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Soil Report:
'Dunedoo Solar Farm' Site

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EXECUTIVE SUMMARY

A soil survey was carried out for 'ib vogt GmbH' in March 2018 at the site of a proposed Solar Farm approximately 2 km north of Dunedoo NSW. The 'area of interest' covers approximately 80 ha.

A soil type map based on 4 soil pit descriptions has been prepared. Approximately 30% of the study area (25 ha) was found to have high quality Black Vertosol soil with 'biophysical strategic agricultural land' (BSAL) qualities. Poorly drained Grey and Brown Vertosols cover approximately 17 ha. Brown Chromosols (light textured topsoil overlying poorly drained clay-rich subsoil) cover approximately 23 ha along the flat southern edge of the study area.

The majority of the site is almost flat (slope <2%) and appears to be an elevated alluvial terrace associated with the Talbragar River, which is within 1 km of the southern boundary of the study area. The only sloping land is in the northwest corner of the study area, with an additional ~15 ha of Brown Chromosols that is underlaid by Siluro-Devonian parent material (including andesite, dacite and tuff).

Key soil issues at the site were as follows:

- Water erosion is unlikely to be a serious issue, except in the northwestern corner (3% slope) where a protective organic groundcover needs to be maintained where possible; preferably perennial pasture. However, the stable subsoil conditions in the sloping area represented by Pit 1 mean that tunnel erosion is very unlikely.
- Wind erosion is a potential problem on Brown Chromosols in the vicinity of Pit 4. The sandy topsoil will be prone to loss by wind erosion if left bare; protection by perennial pasture is recommended.
- All of the Vertosols have a strong shrink-swell potential in both topsoil and subsoil, so structures such as solar panels on steel piles may move as the soil wets and dries.
- The Grey and Brown Vertosols have poorer drainage than the Black Vertosols and may have trafficability problems when there is prolonged wet weather; gypsum application (6 t/ha) will reduce this risk.
- The nutrient status of soil represented by Pits 1 to 4 was favourable.
- Severe pH imbalance is not an issue at the study site. However, lime at a rate of 2 t/ha will help to overcome a slight acidity issue that will be difficult to treat once the solar panels have been installed.
- There was no obvious need for deep ripping to improve plant root growth across the study area.
- Moderate salinity in the depth interval 60-100 cm was observed at Pits 2 and 3; this may have an impact on susceptibility to corrosion of steel piles.

A thorough BSAL assessment would require a total of about 9 soil pits. However, the current 'first approximation' based on a 4-pit assessment indicates that only the Black Vertosol zone (~30% of the area) is BSAL. This contrasts with the NSW Government BSAL mapping which estimates that about 80% of the area of interest (all of the site except for the sloping northwest corner) is BSAL.

1 INTRODUCTION

A soil survey was carried out on 20 March 2018 at the site of a proposed Solar Farm approximately 2 km north of Dunedoo NSW (Figure 1). The study was requested by 'ib vogt GmbH' via Jenny Walsh. The area of interest originally covered approximately 135 ha, but has been reduced to ~80 ha for this version of the soil report.

The aims of the assessment of topsoil and subsoil to a depth of one metre were to:

1. Find out how sodic the soil is and assess the risk of water erosion, particularly tunnel erosion, during and after installation of the solar panels and associated infrastructure. Any soil limitations will be discussed in relation to the agricultural value of the site, with reference to 'biophysical strategic agricultural land' (BSAL) definitions from NSW Government.
2. If the soil is sodic, give recommendations about gypsum (calcium sulphate) and lime (calcium carbonate) application to improve soil drainage when wet and reduce excessive hardness when dry. Improvement of sodic soil structure reduces erosion risk by minimising runoff and through improved pasture growth.
3. Identify any soil nutrient problems that exist so that suitable fertiliser can be added to improve pasture growth. Vigorous pasture production is likely to make the soil better at the end of the project than at the start, eg. through increases in soil carbon content.
4. Provide an overview of soil factors relevant to construction of the solar farm, eg. shrink-swell potential, acidity and subsoil salinity.

