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Caroona Coal Project Application for Gateway Certificate

Appendix B
Agricultural Resource Assessment

March 2014

Agricultural Resource Assessment for Gateway Application: "Caroona Coal Project" Caroona, NSW

Prepared for BHP Billiton Ltd; in conjunction with Resource Strategies Pty Ltd

Dr. David McKenzie
McKenzie Soil Management Pty. Ltd.
Orange NSW

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This report was derived from an extensive range of information sources including literature review and discussions with colleagues and landholders. The author has sought to ensure that sources for his use of text, diagrams, maps and images are provided in the report. If the author inadvertently has failed to adequately acknowledge a source of material used, he would appreciate prompt notification so that the matter can be corrected in the electronic version of the document and a full acknowledgement provided.

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Contents

List of Figures

List of Tables

List of Soil Maps

List of Appendices

List of Attachments (provided in electronic version)

EXECUTIVE SUMMARY

The Caroona Coal Project (the Project) is a proposed underground coal mining operation with an operational life of approximately 30 years. It is located 14 kilometres (km) north-west of Quirindi and 40 km south-southeast of Gunnedah in the New England North West region of New South Wales (NSW).

A soil survey was conducted by McKenzie Soil Management and associates during 2013 as part of the NSW Gateway Application for the Project. The survey included photography, description and sampling of 404 backhoe excavated soil pit profiles.

Based on the site inspection, soil survey and laboratory analysis results, an assessment of biophysical strategic agricultural land (BSAL) status of the survey area was conducted in accordance with the *Interim Protocol for Site Verification and Mapping of Biophysical Strategic Agricultural Land* (NSW Government 2013). Within the Project Assessment Area, three soil landscape units are considered to be BSAL dominant, comprising an area of approximately 2,040 hectares (ha). In addition, four smaller clusters of BSAL (beyond the BSAL dominant soil landscape units) totalling 175 ha are also located within the Project Assessment Area, however only two of these clusters are located above the proposed underground mining area. Accordingly, 2,215 ha of Protocol Verified BSAL[1] is considered to be located within the Project Assessment Area. The remainder of the Project Assessment Area has a broad range of constraints which preclude the land from being classified as BSAL, including subsoil with salinity, alkalinity and sodicity problems, excessive slope (>10%) and rock close to the soil surface.

According to the NSW Government's regional mapping, Vertosols on the alluvial plains surrounding Doona Ridge and Nicholas Ridge are classified as BSAL however this study has shown that these sub-sections of the study area are in fact non-BSAL because of strongly saline and alkaline subsoil.

Possible impacts to agricultural productivity as a result of the Project would be associated with temporary loss of land due to construction of mine infrastructure (e.g. surface facilities) and potential subsidence impacts. With the implementation of proposed management measures for surface cracking, topographical depressions and localised slope changes, it is considered that there would be no significant adverse change to the long term agricultural productivity of the Project area as a result of subsidence impacts on agricultural land. Monitoring of any new topographical depressions in the existing saline alluvial areas should be conducted to identify changes in soil salinity. If salinity levels increase, it may be necessary to modify farming practices to ensure ongoing agricultural productivity. It is noted that no Protocol Verified BSAL is located within these existing saline alluvial areas.

Following completion of mining activities, infrastructure would be removed and the land rehabilitated to a condition consistent with pre-mining land use. A proposed Reject Emplacement Area, at 'Doonavale' on non-BSAL land with Land and Soil Capability classes of predominately 5 or greater, would be rehabilitated to a condition at least as productive as the present status.

This report describes the physical and chemical fertility of topsoil and subsoil in far more detail than previous soil studies (both public and private) in the vicinity of the Project. The comprehensive analysis within this report will allow appropriate rehabilitation and management measures to be developed and implemented for the Project. This will allow for maintenance or enhancement of the productivity and sustainability of topsoil and subsoil in the vicinity of the Project.

[1] BSAL that has been identified through ground survey in accordance with the *Interim Protocol for Site Verification and Mapping of Biophysical Strategic Agricultural Land* (NSW Government, 2013) and, where no access was available for ground survey, has been interpreted as BSAL based on continuity with adjacent BSAL dominant soil landscape units.

Technologies exist to overcome the existing topsoil and subsoil constraints identified in this study through improved soil/agronomic management, and better matching of plant tolerances with subsoil conditions. A consequence of this approach is likely to be improved water use efficiency. Better water uptake by pasture, crops and trees means less deep drainage of high quality water into the alluvial zone subsoil where it can become unavailable for most plants because of mixing with the existing highly saline water-tables close to the surface.

1 INTRODUCTION

The Caroona Coal Project (the Project) is a proposed underground coal mining operation with an operational life of approximately 30 years. It is located 14 kilometres (km) north-west of Quirindi and 40 km south-southeast of Gunnedah in the New England North West region of New South Wales (NSW) (Figure 1).

The Project underground mining area would be located entirely within the Doona Ridge and Nicholas Ridge Targeted Exploration Areas (herein referred to as the Project Assessment Area) within Exploration Licence (EL) 6505, which has an approximate area of 34,400 hectares (ha) (Figure 2). The Project would also involve the development and use of infrastructure required for the handling and transportation of coal. The Project Assessment Area has a total area of approximately 11,850 ha.

The objectives of the assessment presented in this report – as part of the Preliminary Agricultural Impact Statement for a Gateway Application – were to:

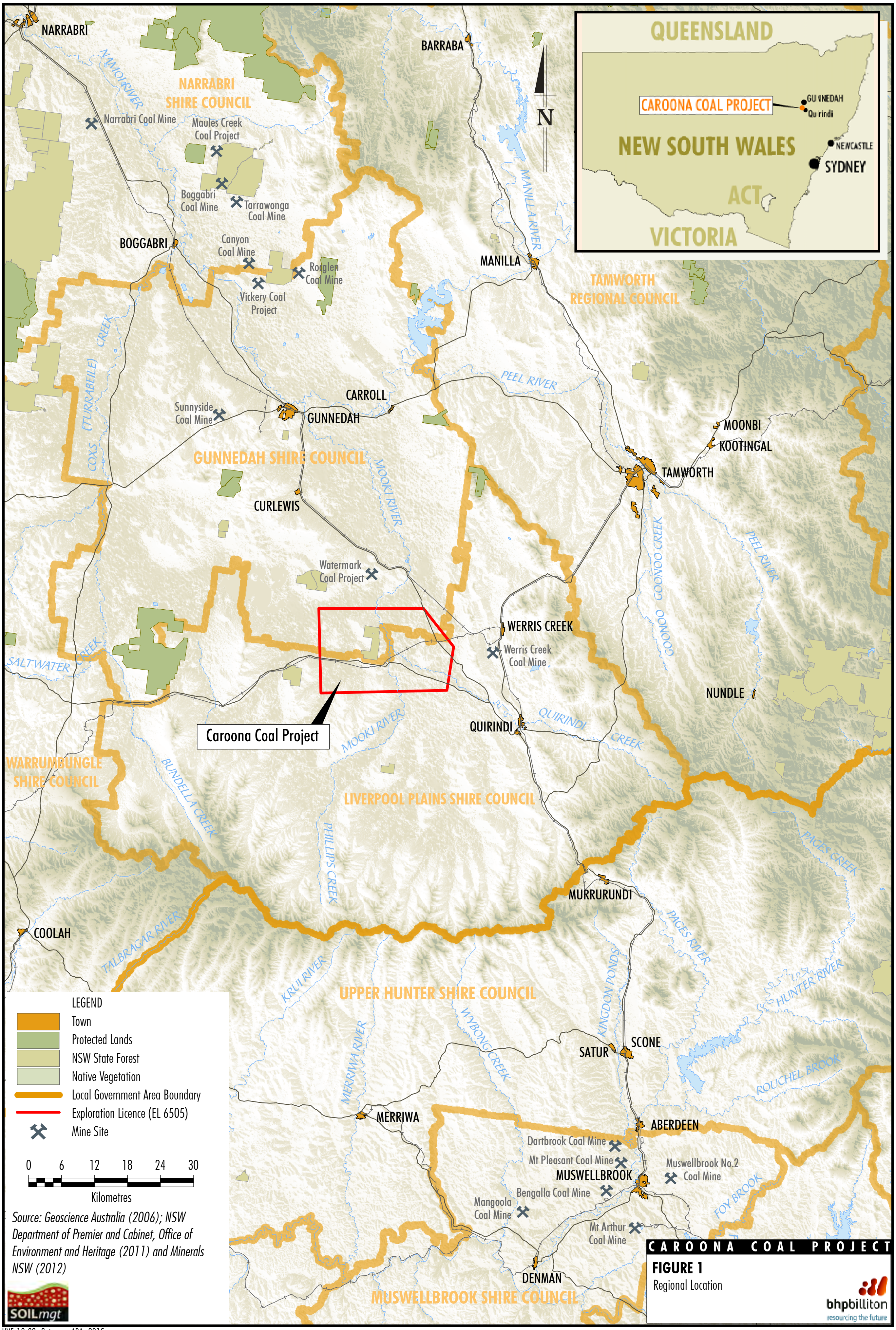
- Describe the agricultural resources (focusing on soil resources) of the lands within the Project Assessment Area.
- Identify areas of biophysical strategic agricultural land (BSAL) in accordance with the *Interim Protocol for Site Verification and Mapping of Biophysical Strategic Agricultural Land* (NSW Government 2013) (Interim Protocol).
- Assess the potential impacts on agricultural productivity (focusing on soil resources) as a result of the Project.
- Recommend management measures for soil resources.

