraulic connectivity across stratigraphic layers.
in reviewing the collective outcomes of research packages. Review of the typical Carmichael case outcomes will be assessed against available literature relating particularly with respect to benchmarking permeability across faults and strata in similar environments.

6.7.

is a qualified and highly experienced geophysicist with considerable experience in the planning and interpretation of seismic and other geophysical methods including radiometrics in the Australian coal industry. by many coal mining companies operating in Australia as a leading expert in the fields of geophysical interpretation on coal mining deposits, in particular for seismic, radiometric and magnetic geophysical methods.

6.8. : Role in the Plan
Reprocessing and interpretation of existing historical regional 2D petroleum seismic lines.

The research package entails reprocessing and interpretation of existing historical petroleum 2D seismic lines. The interpretation will focus on Rewan aquitard and overlying / underlying sequences and fault structures. Completion of this work will provide for improved resolution and definition of the strata sequences and any impacting fault zones.

6.9.

experience in petroleum hydrogeology, unconventional hydrocarbons and carbon storage research.

6.10. Role in this Plan

will coordinate and deliver the following research packages relating to fault seal potential: This will involve:

- The construction of Allan Diagrams that provide a sense of horizontal connectivity on each fault plane.
- Examination of fault zone orientation in combination with the in-situ stress and pore pressure
- Shale Gouge Ratio analysis of faults
- Estimates of fault zone permeability
- Identify key leak points from stress fields
- Mapping of fault planes to assess the potential for up-fault leakage.

6.11.

35 years’ experience in the international underground coal mining industry. He is qualified as follows:
6.12. will provide subsidence modelling and prediction inputs to support section 5.10. In particular, will provide further numerical analysis to determine the extent of fracturing and connectivity through the Rewan strata as a result of longwall goafing.

6.13. over 27 years of experience as a hydrogeologist, focussed mainly on Queensland coal mining projects.

6.14. Role in this Plan

Following completion of the proposed eighteen month desktop study, will be the appointed peer reviewer to fulfil the Condition 27 reference "a peer review of the Rewan Research Plan, by a suitably qualified independent expert, approved by the Minister in writing, and a table of changes made in response to the peer review". will coordinate a joint workshop to be held between all the research leads after completion of their respective research packages delivering the eighteen month desktop study outcomes, to produce a combined report for submission to Department (work package 5.14).
6.15. Longer Term Research Aims, Monitoring, Validation and Control

The eighteen month intensive desktop study as detailed in prior sections of this Plan provides outcomes of targeted research relating to specific aspects that are defined in and that meet Approval Condition 27. However it is recognised that the outcomes of these targeted research packages, whilst they will comply with Condition requirements, are based on the best predictions possible with concurrent information and data. As the Mine Project is executed further information and data will become available which is not expected to materially change outcomes of the eighteen month intensive desk top study, but may result in subtle (none material) variations in predicted outcomes.

Outcomes of the targeted eighteen month desk top research packages will be reviewed and checked in the following circumstances:

- Annually following completion of the eighteen month intensive desk top study should no material differences in research outcomes arise as a result of further exploration or mining operations; or
- Following the realisation of information or data that comes to light as a result of future exploration or mining activity which does, or which could, materially alter the predicted research outcomes based on the eighteen month intensive desk top studies.

The following parameters and aspects will be recorded, measured and validated against the outcomes of the Rewan research eighteen month intensive desktop study:

- Actual intersection of faults and associated geological structures as they are encountered in underground and open cut mining operations will be mapped and reconciled against predicted faults in the geological model in the context of displacement, orientation and style. In particular the nature of fracturing comprising and surrounding any encountered fault / fracture zones and the associated horizontal and vertical permeability both across zones and vertically will be cross-checked against assessments made in the eighteen month intensive desktop study;
- Cross line and centre line subsidence following longwall mining will be accurately measured by surveyors using differential GPS and cross checked against subsidence prediction made through existing studies (refer Section 5.10);
- All future exploration data relating to the Rewan Formation strata and overlying / underlying beds will be incorporated into updated geological models as soon as validated data becomes available, and models will be checked against the interpretations made as outcomes of the eighteen month intensive desk top studies; and,
- Any outcomes from hydrogeological monitoring including the GMMP will be cross-checked against the outcomes of the of the eighteen month intensive desk top studies.