Figure 1. Proposed location and layout of the proposed solar farm near Dunedoo.

2 SITE DESCRIPTION AND EXISTING INFORMATION

2.1 Site Description

The majority of the study site is almost flat (slope <2%) and appears to be an elevated alluvial terrace associated with the Talbragar River, which is within 1 km of the southern boundary of the study area. The only sloping land (3% slope) is an area of about 15 ha in the northwest corner of the study area; it is underlaid by Siluro-Devonian parent material (including andesite, dacite and tuff) (Offenberg, 1967).

Land use at the study site includes improved pasture (lucerne) in the south-eastern corner, sown oats in the north-western paddock, and weedy pasture elsewhere.

2.2 Existing Soil Information

A search of the NSW Government's 'eSPADE' website (part of the NSW Natural Resource Atlas) was conducted to identify any existing soil profile information. There are no eSPADE soil profiles located in the 'area of interest'.

No soil landscape studies exist for the solar farm 'area of interest'.

The *State Environmental Planning Policy (Mining, Petroleum Production and Extractive Industries) 2007* (Mining SEPP) includes mapping of lands identified as BSAL. NSW Government BSAL mapping estimates that about 80% of the area (all of the site except for the sloping northwest corner) is BSAL (NSW Planning & Infrastructure, 2013) (Figure 2).

3 SOIL SURVEY METHODOLOGY

3.1 Field Work

The soil survey involved a survey of 4 detailed soil pit profiles dug with a backhoe (approximately 1.2 m deep). The soil pit coordinates are shown in 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 according to the Australian Soil Classification (Isbell, 2002).

The soil survey was carried out by Dr David McKenzie, who has Certified Professional Soil Scientist accreditation from Soil Science Australia (including 'Recognised Competencies for Australian Soil Survey') and a PhD in soil science. Dr. McKenzie also has 'Chartered Scientist' accreditation with British Society of Soil Science.

The 1.2 m deep pit profiles were trimmed with a geological pick to allow high resolution photography (4MB SLR images) and description of the undisturbed structure and root growth.