2 PROJECT DESCRIPTION

2.1 Project Overview

Table 1 provides an overview of the activities associated with the Project. Additional details of the Project are provided in the Gateway Application Technical Overview Report. The main activities associated with the Project would include:

- an underground mining operation within EL 6505 involving a single longwall in the Hoskissons Seam on Doona Ridge and a second longwall in the Hoskissons Seam on Nicholas Ridge;
- production of approximately 260 million tonnes (Mt) of run-of-mine (ROM) coal over the life of the mine;
- production of up to approximately 10 million tonnes per annum (Mtpa) of saleable thermal coal;
- a mine life of approximately 30 years;
- development and operation of a pit top mine infrastructure area comprising administration offices, bathhouse, workshop, store, coal stockpile areas, coal handling infrastructure, bunded hydrocarbon tanks, laydown areas, car parking, electrical substation, muster area, associated linear infrastructure and access road on Doona Ridge;
- development and operation of a separate men and materials shaft on Doona Ridge;



CAROONA COAL PROJECT

FIGURE 1

Regional Location

HVE-13-02_Gateway_ARA_201C

0 1 2 3 4

Kilometres

GDA 94 MGA Zone 56

Source: Land and Property Management Authority - Topograpraphic Base 2010, Orthophoto (Curlewis 2011 & Tamworth 2010)

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LEGEND

- Exploration Licence (EL 6505)
- Project Assessment Area
- Soil Test Pit

CAROONA COAL PROJECT

FIGURE 2

Project Area and Surrounds and Soil Test Pit Locations

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HVE-13-02_Gateway_ARA_209C

Table 1. Overview of the Caroona Coal Project

Project Feature	Project
Mine Life	Operational life of approximately 30 years.
Mining Method and ROM Coal Production	Longwall mining in the Hoskissons Seam. Production of approximately 260 Mt of ROM coal over the life of the mine. Production of up to approximately 10 Mtpa of ROM thermal coal.
Mining Areas	Doona Ridge. Nicholas Ridge.
Mine Infrastructure Areas and Mine Access	Development and operation of a mine infrastructure area comprising administration offices, bathhouse, workshop, store, coal stockpile areas, bunded hydrocarbon tanks, laydown areas, car parking, electrical substation and associated linear infrastructure and access road on Doona Ridge. Development and operation of a men and materials shaft on southern Doona Ridge with access off 4D Road. Development and operation of a mine infrastructure area comprising coal stockpiles, bathhouse, car parking, administration offices, linear infrastructure and an access road on Nicholas Ridge. Road access to Doona Ridge off Rossmar Park Road and Nicholas Ridge off Waverley Road. Construction and operation of train load-out facilities including a rail spur and loop at Doona Ridge and Nicholas Ridge.
CPP and Transport Infrastructure	Construction and operation of coal handling infrastructure on Doona Ridge for sizing and handling of coal, incorporating an event coal preparation plant (CPP) (1 Mtpa ROM coal capacity) for washing of occasional high-ash ROM coal. Construction and operation of coal handling infrastructure on Nicholas Ridge for sizing and handling of coal. Development and operation of a rail spur and loop and coal loading infrastructure on both Doona Ridge and Nicholas Ridge to allow access to the Binnaway-Werris Creek Railway. Construction and operation of a coal unloading facility on Doona Ridge to allow the transportation of high-ash ROM coal from Nicholas Ridge to Doona Ridge for washing at the CPP. Co-disposal of fine and coarse rejects in an emplacement on Doona Ridge, with rejects to be transported within an infrastructure corridor.
Ventilation and Gas Drainage	Development of ventilation shafts on Doona Ridge and Nicholas Ridge and gas drainage infrastructure. Construction and operation of a connecting gas pipeline between Doona Ridge and Nicholas Ridge.
Water Management	Development of a water management system comprising of water storages, sumps, pumps, pipelines, sediment control, mine dewatering and sewage treatment. Development of a water management strategy based on a detailed site water balance which may include reuse of water on-site, storage of water on-site, licensed water extraction for water supply and/or treatment and beneficial use or controlled licensed release of excess water. Construction and operation of a connecting water pipeline between Doona Ridge and Nicholas Ridge.
Hours of Operation	24 hours per day, seven days per week including drift construction and development.
Operational Workforce	Up to approximately 400 personnel at peak production.
Power Supply	Construction and use of internal power reticulation infrastructure (substations and internal transmission lines) as required. Construction and operation of a 132 kV electricity transmission line from the Werris Creek substation to the Caroona Coal Project (subject to separate approvals).
Exploration	Ongoing exploration activities within EL 6505.
Monitoring of Subsidence Impacts	Monitoring of subsidence and subsidence impacts over the proposed underground mining and mine development areas.
Remediation and Rehabilitation Works	Progressive rehabilitation of surface disturbance areas (e.g. exploration drill pads). Ongoing remediation of subsidence effects. Rehabilitation of mine related infrastructure areas at the end of the Project life.
Construction Workforce	Average number of construction employees approximately 400 with up to 600 at peak construction.

- construction and operation of an event CPP (up to 1 Mtpa ROM coal capacity) on Doona Ridge for washing of occasional high-ash ROM coal;
- construction and operation of a coal unloading facility on Doona Ridge to allow transportation of Nicholas Ridge ROM coal to Doona Ridge via rail for washing;
- co-disposal of fine and coarse rejects in an emplacement on Doona Ridge, with rejects to be transported within an infrastructure corridor;
- development and operation of a separate pit top mine infrastructure area comprising coal handling infrastructure, coal stockpiles, an access road, car parking, administration offices, muster area, electrical substation and associated linear infrastructure on Nicholas Ridge;
- construction and operation of separate rail loops and spurs to connect to the Binnaway-Werris Creek Railway from Doona Ridge and Nicholas Ridge;
- realignment of Rossmar Park Road;
- employment of up to approximately 400 operational personnel at peak production;
- employment of an average number of construction employees of approximately 400 and up to 600 at peak construction;
- emplacement of overburden excavated during the construction of access drifts and shafts;
- progressive development of sumps, pumps, pipelines, water storages and other water management equipment and structures (including dewatering infrastructure);
- development and operation of ventilation surface infrastructure and gas drainage infrastructure;
- development and operation of water and gas pipelines to connect the Nicholas Ridge infrastructure area to the Doona Ridge infrastructure area;
- ongoing exploration activities within EL 6505;
- ongoing surface monitoring and rehabilitation (including rehabilitation of mine related infrastructure areas that are no longer required) and remediation of subsidence effects; and
- other associated minor infrastructure, plant, equipment and activities.

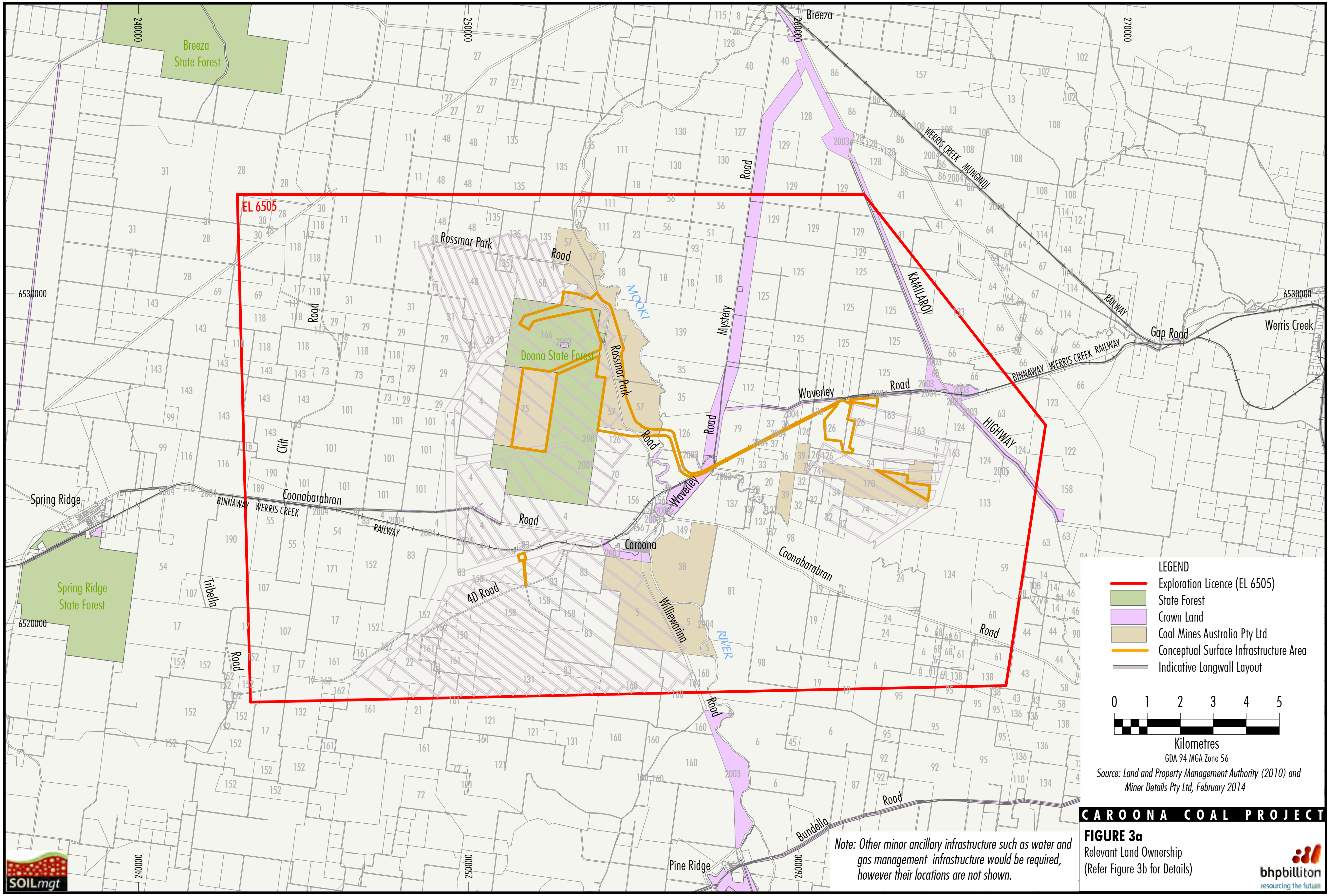
Current land ownership status is described in Figures 3a and 3b.

BHP Billiton's exploration program was undertaken from 2006 to 2012. Exploration activities included:

- drilling of 346 boreholes;
- airborne magnetometer survey;
- 2-Dimensional and 3-Dimensional seismic surveys; and
- ground magnetic surveys.

2.2 Geological Features

The Project is located within the Gunnedah Basin, which forms the central part of the Sydney-Gunnedah-Bowen Basin system (Department of Trade and Investment, Regional Infrastructure and Services – Division of Resources and Energy [DTIRS-DRE] 2014). Surface geology is shown on Figure 4.