Following the completion of the intensive 18 month study, culminating in the final workshop coordinated and signed off by the appointed Plan peer reviewer, the Plan objectives will be achieved and the Plan officially implemented. The final Plan at this point will make recommendations as to:
A) The properties that should be used for the Rewan Formation as relevant to groundwater models;

B) The associated behaviour of fractured Rewan Formation following longwall mining subsidence as relevant to groundwater models;

C) The associated behaviour of other structures and conduits as relevant to groundwater models;

D) A revised 3D geological model will be made available for all future groundwater model revisions, with current data and information at the time of the groundwater model revisions.

In addition, any further data and information collected subsequently from exploration and mining relevant to the above will be utilised in the periodic model reviews and revisions of the groundwater model, and future updates to the GDMEP, GMMP and GABSRP.
7. **Peer Review Statement and Summary of changes made**

Our reference: [redacted]

10 December 2018

Independent Review of Rewan Formation Connectivity Research Plan – Carmichael Project

Adani Mining Pty Ltd (Adani) have requested that [redacted] conduct an independent 3rd party review, as required under Condition 27(f) of the EPBC approval for the Carmichael Coal Project (the Project), of the Rewan Formation Connectivity Research Plan (the Plan) that has been prepared for the Project by Adani Mining Pty Ltd (Adani).

A draft Plan (Version D) was provided to [redacted] for review on 10 June 2015. [redacted] provided review of the draft Plan (as track changes and comments within the MS Word version of the report), with comments provided to Adani as Version E on 10 July 2015. The [redacted] comments have been summarised within the comments register, which lists the Plan version number and a summary of changes made to that version.

A number of minor edits have been made subsequently, with [redacted] providing additional review comments to the Plan as Version F (31 July 2015) and Version I (19 April 2016).

Following final review of the most recent revised Plan (Revision J, 19 November 2018), it is our conclusion that the Plan is suitable for release.

Pleasing contact the undersigned should you have any further queries.

Yours Faithfully,

[redacted]

Director/Principal
### Rewan Formation Connectivity Research Plan Peer review - Summary of Changes