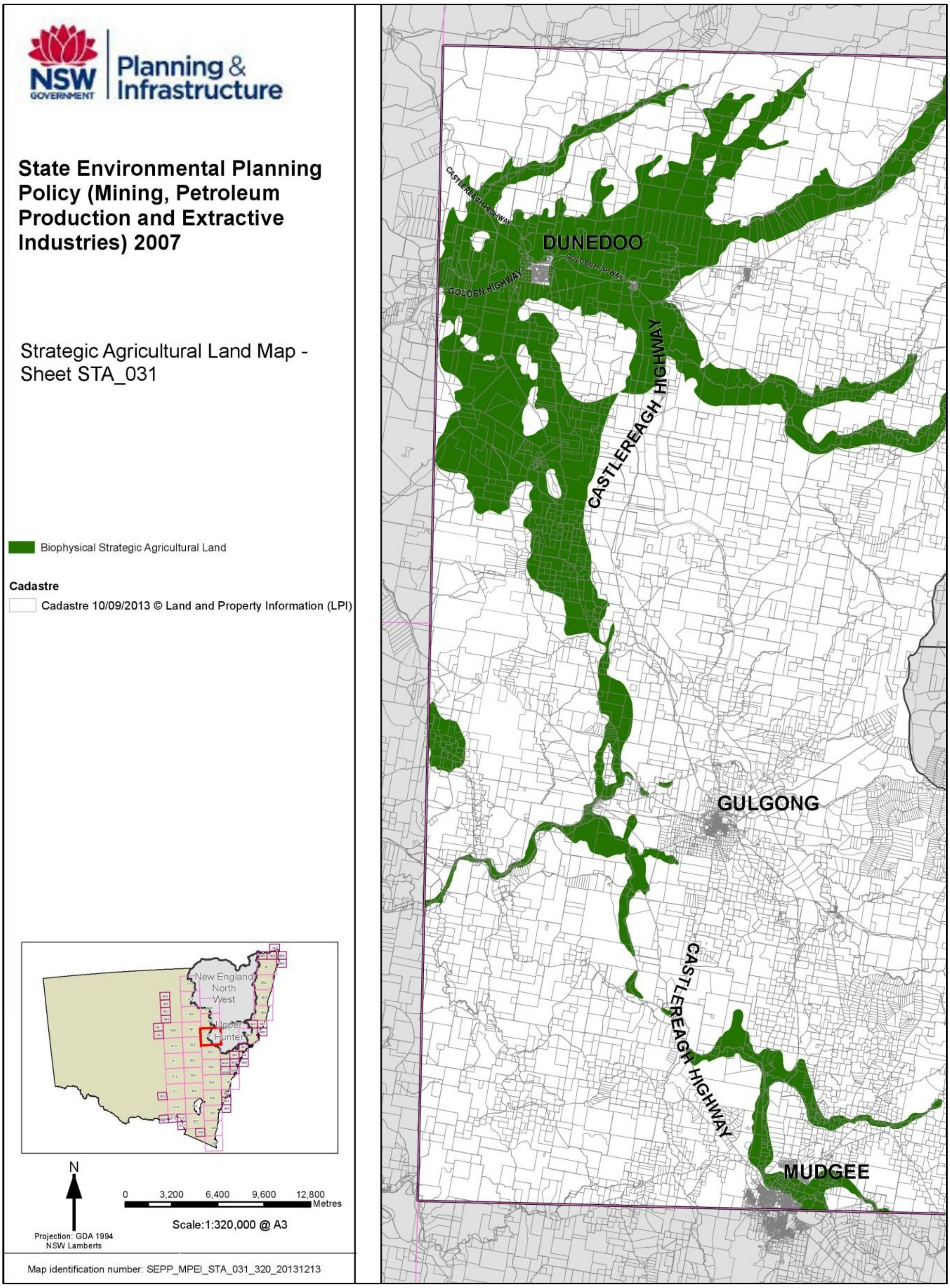


Figure 2. Map of government-estimated BSAL in the Dunedoo district (NSW Planning & Infrastructure 2013).

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) and mottle characteristics;
- 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).

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.

3.2 Laboratory Testing of Soil Samples

All of the soil pits were sampled for laboratory analysis. The sampling intervals for laboratory analysis were as per the BSAL 'Interim Protocol' (NSW Government, 2013), ie. 0 to 5 cm; 5 to 15 cm; 15 to 30 cm; 30 to 60 cm; and 60 to 100 cm.

The soil was analysed by Incitec-Pivot Laboratory, Werribee Victoria for exchangeable cations, pH, electrical conductivity, chlorides, topsoil nutrient status (nitrate-nitrogen, phosphorus, sulfur, zinc, copper, boron) and organic carbon 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). The electrochemical stability index (ESI) = $EC_{1:5} \div ESP$. 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).

Soil dispersibility, as measured by the Aggregate Stability in Water (ASWAT) test (Field *et al.*, 1997), was assessed by Soil Management Designs 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 1. 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 3). The conversion factors of Slavich and Petterson (1993) allowed the ECe to be calculated from the EC of 1:5 soil:water suspensions ($EC_{1:5}$) and texture.