HVE-13-02_Gateway_ARA_211E

Ref. No	Land Holder
1	AMPS Agribusiness Pty Limited
2	Alcorn LJ & MA
3	Alcorn ML
4	JBS Australia Pty Ltd
5	Coal Mines Australia Pty Ltd
6	Bailey TN
7	Cohen GJ & DF
8	Baker RE & BM
9	Shenhua Watermark Coal Pty Ltd
10	Shenhua Watermark Coal Pty Ltd
11	Birrawa Pastoral Company Pty Ltd
12	Bolger EP (Junior)
13	Bonner MLD
14	Boorer CJ
15	Shenhua Watermark Coal Pty Ltd
16	Shenhua Watermark Coal Pty Ltd
17	Brown GW & SL
18	Burt MC, WP & WA
19	Charters CR
20	Charters CR & SJ
21	Charters HF
22	Charters HF
23	Pursehouse Properties Pty Ltd
24	Clarmonds Pty Ltd
25	Shenhua Watermark Coal Pty Ltd
26	Clift DT
27	Clift G
28	Clift M
29	Clift M & KA
30	Clift RS
31	Clift RS & A
32	Cohen RG & TM
33	Cohen GJ
34	Cohen GJ & DF
35	Cohen GJ & DF
36	Cohen GJ & DF
37	Cohen GJ & DF
38	Coal Mines Australia Pty Ltd
39	Coal Mines Australia Pty Ltd
40	Craig ST, JW & NL
41	Craig WTA & P
42	Cudmore RH & SA
43	Dalton R
44	Dalton R & RT
45	Dangar WJ, FH, HC & AA
46	Doolan BV
48	CJ & PA Duddy Pty Ltd
49	Duddy C J
50	Duddy CJ
51	Burt MC & WA
52	Ranken JWL
53	Eleveld KF & GK
54	Elsley FE
55	Elsley FE & DE
56	Burt MC & WA
57	Coal Mines Australia Pty Ltd
58	Eykamp CD
59	Eykamp CW
60	Eykamp LA
61	Eykamp LA & JL
62	Fisher ME, GC & HR
63	Fisher GC
64	Fisher HR
65	Fisher ME & GC
66	Fisher ME, GC & HR
67	Fisher RC
68	Fletcher BI & VR
69	Frofour Pty Ltd
70	Fuller JW & RM
71	Fullers Transport Pty Ltd
72	G.S.S.H Pty Ltd
73	Carbon Minerals NL
74	Glencohen Pty Ltd
75	Coal Mines Australia Pty Ltd
76	SCMB Pty Ltd and BGI Pty Ltd
77	Green T
78	Green TD
79	Hamlin CR & VJ
80	Hamblin NJ
81	Hamblin RJ, FJ, PG & NJ
82	Graham JW, Smith MEL
83	Hanuta Pty Ltd
84	Hickman JM
85	Hickman SSM & Ross-Hickman DS
86	Holifall Pty Ltd
87	Hurley JK
88	Ingall IG,Lyttle KN,Cohen RJF,Squires JA,Bruce JHP,Hosking J
89	Church - Croaker, AMA; Croaker, GDH; and James, MJ Trustees
90	Jarret H & M
91	Shenhua Watermark Coal Pty Ltd
92	Karapiti Holdings Pty Ltd
93	Pursehouse Properties Pty Ltd
94	Lawlor MW & Gorsch JB
95	Lindenow Pastoral Company Pty Limited
96	Hollis M & V
97	Lingard TL
98	Bailey TN
99	Malden J
100	Maraig Pty Ltd
101	Maylan Pty Ltd
102	McBeth W & PE, & AJ
103	McIlrick TW & JA
104	Bradfield NG & MJ
105	Shenhua Watermark Coal Pty Ltd
106	Shenhua Watermark Coal Pty Ltd
107	Mills RA Estate:Perpetual Lease
108	Moore GN & JC
109	Munro NM
110	Murphy PJ & KN
111	Pursehouse Properties Pty Ltd
112	N.R.L.F Pty Ltd
113	AR Grant Estate Perpetual Lease
114	Newcombe IR
115	Nicholson RP
116	Nilwon Pastoral Co Pty Ltd
117	Norman CF
118	Norman GS
119	NSW Grain Corporation Ltd
120	Penick RE
121	Permaid Pty Ltd
122	Pike CT
123	Pike CT & VL
124	Pike MG & CT
125	Piper SL & MJ
126	Priestley JC & CL
127	Pursehouse AL
128	Pursehouse AL & CI
129	Pursehouse Investments Pty Ltd
130	Pursehouse Properties Pty Ltd
131	Rado Ranch Pty Limited
132	Ranken DCL,HRL & JWL
133	Rex Fisher Pty Ltd
134	RG & HD Thompson Pty Ltd
135	Rossmar Park Pastoral Co Pty Ltd
136	Rutter EO & SA
137	Rutter PR
138	Rutter RA & DA
139	Ryan WH & EC
140	Frankham DR & DW
141	Seymour MG & CL
142	Seymour MG & Lingard CL
143	Single Tree Pty Ltd
144	Small HR
145	Shenhua Watermark Coal Pty Ltd
146	Stackman BA & Lingard KL
147	Tandim Investments Pty Ltd
148	Taylor MG Estate
149	Todman, Anthony Reginald & Jennifer Ruth
150	Thyrek Pty Ltd
151	Shenhua Watermark Coal Pty Ltd
152	Tribella Pty Ltd
153	Trustees Of The Roman Catholic Church, Diocese of Armidale
154	Shenhua Watermark Coal Pty Ltd
155	Wadwell KG & SN
156	Walhallow Local Aboriginal Land Council
157	Walhallow Murri Enterprise Aboriginal Corporation
158	Wallalla Holdings Pty Limited
159	Warren CS
160	Williewarina Pty Ltd
161	Willis SNB & RNB
162	Willis SN & MJ
163	Wilson BM & E
164	The Peel-Cuningham County Council
166	Doona State Forest
170	Coal Mines Australia Pty Ltd
171	Elsley FE & DE
172	Willis
180	Shenhua Watermark Coal Pty Ltd
189	TS&CR 32492
190	Penunga Pty Ltd
2001	Doona State Forest
2003	State of NSW
2004	State Rail Authority
2005	The Council of The Shire of Tarmang
2006	The Minister for Public Roads

Source: Miner Details Pty Ltd (2014)

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CAROONA COAL PROJECT

FIGURE 3b

Relevant Land Ownership List
(as at 10 February 2014)

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The formations expressed at the surface within EL 6505 include Quaternary Alluvial Deposits (Qx), Jurassic Formations Pilliga Sandstone (JPS), Purlawaugh (Jpx) and Garrawilla Volcanics (Jgv), Middle Triassic Napperby Formation (Rns), Early Triassic Digby Formation (Rdc) and late Permian Coogal and Nea Sub Groups. The Hoskissons Seam is located within the Coogal Sub Group of the Black Jack Group and is the target seam for the Project.

2.3 Underground Mining Operations and Surface Infrastructure

Through focusing proposed underground mining operations under the Doona Ridge and Nicholas Ridge areas, and with the implementation of other mitigation measures, the Project has been designed to minimise impacts on the alluvial plains.

The Project would involve mining from a single coal seam (Hoskissons) on Doona Ridge and Nicholas Ridge using longwall mining methods for a period of approximately 30 years. The proposed underground mining layout is shown on Figure 5.

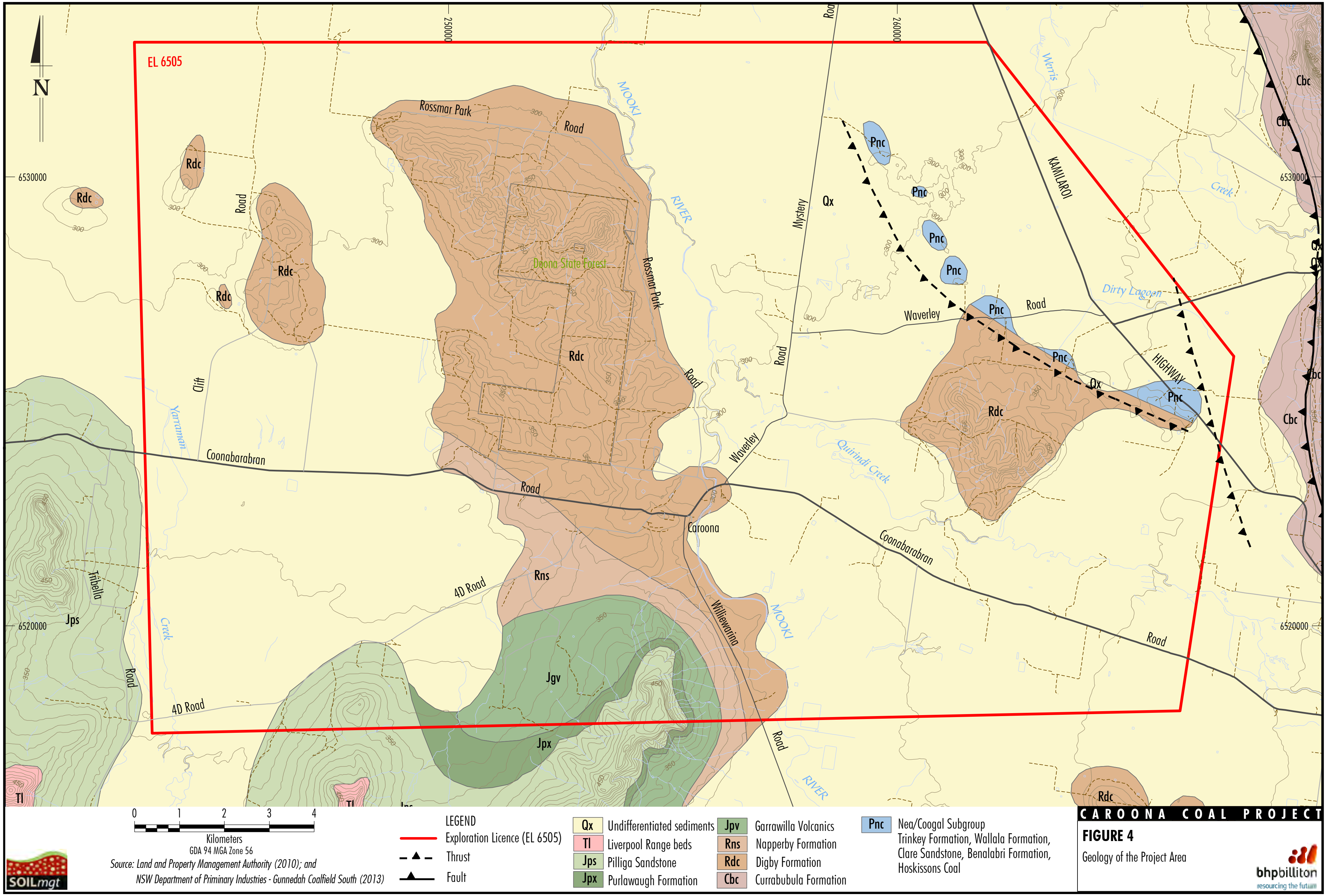
Longwall mining involves extraction of rectangular panels of coal defined by underground roadways constructed around each longwall. The longwall mining machine travels back and forth across the width of the coal face progressively removing coal in slices from the panel. Once each slice of coal is removed from the longwall face, the hydraulic roof supports are moved forward, allowing the roof and a section of the overlying strata to collapse behind the longwall machine (referred to as forming the 'goaf').

Extraction of coal by longwall mining methods results in the vertical and horizontal movement of the land surface. The land surface movements are referred to as subsidence effects.

Other associated infrastructure and activities which would require some surface disturbance include:

- men and materials access via transport drifts from the mine infrastructure areas at both Doona Ridge and Nicholas Ridge;
- personnel access via a separate men and materials shaft;
- materials handling and transport systems to convey coal from the longwall machine to the surface;
- ventilation systems for air intake and to exhaust air from the mining areas;
- a gas pipeline from Nicholas Ridge to Doona Ridge to allow the transfer of gas once Nicholas Ridge is operational;
- gas management systems to monitor and control the concentrations of mine gases; and
- various water management infrastructure.

The Project will also include ancillary mining activities such as ongoing exploration, monitoring, remediation of surface disturbance, and development of other associated minor infrastructure, plant, equipment and activities. The final location of surface infrastructure (where required) would be determined through detailed mine planning, environmental assessment outcomes and consideration of alternatives, and would be documented in the Project Environmental Impact Statement (EIS). The conceptual surface infrastructure area and rail infrastructure alignment are shown on Figure 5.