<table>
<thead>
<tr>
<th>Report Section</th>
<th>Comment from</th>
<th>Changes made</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 3 - Purpose and Objective of plan</td>
<td>The objective must be that RFCRP outcomes must be used for validation through monitoring/analysis of actual mining impacts versus predicted impacts and that this will allow actions to be taken as required (additional monitoring, assessment etc.) under the GMMIP.</td>
<td>Section 3 has been updated</td>
</tr>
<tr>
<td>Section 3 - Purpose and Objective of plan</td>
<td>Objectives must clearly include a summary of proposed work in each of individual work packages.</td>
<td>Section 3 has been updated to explicitly include scope and objectives of individual work packages</td>
</tr>
<tr>
<td>Section 4</td>
<td>Background Information on geology and Rewan formation - Several edits suggested to description of geology</td>
<td>Edits made as per suggestions</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Replace figure with better quality image</td>
<td>New Figure 3 included</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Conceptual Hydrogeological model - Recommended changes to this figure.</td>
<td>New conceptual hydrogeological model is included</td>
</tr>
<tr>
<td>Section 4.2 Overview of information</td>
<td>Suggested to include the details of existing information like no of bore holes used in the studies and changes to description of existing knowledge of geological information</td>
<td>Edits made as per suggestions and included number of bore holes used for studies</td>
</tr>
<tr>
<td>Section 4.3 Conceptualisation of Conditions (Now interpretation of Preferential pathways - concept)</td>
<td>Suggested to include the key aspects of the plan with additional details</td>
<td>The following changes were made to the plan: The key aspects to address the Plan within the area impacted by the mine are summarised as follows: • The nature and extent of fractures and the extent to which fractures could provide preferential pathways; • The type, extent and location of faults and the extent to which faults could act as conduits for groundwater flow (via cross-fault leakage and/or along-fault leakage); • The potential impacts of fault throw (i.e. vertical displacement of hydro stratigraphic units) on groundwater flow;</td>
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<tr>
<td>Section 4.4 - Existing Knowledge base and position</td>
<td>Suggested several edits to existing knowledge base: (Comment as inserted by): I understand that Adani wish to make a number of points as to their stance on the level of risk of groundwater level impacts; however this section (from this paragraph to the end of the section) needed a re-write to enhance the flow of the document and to provide a consistent tone to the comments. I have made a number of suggested format and wording changes so that these points can still be made, while acknowledging that the EPBC conditions that have been imposed will result in an increased level of robustness (and a significant knowledge base), allowing for a greater level of confidence that the monitoring and mitigation strategies that result from this project (and that are incorporated in the GMMIP) will protect sensitive features such as the Doongmabulla Spring and the groundwater resources of the GAB.</td>
<td>Edits made as per suggestions regarding thickness of Cenomian Sandstone, Molloyember formation and Rewan formation and accepted all changes suggested by so as to present existing information and also acknowledge the requirement of EPBC conditions on further research works to be carried out.</td>
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<tr>
<td>Section 4.5 - Summary of Plan Aims, Approach and Methods</td>
<td>I addition to Table 3 - to prepare a time schedule covering all work packages</td>
<td>A new schedule in .xls has been prepared and attached as Appendix to Research plan</td>
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<tr>
<td>Report Section</td>
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<tr>
<td>Section 5.1 Review of data from supplementary field investigations</td>
<td>Suggested several changes to study package- Review of Data from supplementary field investigations</td>
<td>All Changes were accepted</td>
</tr>
<tr>
<td>Section 5.2 - Detailed geological Interpretation of Rewan Lithofacies from Existing Data</td>
<td>Suggestions to remove fault interpretations from lithofacies study</td>
<td>All Changes were accepted; Fault interpretations now moved to Fault Juxtaposition analysis section</td>
</tr>
<tr>
<td>Section 5.3 - Conceptualisation of groundwater resources associated with the Rewan</td>
<td>Suggested minor edits</td>
<td>All Changes were accepted</td>
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<tr>
<td>Section 5.5 Reprocessing and interpretation of existing historical regional 2D petroleum seismic lines.</td>
<td>Suggested minor edits on obtaining new Seismic information is not necessary as reprocessing existing data will provide extremely valuable dataset and will meet the requirement of study objective</td>
<td>All Changes were accepted</td>
</tr>
<tr>
<td>Section 5.13 Plan workshop</td>
<td>Suggested edits for structuring the workshop</td>
<td>All Changes were accepted</td>
</tr>
</tbody>
</table>
8. References


Biggs, M. "A Short Review of Regional Structure in the Region of the Carmichael Coal Deposit". Mark Biggs Principal Geologist, ROM Resources Pty Ltd. February 2014.


Lindsay, N. G., Murphy, F. C., Walsh, J. J. and J. Watterson, 1993, Outcrop studies of shale smear on fault surfaces: Spec. Publ. Int. Assoc. Sedimentol., v. 15, p. 113-123.


Turner, T. “Adani Mining Pty Ltd JORC Coal Resource Estimate - Carmichael Coal Project” Completed by Xenith Consultants Pty Ltd. For Adani Mining Pty Ltd. April 2013


# Rewan Connectivity Research Plan - Task Chart

## Appendix 1: Proposed Timeframes for Research and Reporting

<table>
<thead>
<tr>
<th>Topic</th>
<th>Task Leader</th>
<th>Organisation</th>
<th>1 to 6</th>
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<tbody>
<tr>
<td>Exploration</td>
<td>Drilling and data gathering</td>
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<td>5.1</td>
<td>Data Analysis from Supplementary Field Investigations</td>
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<td>5.2</td>
<td>Lithofacies Interpretation</td>
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<td>5.3</td>
<td>Interpretation of Groundwater Resources</td>
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<td>Assignment of Hydraulic Properties from Supplementary Field Work</td>
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