Table 1. 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

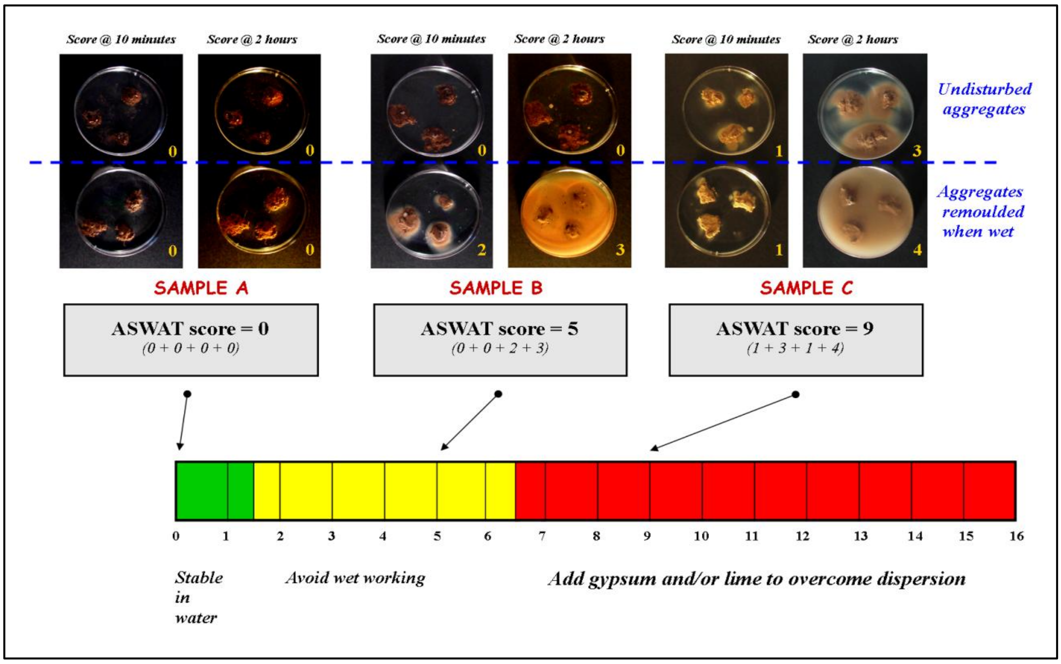


Figure 3. The link between ASWAT results and soil management options.

4 SOIL SURVEY RESULTS

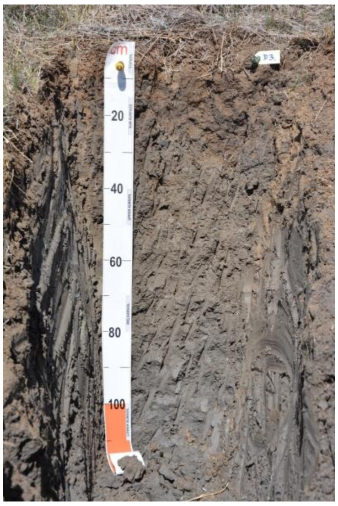
4.1 Soil Types

The Australian Soil Classification (ASC) (Isbell, 2002) has been used to determine soil types at each of the 4 sampling sites. Photographs of the soil profiles (and associated landscapes) at each site are presented in Figure 4.

A soil map for the area of interest is shown in Figure 5. Soil boundaries in-between the pits were estimated from the patterns on 'Google Earth' image, and impressions of soil and landscape conditions when driving around the study area.

The soil types on the soil map have the following characteristics (Isbell, 2002):

- Vertosols are clay-rich soils with shrink-swell properties in both topsoil and subsoil that exhibit strong cracking when dry.
- Chromosols have strong texture contrast between the A and B horizons, and the B horizon is non-sodic with a neutral to alkaline pH.

Site	Soil profile and ASC description	Landscape View
Pit 1	Brown Chromosol 	
Pit 2	Black Vertosol 	
Pit 3	Grey Vertosol 	 ***Cont.***

Site	Soil profile and ASC description	Landscape View
Pit 4	Brown Chromosol 	

Figure 4. Photographs of soil profiles and landscapes at each of the four sampling sites.