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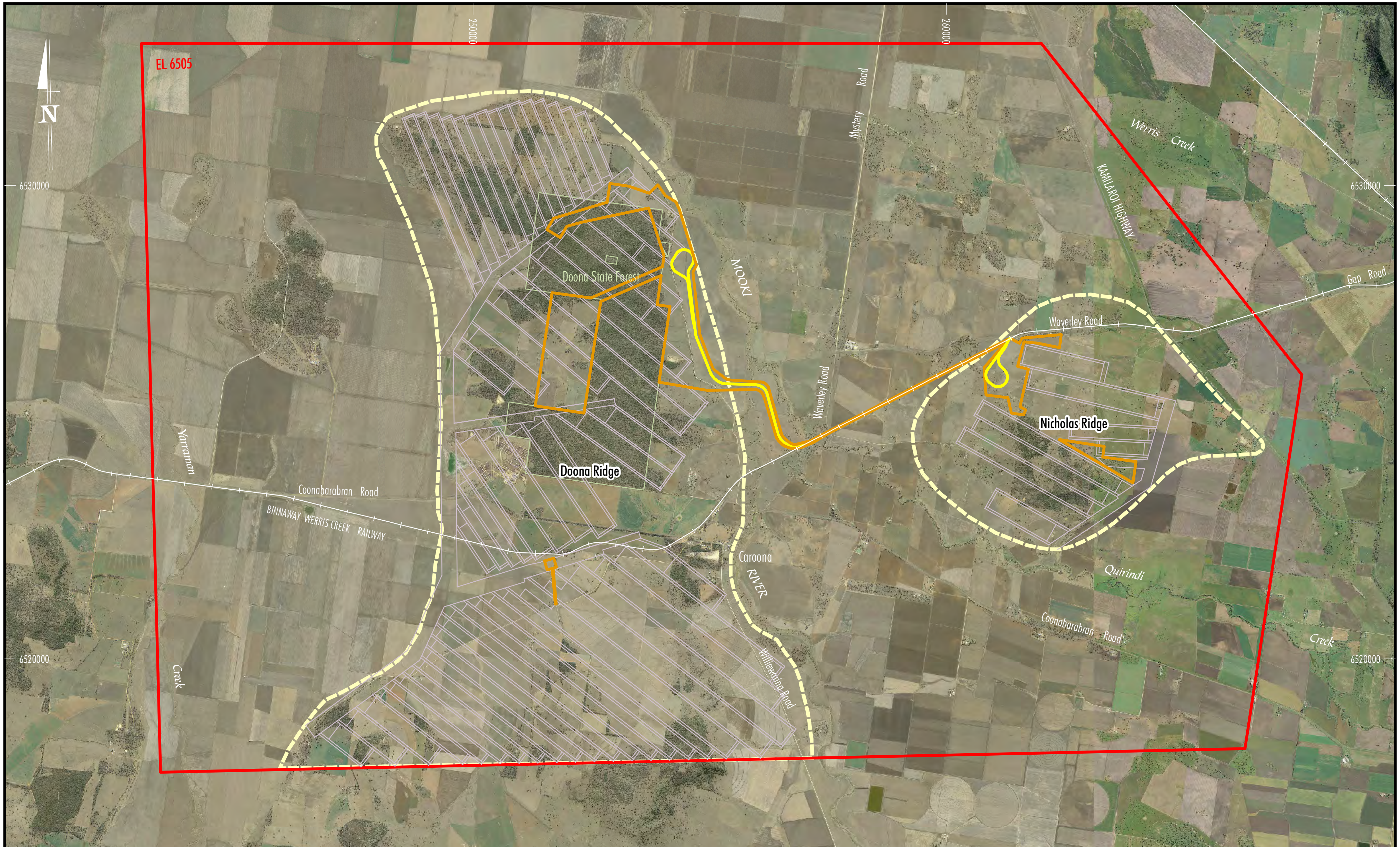

0 1 2 3 4

Kilometres

GDA 94 MGA Zone 56

Source: Land and Property Management Authority - Topographic Base 2010, Orthophoto (Curlewis 2011 & Tamworth 2010)

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LEGEND

- Exploration Licence (EL 6505)
- Project Assessment Area
- Conceptual Surface Infrastructure Area
- Conceptual Rail Infrastructure Alignment
- Indictative Underground Mining Layout

Note: Other minor ancillary infrastructure such as water and gas management infrastructure would be required, however their locations are not shown.

CAROONA COAL PROJECT

FIGURE 5

Indicative Mining Layout and Surface Infrastructure

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3 PROJECT SITE DESCRIPTION

The Project is located within the upper Namoi River catchment of the Murray-Darling Basin. The topography of EL 6505 is dominated by the north-south trending Doona Ridge (Figure 6). The northern end of the ridge is mainly under native vegetation (Doona State Forest), but south of the railway line most of the vegetation on the ridgeline has been cleared.

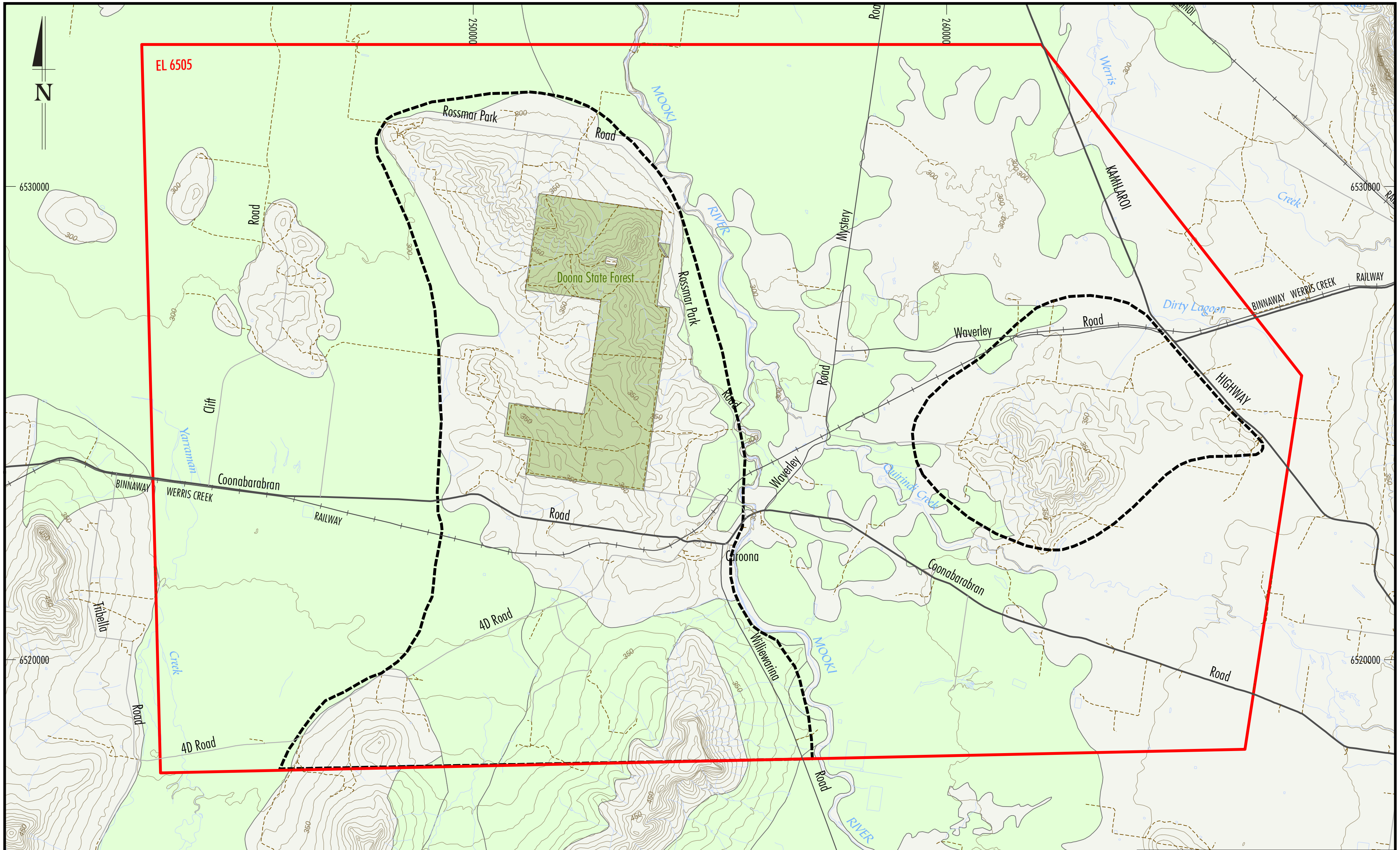
The north-flowing Mooki River is immediately to the east of Doona Ridge (Figure 6). A second prominent elevated area, Nicholas Ridge, lies to the east of the Mooki River. All of Nicholas Ridge and the northern end of Doona Ridge are surrounded by dark cracking clay soil (treeless plains) associated with flood plains of the Mooki River and its tributaries. Overflow from Lake Goran flows in an easterly direction into the Mooki River near the northern end of Doona Ridge via Native Dog Gully. Water from Yarraman Creek (located approximately along the western boundary of EL 6505), a disconnected ephemeral drainage line draining the elevated country to the southwest of the Project, also enters the Mooki River at this point. Quirindi Creek flows into the Mooki River around the southern end of Nicholas Ridge. The Mooki River joins the Namoi River near Gunnedah (Figure 1). A large proportion of runoff within the Project Assessment Area drains to the Mooki River via ephemeral drainage lines from Doona Ridge and Nicholas Ridge.

Elevations in EL 6505 range from approximately 300 metres (m) Australian Height Datum (AHD) on the floodplain to 486 m AHD on the southern end of Doona Ridge (Figure 6). The highest point on Nicholas Ridge is 411 m.

A Bureau of Meteorology monitoring station located in the Caroona Village recorded rainfall data from 1925 until closure of the recording station in 2007. The long-term mean annual rainfall for this station is 626 millimetres (mm), and with a range from lowest to highest of 278-1,005 mm (Bureau of Meteorology 2013). The nearby Pine Ridge recording station (10 km south-southeast of Caroona) is still operational with data recorded since 1886 showing the annual mean rainfall as 589 mm with a minimum-maximum range of 198-1,044 mm.

Cleared land within the Project Assessment Area is generally used for agricultural purposes. Beef cattle grazed on rain-fed pasture is the main agricultural activity. Annual crop production also is an important land use, although substantial areas of sloping cropping land (with contour banks for erosion control) have been converted to improved pasture. A prominent feature to the west-northwest of the Caroona Village is the large beef cattle feedlot operated by JBS Australia.

According to regional BSAL mapping presented in the *New England North West Strategic Regional Land Use Plan* (NSW Government 2012) much of the Project Assessment Area is considered to be BSAL (Figure 6), however, as described in Section 5, this assessment has verified that a large proportion of the regional BSAL mapping is incorrect.