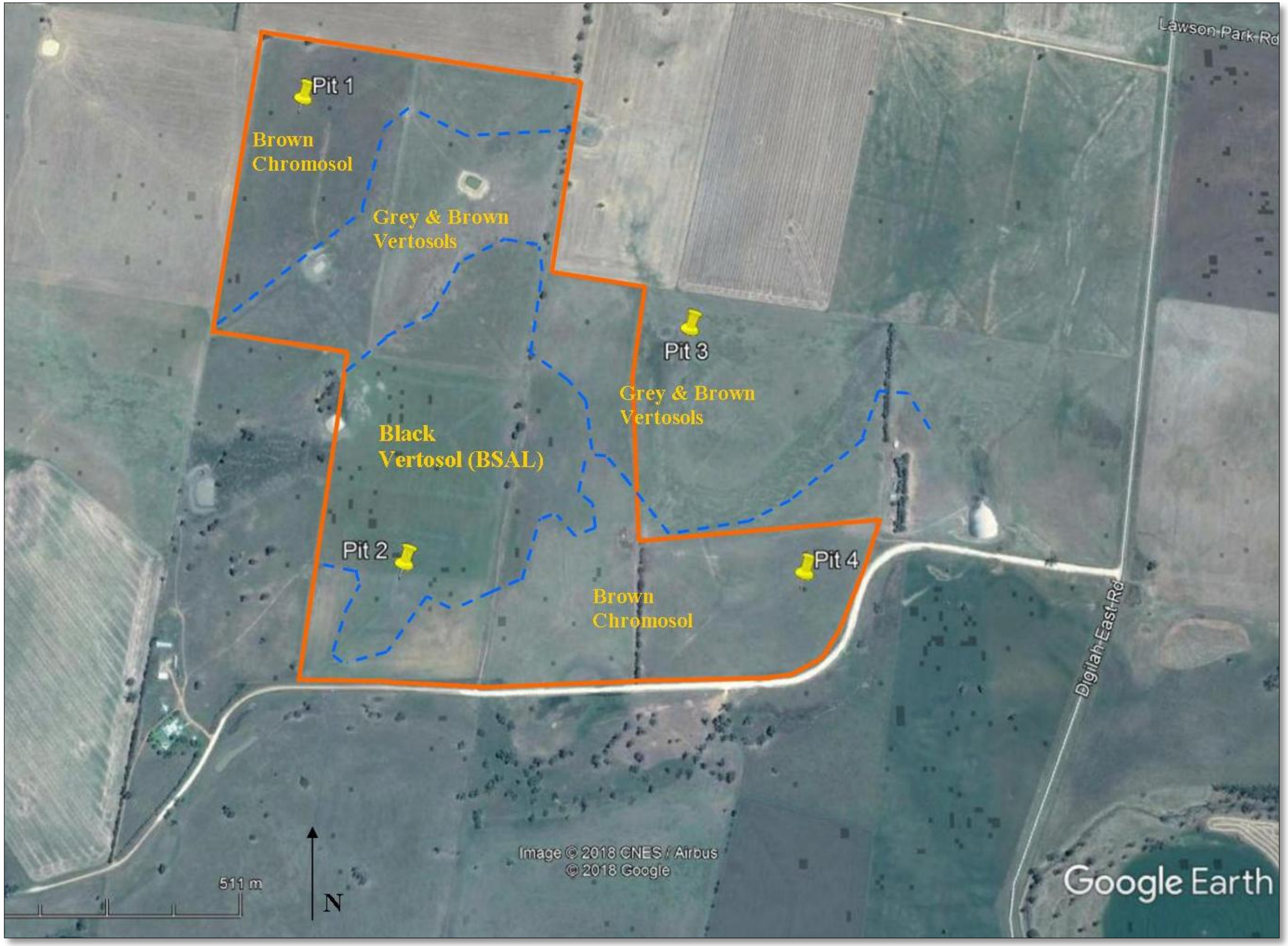


Figure 5. Soil type map.

4.2 Soil Factors

Water erosion

Water erosion is unlikely to be a serious issue, except in the north-western corner (3% slope) where a protective organic groundcover needs to be maintained where possible (preferably perennial pasture). However, the absence of extreme subsoil sodicity in the sloping area represented by Pit 1 means that tunnel erosion is very unlikely.

Wind Erosion

Wind erosion is a potential problem on Brown Chromosols in the vicinity of Pit 4. The sandy topsoil will be prone to loss by wind erosion if left bare. Protection by perennial pasture is recommended.

Shrink-swell Capacity

All of the Vertosols have a strong shrink-swell potential in both topsoil and subsoil, so structures such as solar panels on steel piles may move as the soil wets and dries.

Site Drainage and Trafficability

The area represented by Pit 3 (Grey and Brown Vertosols) has poorer drainage than the Black Vertosols and mayhave trafficability problems when there is prolonged wet weather. Gypsum application (see Section 5) will reduce this risk. The high ASWAT scores for Pit 3 are caused by moderately high exchangeable sodium percentages and low calcium-magnesium ratios. The poor drainage is aggravated by landscape flatness.

The restricted drainage in subsoils of the Brown Chromosol zones (evidenced by mottling and strong grey colouration) is associated with moderate ASWAT scores caused by low electrolyte concentrations (low ESI values).

pH and Nutrients

The nutrient status of Pits 1 to 4 was favourable.

Severe pH imbalance is not an issue at the study site. However, lime application will help to overcome a slight acidity issue that will be difficult to treat once the solar panels have been installed.

Compaction

There was no obvious need for deep ripping to improve plant root growth across the study area.

Salinity

Moderate salinity in the depth interval 60-100 cm was observed at Pits 2 and 3; this may have an impact on rates of corrosion of steel piles

4.3 BSAL Status Within the Study Area

A thorough assessment of 'biophysical strategic agricultural land' (BSAL) within the study area would require a total of about 9 soil pits on a spacing of approximately 420 metres (NSW Government, 2013).

However, the current 'first approximation' based on a 4-pit assessment indicates that only the Black Vertosol zone (~30% of the area) is BSAL. This contrasts with the NSW Government BSAL mapping which estimates that about 90% of the area – all of the site except for the sloping northwest corner – is BSAL.

Reasons for three of the four soil pits being non-BSAL are as follows:

- Pit 1; distinct mottling (an indicator of waterlogging in the subsoil when moist) within 75 cm of the soil surface.
- Pit 3; prominent mottling in the topsoil and a sodic/dispersive subsoil below 30 cm.
- Pit 4; prominent mottling within 75 cm of the soil surface.

5 SOIL MANAGEMENT RECOMMENDATIONS

Soil management requirements for the proposed Dunedoo Solar Farm site are as follows:

- Establish and maintain perennial pasture that provides 100% groundcover, even under very dry conditions. Grazing of the pasture by livestock is needed to keep the pasture low enough to allow easy access and minimize fire risk, but over-grazing must be avoided.
- Gypsum (calcium sulphate; $CaSO_4$) application (6 t/ha) is recommended for the 'Grey and Brown Vertosol' zone (Figure 5). This is because the subsoil is strongly dispersive and therefore poorly drained. The gypsum will improve subsoil drainage via its electrolyte effect and through replacement of exchangeable sodium and magnesium by calcium. A coarse-grade gypsum product is recommended that maintains the beneficial electrolyte for a long as possible. For the remainder of the study area, gypsum application at a rate of 3 t/ha is recommended to improve both subsoil drainage and sulphur nutrition.
- Some sections of the study area may have excessive flatness problems which will aggravate bogginess issues in wet weather. It is recommended that an elevation survey be carried out to accurately identify problem areas. Small V-drains may be required to convey excess surface water away from the flat spots following heavy rain.
- Lime (calcium carbonate; $CaCO_3$) at a rate of 2 t/ha across the entire area will help to overcome a slight acidity issue that exists.

Ongoing monitoring of pasture vigour across the proposed solar farm is recommended. Additional soil testing can be carried out if/where poor pasture growth is identified.

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Attachment A. Overview Data.

Site	Easting, m WGS84	Northing, m WGS84	Elevation m	Slope %	Australian Soil Classification (ASC)				BSAL	Aspect	Depth to rock, cm	Depth to water-logged layer, cm	Depth to Lime, cm	Surface Stones, %	Ground Cover
					Subgroup	Great Group	Suborder	Order							
1	725556	6458714	385	3	Mottled	Eutrophic	**Brown**	**Chromosol**	No	SE	>120	40	-	30%, 15mm	60
2	725767	6457761	381	1	Endocalcareous	Epipedal	**Black**	**Vertosol**	Yes	NW	>120	-	55	0	50
3	726343	6458214	381	1	Haplic	Self-mulching	**Grey**	**Vertosol**	No	S	>120	0	-	0	100
4	726548	6457727	382	1	Bleached-Mottled	Eutrophic	**Brown**	**Chromosol**	No	NW	>120	33	-	0	80

Attachment B. Layer Data.