0 1 2 3 4

Kilometers

GDA 94 MGA Zone 56

Source: Land and Property Management Authority (2010); and Office of Environment and Heritage (2014)

LEGEND

- Exploration Licence (EL 6505)
- Project Assessment Area
- State Forest
- New England North West SRLUP Potential BSAL

CAROONA COAL PROJECT

FIGURE 6

NSW Government Assessment of BSAL in the Vicinity of the Project

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4 SOIL RESOURCES

4.1 Review of Existing Information

The following existing information relevant to the Project area was reviewed for this agricultural resource assessment:

- Geology map (Department of Primary Industries, 2013).
- Soil Profile Attribute Data Environment (SPADE) soil profiles (part of the NSW Natural Resource Atlas).
- Soil type and landscape mapping: Soil Landscapes of the Curlewis 1:100,000 Sheet (Banks 1995). Soil Landscapes of the Tamworth 1:100,000 Sheet (Banks 2001).
- Soil and Land Resources of the Liverpool Plains Catchment DVD-R (NSW Office of Environment and Heritage [OEH] 2012a).
- Regional Inherent Soil Fertility mapping and Regional Land and Soil Capability (LSC) mapping prepared by OEH.
- BSAL mapping presented in the *New England North West Strategic Regional Land Use Plan* (NSW Government 2012).

A brief summary of relevant information from these reports is provided in the following sub-sections.

Parent Materials for Soil Formation

Rock types that are the parent material for soil formation in the Project area are shown in Figure 4. The dominant surface geological unit is Triassic conglomerate and sandstone (Digby Formation) beneath Nicholas Ridge and the northern end of Doona Ridge. It is overlaid, respectively, at the southern end of Doona Ridge by Jurassic basalt (Garrawilla Volcanics) and Jurassic sandstone (Pilliga Sandstone). Inputs of wind-blown dust over many centuries also would have contributed to soil forming processes.

Soil Types, Soil Landscapes, Inherent Soil Fertility and Land and Soil Capability

Appendix 1 shows the location of soil landscape units as mapped and described by Banks (1995, 2001) in the vicinity of the Project area. The soil types were described according to the superseded Great Soil Group system (Stace *et al.* 1968), and very little laboratory data was provided to give a detailed characterisation of soil fertility at key locations. Nevertheless, the descriptions of the soil landscape units (Appendix 2) gave a useful first approximation of land degradation status, soil conditions for plant growth and likely future hazards associated with land management in the area. Also, the geomorphic descriptions provided a useful starting point when describing the Soil Landscape Units in this study.

The 2013 NSW Government 'Australian Soil Classification' (ASC) Soil Type map (Appendix 3) gives an overview of the Banks (1995) information in a modern format. Vertosol is considered to be the dominant soil type in vicinity of the Project.

The regional 'Inherent Soil Fertility' and 'Land and Soil Capability' mapping prepared by OEH in the vicinity of the Project is presented, respectively, in Appendixes 4 and 5.

SPADE Soil Profile Database

A search of the NSW Government's Soil Profile Attribute Data Environment (SPADE) website (part of the NSW Natural Resource Atlas) was conducted to identify existing soil profile information in the Project area. Appendix 6 provides an overview of available information.

It should be noted that the soil sampling depths used in previous studies are not compatible with the Interim Protocol procedures used in this report. The main limitation, however, with existing soil data sets in the Caroona district is the very sparse coverage of soil characterisation sites used for soil landscape mapping, in conjunction with a lack of comprehensive laboratory testing of soil samples associated with the described soil profiles.

Strategic Agricultural Land

The *New England North West Strategic Regional Land Use Plan* (NSW Government 2012) includes regional mapping of Strategic Agricultural Lands. Strategic Agricultural Lands include BSAL and Critical Industry Clusters. BSAL is classified as land with reliable water supply of suitable quality, with a soil fertility of 'high' or 'moderately high' (Inherent General Fertility of NSW) and Class I, II or III LSC, or a soil fertility of 'moderate' and Class I or II LSC (NSW Government 2012). It is noted that no Critical Industry Clusters are located within the New England North West.

According to the regional mapping, 3,423 ha of BSAL is located within the Project Assessment Area. Of this, only a small amount of BSAL is shown in the vicinity of Doona State Forest, however, south of the Binnaway - Werris Creek railway line there is a considerable area of land classed as BSAL (Figure 6). Most of the alluvial plains are mapped as BSAL, despite the presence of severe subsoil salinity limitations noted by Banks (1995); for example, the 334 square kilometres (km^2) Yarraman Soil Landscape Grouping on the western side of Doona Ridge is noted by Banks (1995) as having '*extensive high saline watertables and associated extreme dryland salinity hazard*'. The issue of excessive drainage below the root zone, and subsequent dryland salinisation, as a result of replacement of perennial native vegetation with fallow-based annual cropping on the Liverpool Plains, has been the subject of several large research and development programs, e.g. Ringrose-Voase *et al.* (2003). Notes accompanying the Curlewis Soil Landscape Series Sheet (Banks 1995) suggest however that the severity of salinity problems in Alluvial Landscapes tends to diminish towards the northern reaches of the Mooki River floodplain. For example, the 74 km^2 Carroll Creek Soil Landscape Grouping only has '*localised dryland salinity hazard*'.

4.2 Soil Survey Methodology

A soil survey was conducted by McKenzie Soil Management in 2013 to characterize and assess the soils within the Project Assessment Area. This section provides a description of the soil survey methodology and outcomes.

The primary aim for the Gateway Application has been to identify BSAL within the Project Assessment Area. BSAL identification has been conducted in accordance with the Interim Protocol (as discussed in Section 5).

The following soil information is regarded by Ward (1998) as being important for soil assessment associated with mine site reclamation, and has been incorporated into the methodology for this assessment:

- Classification (structure, texture, etc.); allows existing data and experience on managing similar soils elsewhere to be applied.
- Dispersion index and particle size analysis; indicates soil structural stability and erodibility.

- pH; need to identify extreme ranges for treatment of lime or selection of suitable plant species.
- Electrical conductivity (EC); indicates soluble salt status.
- Macro- and micro-nutrients.

More specifically, Elliott and Reynolds (2007) suggest that the following soil factors need to be considered when assessing suitability of soil for mine site reclamation:

- Structure grade, which affects the ability of water and oxygen to enter soil.
- The ability of a soil to maintain structure grade following mechanical work associated with the extraction, transportation and spreading of topdressing material.
- The ability of soil peds to resist deflocculation when moist.
- Macrostructure; where soil peds are larger than 100 mm in the subsoil, they are likely to slake or be hard-setting and prone to surface sealing.
- Mottling; its presence may indicate reducing conditions and poor soil aeration.
- Texture; soil with textures equal to or coarser than sandy loam are considered unsuitable as topdressing materials because they are extremely erodible and have low water holding capacities.
- Material with a gravel and sand content greater than 60% is unsuitable.
- Saline material is unsuitable.

The introduction of the *New England North West Strategic Regional Land Use Plan* by the NSW Government in 2012, and subsequent amendments in 2013 now requires proponents of new mining and coal seam gas projects in NSW to consider the potential impacts of projects on agricultural resources up-front in the project assessment process. This involves describing existing soil profiles in a way that allows the productivity of crops, pasture and trees to be predicted accurately, as well as assisting with prediction of impacts of mining on agriculture, and provision of information about soil materials that will assist with any mine rehabilitation activities that are required.

Therefore, in addition to following the BSAL identification process described in the Interim Protocol, the soil survey methodology for intensive agricultural developments described by McKenzie *et al.* (2008) and McKenzie (2013) also has been taken into account when planning the soil assessment methodology for the Project. The combination of techniques from this variety of sources, and its compatibility with requirements of the Interim Protocol, is described in the following sections.

Field Survey

The soil survey was carried out by Dr David McKenzie and Dr Ian Hollingsworth. Both Dr McKenzie and Dr Hollingsworth have Certified Professional Soil Scientist Stage 3 accreditation (http://www.cpss.com.au/) from Soil Science Australia and PhDs in soil science. Dr McKenzie also has 'Chartered Scientist' accreditation with British Society of Soil Science.

A site inspection and soil survey was conducted as part of this Agricultural Resource Assessment. The field work was carried out between May and December 2013 (Table 2). The order in which test pits were surveyed was influenced mainly by timing of landholder access and weather conditions, with field work confined to the lighter textured ridge country following rainfall events.

Access was not available to conduct soil investigations for several parts of the Project Assessment Area between May and December 2013. BHP Billiton endeavours to gain access to these areas to conduct soil investigations, with the results of any additional work to be presented in the Agricultural Resource Assessment for the EIS.

Table 2. Details of Field Work Campaigns

Soil pits completed	Dates in 2013	Soil Scientists*	Area
1-58 (*field numbering*)	May	DMcK	Caroona Feedlot, Fuller Property
59-68	June	IH and DMcK	'Bonniedoon', 'Elong Elong'
69-114	June/July	IH	'Doonavale', 'Burwood', 'West Mooki'
115-178	July	DMcK	'Woodlands', 'The Ridge', 'The Hill', Doona State Forest
179-240	July/August	IH	Doona State Forest, 'Lynden'
241-246	August	DMcK	'Lynden'
247-298	September	IH	'Prarie Downs', 'Menindi', 'Lynden'
299-332	September/October	DMcK	4D Road, Rossmar Park Road
333-404	December	DMcK	'Colorado', 'Lanark', 'Williwarina'

* DMcK = Dr David McKenzie, IH = Dr Ian Hollingsworth

Four hundred and four backhoe pits (approx. 1.4 m deep; shallower where hard rock was encountered) were assessed for this report. The locations of the pits are shown on Figure 2 and Maps 1 to 14. The soil pits were located in a way that covered as many of the major variations in elevation and landforms as possible. The pits in the areas with slope <10% were on a flexible grid spacing of approximately 400 m (approximately 1 pit per 16 ha). This provided an intensity of sampling that satisfied the Interim Protocol (NSW Government 2013) nominated sampling density of 1 site per 5 – 25 ha for intensive mining developments (see Gallant *et al.* 2008).

More importantly, the pit spacing allowed an assessment of the size of an area of BSAL to determine whether it met the minimum area requirement of 20 ha, as described in the Interim Protocol:

- One pit on its own that satisfied Steps 1 to 12 of the BSAL criteria (Section 5) – represents approximately 16 ha, i.e. not above the BSAL threshold of 20 ha.
- Two pits together that satisfied Steps 1 to 12 of the BSAL criteria (Section 5) – represents approximately 30 ha, i.e. almost certainly above the BSAL threshold of 20 ha.

This meant that all of the <10% slope field sites with a soil depth >75 centimetres (cm) required laboratory analysis to determine whether or not each site actually had BSAL characteristics. Key soil factors such as salinity, sodicity and cation exchange capacity (CEC) cannot be measured or predicted accurately in the field.

In the steeper areas (>10%) where BSAL status can only be negative, a broader pit spacing of approximately 800 m was used.

The slope information used to assist with soil pit location is shown in Appendix 7. Slope was interpreted using detailed LiDAR data obtained by BHP Billiton.

Several representative pits in alluvial/colluvial areas also were sampled to a depth of 3 m and 2 m and 3 m samples were taken for testing. The main aim of this sampling was to test for the possible presence of permeable sand/gravel lenses beneath clay-rich soil profiles.

A Garmin '*GPSmap 62S*' instrument with an accuracy of about ±4 m was used to record the pit coordinates (Attachment A).

The field description methods were as described in the '*Australian Soil and Land Survey Field Handbook*' (National Committee on Soil and Terrain 2009) and the '*Guidelines for Surveying Soil and Land Resources, Chapter 29*' (McKenzie *et al*. 2008). The soil profiles have been classified (Appendix 8) according to the ASC (Isbell 2002).