Site	Horizon	Lower depth cm	Texture	pH water	Moist soil colour (Munsell)	Colour from Munsell sheet	Mottles	Mn	SOILpak compaction score	Coarse fragments % GV	Coarse fragments Size	Dispersion 10 minutes	Moisture	Lime %	Root score
1	A11/AP	10	SL	4.0	7.5YR3/3	Dark brown	-	-	1.2	20	8	0	D	-	1
	A12	23	SCL	4.5	7.5YR3/4	Dark brown	-	-	1.3	30	10	0	M	-	2
	A2	40	SCL	5.5	7.5YR4/6	Strong brown	-	-	1.3	30	10	0	S	-	1
	B21	80	LC	7.0	10YR4/6	Dark yellowish brown	Grey 20% distinct	5%	1.1	10	10	0	S	-	1
	B22	115+	LC	7.5	10YR5/6	Yellowish brown	Grey 20% prominent; Red 20% prominent	10%	0.8	10	10	1	S	-	0
2	A1	5	LMC	5.5	10YR2/2	Very dark brown	-	-	1.2	-	-	2	D	-	2
	B1	55	MC	6.0	10YR2/2	Very dark brown	-	-	1.1	-	-	1	S	-	2
	B21	80	MC	7.5	7.5YR4/4	Brown	-	-	1.2	-	-	0	S	10	1
	B22	120+	MC	8.5	7.5YR4/4	Brown	-	-	1.2	-	-	0	S	30	1
3	A1	7	LC	4.5	10YR5/2	Greyish brown	Brown 15% prominent	-	1.6	-	-	0	D	-	2
	B21	65	MHC	6.0	2.5Y4/1	Dark grey	-	-	1.2	-	-	2	S	-	2
	B22	115+	MHC	5.5	5Y4/1	Dark grey	-	-	0.8	-	-	1	M	-	1
4	A1	15	LS	5.5	7.5YR4/4	Brown	-	-	1.5	-	-	0	D	-	2
	A2	33	LS	5.5	7.5YR4/3	Brown	-	-	1.2	-	-	2	D	-	1
	B21	60	LMC	6.0	7.5YR5/6	Strong brown	Grey 20% prominent; Red 10% prominent	-	0.8	-	-	0	S	-	1
	B22	110+	LMC	7.0	7.5YR4/6	Strong brown	Grey 20% prominent; Red 20% prominent	-	0.5	-	-	0	S	-	0

Attachment C. Soil Structure Details.

Site	Lower Depth	Grade	Type	Size	Fabric	Consistence	SOILpak compaction score
1	10	W	PO	8	E	2	1.2
	23	M	PO	7	E	2	1.3
	40	M	PO/LE	7	E	2	1.3
	80	M	LE	10	RP	3	1.1
	115+	W	LE	12	RP	4	0.8
2	5	M	PO	7	RP	2	1.2
	55	S	LE	10	RP/SP	3	1.1
	80	S	LE	8	RP/SP	3	1.2
	120+	S	LE	8	RP/SP	3	1.2
3	7	S	PO	3	RP	3	1.6
	65	S	PO/LE	10	RP	3	1.2
	115+	S	LE	15	RP/SP	5	0.8
4	15	apedal					1.5
	33	apedal					1.2
	60	M	PO	8	RP	3	0.8
	110+	M	LE	10	RP	4	0.5

Attachment D. Laboratory Data.