Field Soil Observations/Testing

The 1.4 m deep backhoe excavated pit profiles were trimmed with a geological pick to allow high resolution photography and description of the undisturbed structure and root growth.

The following characteristics were assessed for the layers identified in each of the soil profiles:

- thickness of each layer (horizon);
- soil moisture status at the time of sampling;
- pH (using Raupach test kit);
- colour of moistened soil (using Munsell reference colours);
- pedality of the soil aggregates;
- amount and type of coarse fragments (gravel, rock, manganese oxide nodules);
- texture (proportions of sand, silt and clay), estimated by hand;
- presence/absence of free lime and gypsum;
- root frequency; and
- dispersibility and the degree of slaking in deionised water (after 10 minutes).

Site factors noted included current land use, landform, slope (measured with a SUUNTO clinometer), aspect, and surface rock. Outcropping bedrock and gilgai microrelief were always under consideration, but their occurrence was negligible in this study.

Field observations for each pit are presented in Attachments A, B and C.

The soil structure information (Attachment C) has been summarised to give SOILpak 'compaction severity' scores (McKenzie 2001). This allows deep tillage recommendations to be made from the structure observations. The score is on a scale of 0.0 to 2.0, with a score of 0.0 indicating very poor structure for crop root growth and water entry/storage. Ideally, the SOILpak score of the root zone should be in the range 1.5 to 2.0.

Hand texturing (National Committee on Soil and Terrain 2009) provides an approximation of the clay content of a soil. In conjunction with the estimation of coarse fragment (gravel) content, it provides a low-cost alternative to particle size analysis.

Total available water (TAW) for the upper 1 m of soil (Attachment A) has been estimated using texture, structural form and coarse fragment content data (McKenzie *et al*. 2008).

Laboratory Soil Testing

All of the pits on land <10% slope and >75 cm soil depth were sampled for laboratory analysis. The sampling intervals for laboratory analysis were as per the Interim Protocol, i.e. 0 to 5 cm; 5 to 15 cm, 15 to 30 cm; 30 to 60 cm and 60 to 100 cm. Where important horizon boundaries did not coincide with these depth intervals, extra samples were taken to ensure that distinctive horizons (e.g. A2 horizons) were kept separate for analysis.

Where extra pits were dug to a depth of 3 m, 2 m and 3 m soil samples were also analysed.

The soil was analysed by Incitec-Pivot Laboratory, Werribee Victoria for exchangeable cations, pH, EC, chlorides, nutrient status (nitrate-nitrogen, phosphorus, sulfur, zinc, copper, boron) and organic matter content (Attachment D). An ammonium acetate method was used for the extraction of exchangeable cations. The CEC values are the sum of exchangeable sodium, potassium, calcium, magnesium and aluminium; exchangeable sodium data are presented as exchangeable sodium percentage (ESP). Phosphorus was determined using the Colwell method, sulphur by the CPC method, boron by a calcium chloride ($CaCl_2$ extraction) and zinc/copper by a DTPA extraction (see Rayment and Lyons [2011] for further details). These methods are compatible with the key components of the Interim Protocol.

Soil dispersibility, as measured by the Aggregate Stability in Water (ASWAT) test (Field *et al.* 1997), was assessed by McKenzie Soil Management in Orange, NSW. The results are presented in Attachment D. The ASWAT test has been related to the well-known Emerson aggregate stability test by Hazelton and Murphy (2007) – see Table 3. An advantage of the ASWAT test is that the results can be linked with management issues such as the need for gypsum application and avoidance of wet working (McKenzie 2013) (Figure 7). The conversion factors of Slavich and Petterson (1993) allowed the electrical conductivity of saturated paste extracts (EC_e) to be calculated from the EC of 1:5 soil:water suspensions ($EC_{1:5}$) and texture.

Table 3. The Relationship Between the Emerson Aggregate Stability Test and the ASWAT Test

Dispersibility	**Emerson Aggregate Classes**	**Probable score for the ASWAT test (Field *et al.* 1997)**
Very high	1 and 2(3)	12-16
High	2(2)	10-12
High to moderate	2(1)	9-10
Moderate	3(4) and 3(3)	5-8
Slight	3(2), 3(1) and 5	0-4
Negligible/aggregated	4, 6, 7, 8	0

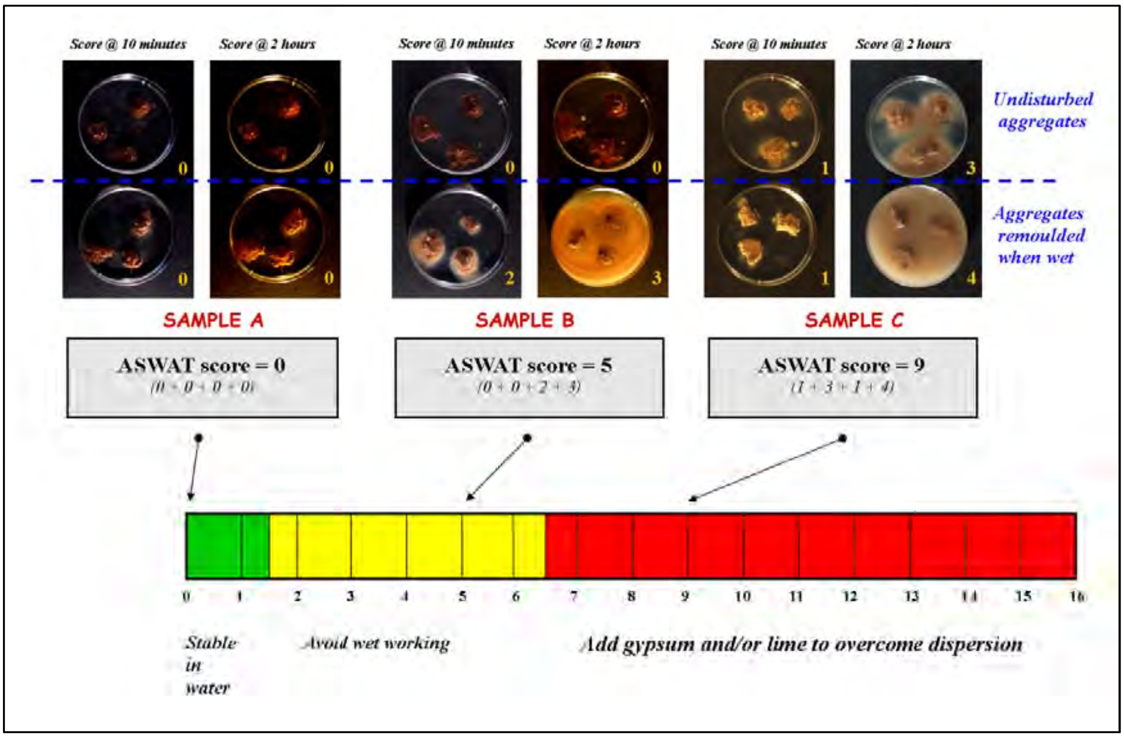


Figure 7. The Link between ASWAT Results and Soil Management Options

As part of the Agricultural Resource Assessment for the EIS, calibration samples from selected field survey sites will be analysed by NSW Soil Conservation Service Laboratory for the following soil properties which are part of the 'Erosion and Sediment Control' package:

- Dispersion percentage.
- Emerson Aggregate Stability Test.
- Organic carbon.
- Particle size analysis.
- Particle size analysis – mechanical dispersion.
- Soil erodibility factor (K factor).

The following key soil factors are attached in the form of colour coded maps:

Map 1. Pit positions in relation to BSAL slope categories.
Map 2. Soil types (ASC).
Map 3. Depth to rock.
Map 4. Plant available water (TAW).
Map 5. Depth of mottled layer.
Map 6. Depth to layer with lime.
Map 7. Dispersion (ASWAT scores).
Map 8. Dispersion (ESP values).
Map 9. Compaction severity (SOILpak score).
Map 10. Cation Exchange Capacity (CEC).
Map 11. Salinity (electrical conductivity [ECe]).
Map 12. pH ($CaCl_2$).

Map 13. Phosphorus (Colwell P).

Map 14. Organic carbon (%).

4.3 Soil Types and Mapping

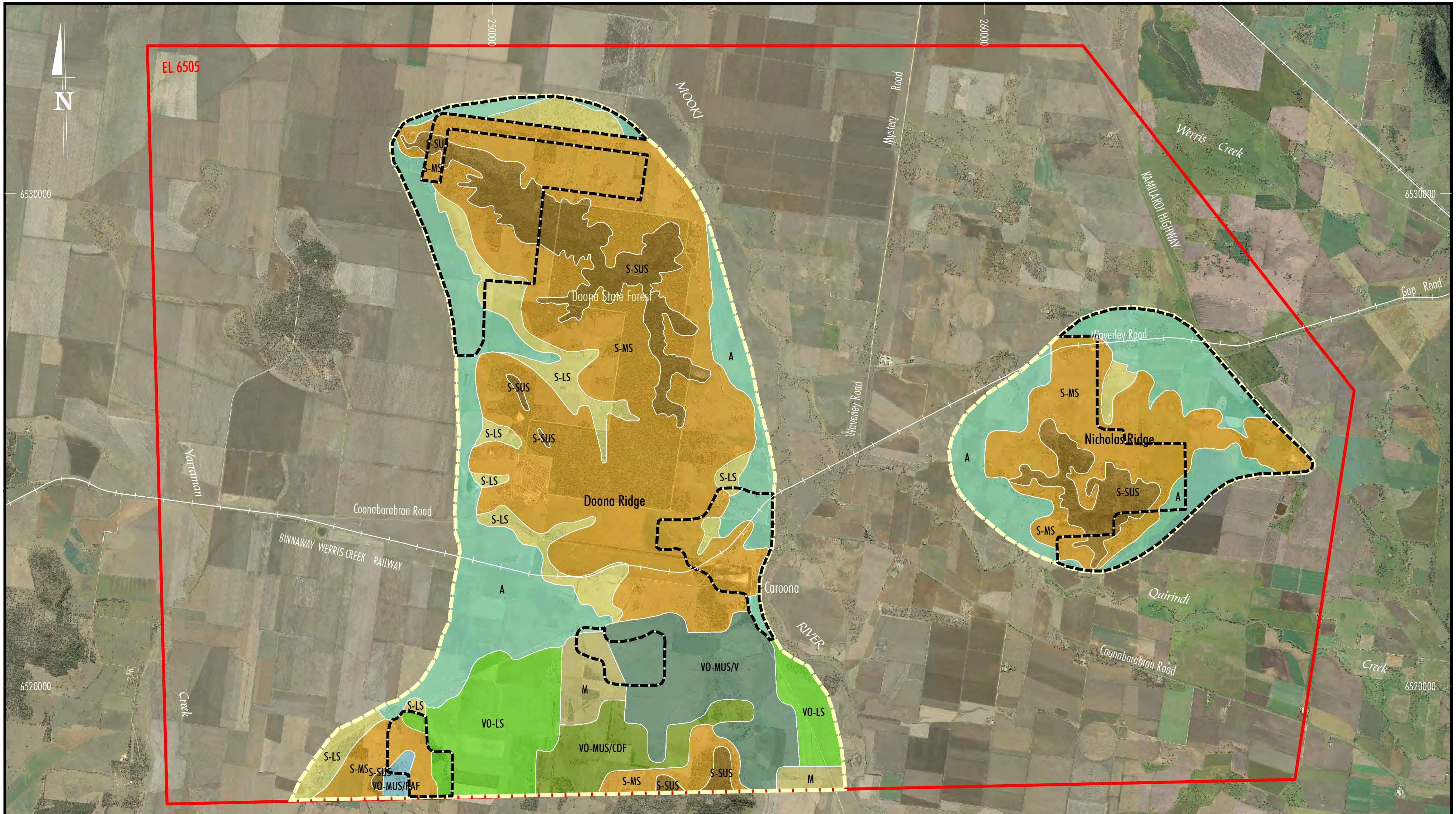
Soil Landscape Units

Soil Landscape Units within the Project Assessment Area that host the soil types described in the next section are described in Table 4 and presented in Figure 8. The Soil Landscape Unit is an association of soils described and delineated by means of landforms (Dent and Young 1981).

Table 4. Soil Types Associated with the Nine Soil Landscape Units Identified in the Project Assessment Area

Soil Landscape Unit	Number of sites	Map code	Dominant soil types	Sub-dominant soil types	Additional comments
Alluvial[1]	90 sites	A	Black Vertosol, other Vertosols	Chromosol	Subsoil saline/ alkaline/sodic
Volcanic Parent Material (PM): Transferral[1] Zone/Lower Slope	37 sites	VO-LS	Black Vertosol	Vertosol, Chromosol	Subsoil relatively free of subsoil constraints
Volcanic PM: Mid/Upper Slope (Vertosols)	39 sites	VO-MUS/V	Black Vertosol, other Vertosols	Dermosol	Subsoil relatively free of subsoil constraints
Volcanic PM: Mid/Upper Slope (Chromosols, Dermosols, Ferrosols)	17 sites	VO-MUS/CDF	Chromosol	Dermosol, Ferrosol	Subsoil relatively free of subsoil constraints
Volcanic PM: Ridge (Acidic Ferrosol)	1 site	VO-MUS/RAF	Ferrosol	-	Strongly acidic subsoil
Sedimentary PM: Steep Upper Slope	16 sites	S-SUS	Dermosol	Chromosol, Tenosol, Vertosol, Kandosol, Kurosol	Shallow soil; slope >10%
Sedimentary PM: Mid Slope	165 sites	S-MS	Chromosol, Dermosol	Rudosol, Tenosol, Kandosol, Sodosol, Vertosol, Kurosol	Soil Landscape Unit with the greatest number of sampling sites
Sedimentary PM: Lower Slope	29 sites	S-LS	Chromosol	Vertosol, Dermosol, Rudosol, Black Vertosol, Sodosol, Kandosol, Kurosol	-
Mixed Origin Transferral[1] Zone	10 sites	M	Rudosol, Chromosol, Dermosol	Vertosol, Ferrosol, Calcarosol	-

[1] Definitions of 'Alluvial' and 'Transferral' landscapes are presented in Appendix 2.



0 1 2 3 4

Kilometres

GDA 94 MGA Zone 56

Source: Land and Property Management Authority - Topograpraphic Base 2010, Orthophoto (Curlewis 2011 & Tamworth 2010) and Office of Environment and Heritage (OEH), 2013

SOILmgt

LEGEND

- Exploration Licence (EL 6505)
- Project Assessment Area
- Soil Landscape Units Interpreted Using Destop Methods

- Alluvial (A)

Volcanic Parent Material

- Transferral Zone/Lower Slope (VO-LS)
- Mid/Upper Slope (Vertosols) (VO-MUS/V)
- Mid/Upper Slope (Chromosols, Dermosols, Ferrosols) (VO-MUS/CDF)
- Ridge Acidic Ferrosol (VO-MUS/RAF)

Sedimentary Parent Material

- Steep Upper Slope (S-SUS)
- Mid Slope (S-MS)
- Lower Slope (S-LS)

Sedimentary /Volcanic Parent Material

- Mixed Origin Transferral Zone (M)

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FIGURE 8

Project Soil Landscape Units

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ASC Soil Types

The ASC (Isbell 2002) has been used to determine soil types at each of the 404 pits (Map 2). Photographs of representative soil profiles identified during the survey are presented in Figures 9 and 10 (for each Soil Landscape Unit and ASC soil type described below). All of the sites have three to four photographs to record the following: a) Landscape view, b) Trimmed soil profile, c) Neatness of rehabilitation of the pit site following infilling, and d) Close-up view of soil surface and associated vegetation where required.

This comprehensive collection of photographs is provided in Attachment E.

Total numbers of the contrasting ASC soil types, and the equivalent Great Soil Group terminologies, are shown in Table 5.

Table 5. Soil Types Identified; Classified According to the ASC and Great Soil Groups

ASC Soil Type	Number of Sites	Great Soil Group Equivalent
Chromosol	93	Red-brown Earths, Non-calcic brown soils
Black Vertosol	93	Black Earths
Vertosol	83	Grey, Brown and Red Clays
Dermosol	73	Chocolate Soils, Red Podzolics
Rudosol	20	Alluvial Soils
Tenosol	14	Lithosols
Kandosol	10	Calcareous red earths
Sodosol	7	Solodic Soils
Kurosol	7	Podzolic soils and Soloths
Ferrosol	3	Kraznozems, Euchrozems
Calcarosol	1	Solonised Brown Soil

The soil types in Table 5 have the following characteristics:

- Vertosols are shrink-swell soils with a clay-field texture containing 35% or more clay; when dry they often crack to considerable depth (McKenzie *et al*. 2004).
- Chromosols have strong texture contrast (Isbell 2002) between the A and B horizons, and a non-sodic subsoil with pH_{water} greater than 5.5.
- Dermosols lack a strong texture contrast between the A and B horizons and have moderately to strongly structured B2 horizons.
- Rudosols are derived from recently deposited materials that have only minimal profile development.
- Tenosols at this location are shallow and have only weak pedological development.
- Kandosols lack strong textural contrast and have a massive or only weakly structured B horizon.
- Sodosols have strong texture contrast between topsoil and subsoil, and the B horizon is sodic (ESP of 6 or greater).
- Kurosols have strong texture contrast between topsoil and subsoil, and the B horizon is strongly acidic (pH_{water} less than 5.5).
- Ferrosols lack strong texture contrast between A and B horizons and have B2 horizons which are high in free iron oxide (and, for the purpose of this report, having subplastic field textures).
- Calcarosols lack strong texture contrast between A and B horizons and are dominated throughout profiles by the presence of calcium carbonate.

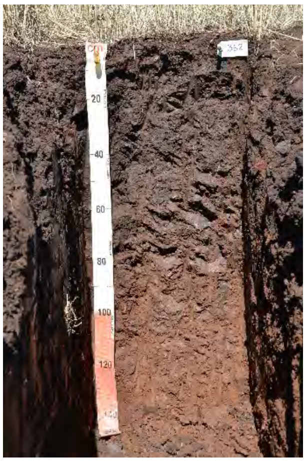
Soil Landscape Unit (Table 4)	**Soil Profile Photographs (Dominant ASC Profiles)**		
Alluvial (A)	 114 (C312): Vertosol	 Pit 168 (C51): Black Vertosol	
Volcanic: PM: Transferral Zone/Lower Slope (VO-LS)	 296 (C362): Black Vertosol		
Volcanic PM: Mid/Upper Slope (Vertosols) (VO-MUS/V)	 225 (C192): Black Vertosol	 325 (C238) Vertosol	

Figure 9. Photographs of Soil Types – Dominant ASC Orders

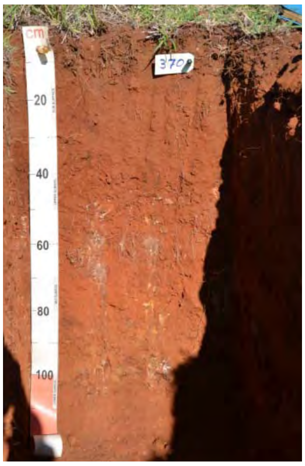
Soil Landscape Unit (Table 4)	Soil Profile Photographs (Dominant ASC Profiles)		
Volcanic PM: Mid/Upper Slope (Chromosols, Dermosols, Ferrosols) (VO-MUS/CDF)	 323 (C236) Chromosol		
Volcanic PM: Ridge Acidic Ferrosol (VO-MUS/RAF)	 336 (C370) Ferrosol		
Sedimentary PM: Steep Upper Slope (S-SUS)	 40 (C186) Dermosol		

Figure 9. Photographs of Soil Types – Dominant ASC Orders (continued)

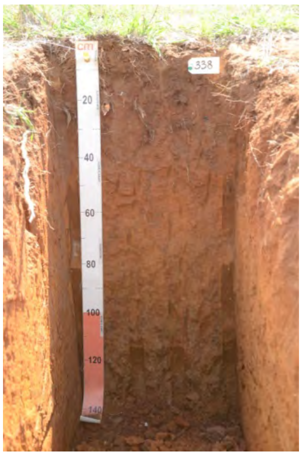
Soil Landscape Unit (Table 4)	Soil Profile Photographs (Dominant ASC Profiles)		
Sedimentary PM: Mid Slope (S-MS)	 94 (C101) Chromosol	 176 (C12) Dermosol	
Sedimentary PM: Lower Slope (S-LS)	 211 (C220)Chromosol		
Mixed Origin Transferral Zone (M)	 352 (C403) Rudosol	 281 (C338) Chromosol	 244 (C386) Dermosol

Figure 9. Photographs of Soil Types – Dominant ASC Orders (continued)

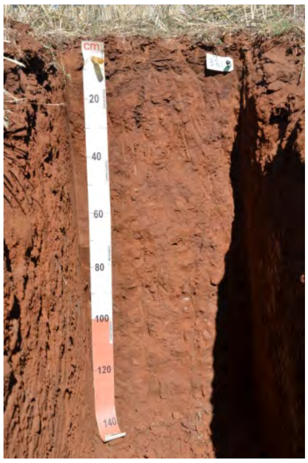
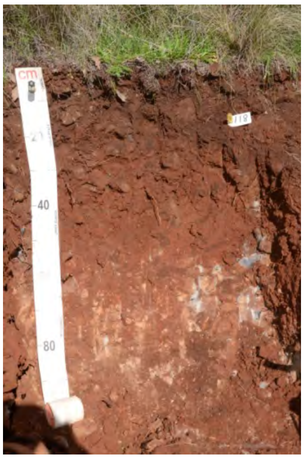
Soil Landscape Unit (Table 4)	Soil Profile Photographs (Sub-Dominant ASC Profiles)		
Alluvial (A)	 69 (C308): Chromosol		
Volcanic: PM: Transferral Zone/Lower Slope (VO-LS)	 261 (C347) Vertosol	 295 (C361) Chromosol	
Volcanic PM: Mid/Upper Slope (Vertosols) (VO-MUS/V)	 248 (C118) Dermosol		