Site	Depth, cm	pH	pH	EC1:5	ECe	Chloride	Exchangeable cations (meq/100g)						ESP	ESI	Ca/Mg	ASWAT	NO3-N	Colwell-P	PBI	Zinc	Copper	Boron	SO4-S	Org. C
		water	$CaCl_2$	dS/m	dS/m	mg/kg	Ca	Mg	K	Na	Al	CEC				dispersion	mg/kg	mg/kg		mg/kg	mg/kg	mg/kg	mg/kg	%
1	0 to 5	6.0	5.5	0.25	3.45	29	8.6	2.6	1.6	0.1	0.0	12.9	0.6	0.40	3.3	4	80	70	58	5.8	1.7	1.2	18	4.8
1	5 to 15	5.3	4.5	0.09	1.24	15	3.5	1.2	0.6	0.1	0.1	5.6	2.0	0.05	2.9	2	37	11	62	0.5	1.9	0.7	8	1.1
1	15 to 30	6.3	5.2	0.03	0.41	5	3.5	1.4	0.4	0.1	0.0	5.4	1.1	0.03	2.5	2	9							0.5
1	30 to 60	7.3	6.1	0.03	0.26	5	5.2	5.0	0.7	0.3	0.0	11.3	3.0	0.01	1.0	5	3							0.3
1	60 to 100	8.2	7.1	0.07	0.60	5	6.8	9.2	1.1	1.0	0.0	18.1	5.4	0.01	0.7	5	1							0.2
2	0 to 5	6.0	5.3	0.19	1.63	48	9.1	8.1	1.9	0.2	0.0	19.3	1.2	0.15	1.1	4	53	110	98	1.2	2.5	1.1	11	1.9
2	5 to 15	6.7	5.5	0.06	0.45	5	12.0	12.0	1.2	0.7	0.0	25.9	2.5	0.02	1.0	11	0	35	120	0.2	2.4	1.0	2	1.3
2	15 to 30	7.6	6.4	0.08	0.60	25	14.0	14.0	1.0	1.1	0.0	30.1	3.7	0.02	1.0	11	0							1.0
2	30 to 60	8.3	7.2	0.17	1.28	110	14.0	18.0	0.9	2.0	0.0	34.9	5.7	0.03	0.8	10	0							0.8
2	60 to 100	8.7	8.1	0.70	5.25	710	23.0	22.0	1.1	3.9	0.0	50.0	7.8	0.09	1.0	0	0							0.2
3	0 to 5	5.2	4.7	0.30	2.58	50	9.4	8.4	1.5	0.4	0.2	19.9	2.0	0.15	1.1	3	100	240	210	0.7	3.0	0.9	18	2.6
3	5 to 15	6.4	5.2	0.06	0.40	17	10.0	10.0	1.3	0.5	0.0	21.8	2.2	0.03	1.0	10	4	45	150	0.1	2.9	0.8	3	0.8
3	15 to 30	7.5	6.3	0.07	0.47	20	11.0	12.0	1.2	1.0	0.0	25.2	4.0	0.02	0.9	14	1							0.4
3	30 to 60	7.1	6.1	0.18	1.21	170	11.0	13.0	0.9	1.9	0.0	26.8	7.1	0.03	0.8	14	0							0.3
3	60 to 100	6.6	5.8	0.39	2.61	460	12.0	16.0	1.1	2.9	0.0	32.0	9.1	0.04	0.8	11	0							0.2
4	0 to 5	5.0	4.3	0.10	2.27	18	1.2	0.6	0.5	0.0	0.2	2.5	1.2	0.08	2.1	4	29	68	21	1.3	0.5	0.3	9	1.5
4	5 to 15	5.4	4.8	0.24	5.45	29	5.4	7.0	1.5	0.4	0.0	14.3	2.5	0.10	0.8	5	85	220	140	1.4	3.4	0.9	16	1.8
4	15 to 30	6.0	5.0	0.02	0.45	5	0.3	0.3	0.1	0.0	0.2	0.8	1.2	0.02	1.2	8	1							0.1
4	30 to 60	6.4	5.1	0.04	0.34	5	6.1	8.0	1.5	0.7	0.1	16.4	4.3	0.01	0.8	10	2							0.1
4	60 to 100	7.4	6.0	0.04	0.34	5	6.5	9.5	1.7	1.0	0.0	18.7	5.3	0.01	0.7	13	0							0.1