Figure 10. Photographs of Soil Types – Sub-Dominant ASC Orders

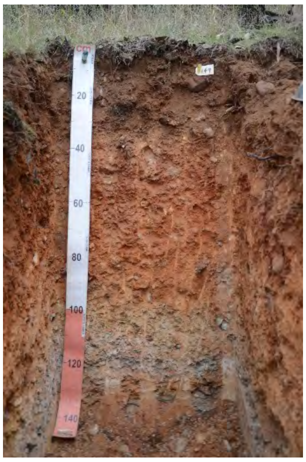
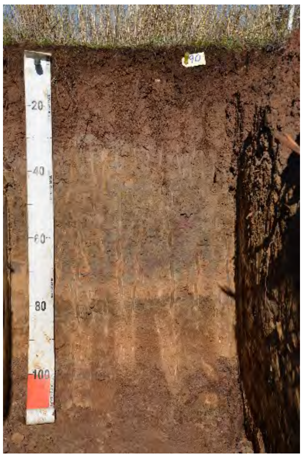
Soil Landscape Unit (Table 4)	Soil Profile Photographs (Sub-Dominant ASC Profiles)		
Volcanic PM: Mid/Upper Slope (Chromosols, Dermosols, Ferrosols) (VO-MUS/CDF)	 343 (C354) Dermosol	 288 (C116) Ferrosol	
Sedimentary PM: Steep Upper Slope (S-SUS)	 97 (C170) Tenosol	 81 (C66) Kandosol	 403 (C149) Kurosol
Sedimentary PM: Mid Slope (S-MS)	 6 (C327) Rudosol	 131 (C158) Tenosol	 65 (C90) Sodosol

Figure 10. Photographs of Soil Types – Sub-Dominant ASC Orders (continued)

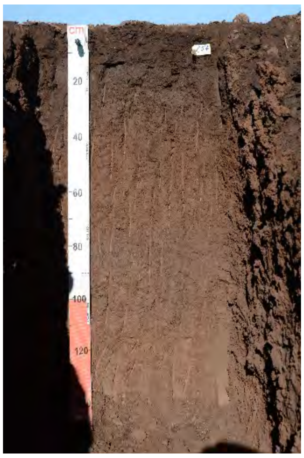
Soil Landscape Unit (Table 4)	Soil Profile Photographs (Sub-Dominant ASC Profiles)		
Sedimentary PM: Lower Slope (S-LS)	 159 (C54) Vertosol	 148 (C48) Rudosol	 95 (C103) Kandosol
Mixed Origin Transferral Zone (M)	 262 (C385) Calcarosol		

Figure 10. Photographs of Soil Types – Sub-Dominant ASC Orders (continued)

4.4 Soil Conditions for Plant Growth

Soil Depth, Texture and Waterholding Capacity

As soil becomes shallower, stonier and/or sandier, its ability to store water declines (White 2006).

The shallowest soil in the Project Assessment Area was mainly along and adjacent to the Doona and Nicholas Ridge lines (Map 3). The impact of profile shallowness/stoniness and sandiness on the ability of the soil to store plant available water (measured as TAW) is shown in Attachment A and on Map 4.

Plants are more likely to suffer drought stress where soil has a poor water storage capacity, particularly in hot weather with extended dry periods between rainfall events. At the Project area, the lack of water holding capacity in shallow/stony soils is a significant constraint to agricultural productivity.

The deeper soil tended to have very good water holding capacity because of a combination of moderate clay content, minimal coarse fragments and favourable soil structure. However, where soil profiles are saline, plants with a poor tolerance of salinity will only be able to extract a small proportion of the soil water because of adverse osmotic potentials at the soil-root interface.

Waterlogging Hazard

When soil is waterlogged, several adverse processes take place (Batey 1988):

- The lack of oxygen reduces the ability of plant roots to function properly.
- Anaerobic conditions can cause large losses of soil nitrogen to the atmosphere.
- Near-surface waterlogging is associated with inefficient storage of water due to excessive evaporation losses.

An indicator of waterlogging in the field is the presence of mottling (Map 5). Mottles are blotches of sub-dominant colours different from the matrix colour; for example, grey or yellow blotches within a reddish-brown subsoil. The impedance of internal drainage that creates mottling is usually caused either by impermeable rock close to the surface or dispersive subsoil. Mottling often is associated with the presence of black manganiferous nodules or concretions. Evidence of severe subsoil mottling was more evident on the sedimentary parent material than in the volcanic zone in the south of Doona Ridge (Map 5).

The widespread subsoil salinity (see below) has helped to flocculate the subsoil and maintain profile internal drainage, even though large amounts of naturally occurring lime in the subsoil (Map 6) indicated that there have not been large amounts of water flushing through the soil profiles.

Soil Stability in Water – Dispersion and Slaking

Dispersion is the separation of soil micro-aggregates into sand, silt and clay particles, which tend to block soil pores and create problems with poor aeration (Levy 2000). Excessive hardness then becomes a problem when the soil is dry. Dispersion is a process with the potential to reduce root growth and adversely affect profitability of most crop and pasture enterprises.

Dispersion may be associated with slaking, which is the collapse of soil aggregates to form micro-aggregates under moist conditions (So and Aylmore 1995). Slaking is associated with a lack of organic matter, which is important for the binding of soil micro-aggregates.

Soil prone to slaking, and particularly dispersion, is much more likely to be lost by water erosion than stable soil. This is because the soil tends to seal over under moist conditions and lose water as runoff, rather than taking in the water for storage in the subsoil (So and Aylmore 1995).

Two maps relating to soil stability in water are presented (Maps 7 and 8). The ASWAT score (Map 7) shows how prone the soil is to dispersion under conditions that existed when the soil was sampled (Field *et al*. 1997). The 'working when wet' procedure that is part of the ASWAT test is a simulation of processes such as raindrop impact on wet soil and the cutting/stockpiling of moist soil. Dispersion was evident in the sub-surface (15-30 cm) across much of the site (Map 7). The dispersion problems can be overcome in a cost-effective manner through gypsum application. However, elevated sodicity in the subsoil of some of the alluvial soil tended not to lead to dispersion because of the high salt concentrations – discussed further below.

The main chemical factor influencing the behaviour of clay particles in unstable soils upslope from the alluvial plains is moderate amounts of ESP (Map 8), aggravated by low electrolyte concentrations (Levy 2000). On red soil derived from volcanic parent material, stability in water is enhanced by the presence of iron oxides.

Compaction Status

Compaction can strongly restrict plant growth because of poor water entry, poor efficiency of water storage, waterlogging when moist, and poor access to nutrients by plant roots (McKenzie 1998).

Compaction was assessed in this study using the SOILpak scoring system (Map 9). It was not a serious problem on most of the Vertosols where structural regeneration through natural processes (see next section) has helped to alleviate previous compaction problems. However, much of the non-shrinking volcanic soil had compaction problems, caused apparently by farm machinery and grazing by livestock when the soil was too moist to prevent deformation.

Structure Self-repair Ability

The ability of a soil to overcome compaction through shrinking and swelling induced by wet-dry cycles (soil structural resilience) can be estimated via CEC values (Map 10) (McKenzie 1998). The Vertosols in this study had topsoil with favourable self-repair capacity via shrink-swell processes.

Salt Concentrations

Subsoil salinity was a major constraint across the alluvial sections of the Project Assessment Area (Map 11). High subsoil salinity reduces the ability of many plant species to absorb water from the soil. However, some plant species are adversely affected much less than others, so they should be selected by farm managers in this area, e.g. when new pastures are being established. It is not practical to reduce the subsoil salt loads through increased leaching – the salty deep drainage water has nowhere to go on the alluvial plains which already have shallow saline watertables.

Boron toxicity is an associated issue for some of the alluvial plain soils. Mean boron concentration for all of the 60-100 cm soil samples from the Project Assessment Area was 2.78 mg/kg, with a range from 0.15 – 16.0 mg/kg. Boron concentrations greater than about 5 mg/kg are likely to be undesirable for crops with a poor tolerance of boron toxicity.

pH Imbalance

Topsoil acidity was noted (Map 12), particularly along the ridge lines. However, pH tended to increase rapidly with depth and many of the soils had excessively high pH in the subsoil. Serious alkalinity (pH > 8.1; see Map 12) is likely to be associated with undesirable bicarbonate salts. Very high pH values are likely to adversely affect nutrient uptake by plant roots.

Nutrients

The topsoil and subsoil was deficient (from an agricultural point of view) in phosphorus in southern sections of Doona Ridge, and the central and eastern parts of Nicholas Ridge (Map 13). However, central parts of Doona Ridge showed evidence of phosphorus application in excess of crop requirements. This appears to be a consequence of large amounts of phosphorus-rich manure being applied to the land.

As the sum of exchangeable cations (an approximation of CEC) increases, the ability of soil to hold cation nutrients such as calcium, magnesium and potassium becomes greater (White 2006). High CEC values (Map 10) therefore are favourable from a nutritional perspective in the zones with clay-rich soil.

Soil Carbon and Soil Biological Health

The relatively high organic carbon concentrations in much of the topsoil (0-5 cm and 5-15 cm) (Map 14) provide beneficial soil organisms with a ready supply of food.

4.5 Inherent Soil Fertility

The alluvial plain Vertosols have an excellent ability to regenerate structure through shrink-swell processes, a relatively high nutrient holding capacity, and very good water holding capacity. However the growth of salt sensitive plant species in this soil type can be very poor if weather conditions are dry and the plants attempt to grow roots deeply into toxic saline/boric layers in search of moisture. Elevated pH is an associated problem that can restrict plant growth through its adverse impact on nutrient availability. Dispersion problems (associated with soil sodicity) which are masked by elevated salinity can create waterlogging problems if the soluble salts are leached from the soil profile.

Vertosols on land above the Alluvial areas within the Project Assessment Area, however, have all the benefits listed in the previous paragraph, but mostly are not constrained by salinity and high pH.

The Chromosols, Dermosols and Ferrosols derived from basic volcanic parent material mostly have excellent waterholding capacity, favourable internal drainage and neutral pH profiles. However, many of these profiles have constrained agricultural productivity because of compaction problems. Compaction fortunately is a soil problem that easily be overcome through mechanical deep loosening.

Many soil profiles in the Project Assessment Area have excessive chemical fertility, i.e. high phosphorus levels probably associated with large applications of manure. Further manure application to these areas should be avoided – instead it could be transported further afield to improve soil in the region that has a phosphorus deficiency.

This report describes the physical and chemical fertility of topsoil and subsoil in far more detail than previous soil studies (both public and private) in the vicinity of the Project. The comprehensive analysis within this report will allow appropriate rehabilitation and management measures to be developed and implemented for the Project. This will allow for maintenance or enhancement of the productivity and sustainability of topsoil and subsoil in the vicinity of the Project.

Technologies exist to overcome the existing topsoil and subsoil constraints identified in this study through improved soil/agronomic management, and better matching of plant tolerances with subsoil conditions. A consequence of this approach is likely to be improved water use efficiency. Better water uptake by pasture, crops and trees means less deep drainage of high quality water into the alluvial zone subsoil where it can become unavailable for most plants because of mixing with the existing highly saline water-tables close to the surface.