APSoil plant available water capacity (PAWC) characterisation of select soils of the Macquarie-Bogan Floodplain and their landscape context.

Kirsten Verburg[1], Tony Webster[1], Brian Murphy[2], Brett Cocks[1], Neroli Brennan[3], Michael Braunack[1]

[1] CSIRO Agriculture and Food

[2] NSW OEH

[3] NSW Central West Local Land Services

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Available from: https://www.apsim.info/apsim-model/apsoil/

Contents

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The Plant Available Water Capacity (PAWC) characterisations were undertaken by CSIRO in close collaboration with a group of local agronomists and consultants representing NSW Central West Local Land Services and Delta Agribusiness. In-kind funding from these organisations is acknowledged. We thank the agronomists (Graeme Callaghan and Penny Heuston) and local farmers (Simon Ward, Tim Johnson, Gary Wrigley, Angus Dixon, Andrew Freeth, Mark Freeth, Cameron Ferguson and Breil Jackson) who helped locate, set-up or monitor sites for their invaluable assistance. We acknowledge Ainsleigh Wilson (formerly CSIRO) for her assistance with sample processing. Some of the characterisations were done in collaboration with GRDC project CSP00184.

The analysis of results also draws on past PAWC investment by GRDC, CSIRO and other collaborators, notably several APSoil PAWC characterisations carried out by Steve Henry (CSIRO) in collaboration with DPI Trangie. The concept of drawing on soil-landscape information for the analysis also benefitted from discussions with Mark Glover and Neil McKenzie (CSIRO) and Robert Banks (Soil Futures Consulting).

We thank Neal Dalgliesh (CSIRO) for all his work in developing the field measurement of PAWC as a pragmatic provision of soil information for paddock-specific farmer decision making and simulation, setting up the APSoil database and ‘spreading the message’ about PAWC and soil water management widely during previous GRDC funded projects. We also thank Mark Glover, Uta Stockmann, Janet Austin, John Gallant and Mark Thomas for discussions as part of work that has built on this report to evaluate different spatial prediction methods.

Executive summary

Knowledge of the plant available water capacity (PAWC) of soils on their farm can help growers and advisors improve the quality of yield forecasts (consisting of rules of thumb or assisted by tools like Yield Prophet®) used to inform management decisions such as whether to sow or not (i.e. opportunity cropping), timing of sowing (and associated crop type and variety choice) and the input level of resources such as nitrogen fertiliser. Past investments by GRDC, CSIRO and other collaborators helped deliver a database ('APSoil') of 1000+ PAWC characterisations across the country. Between 2014 and 2017 GRDC funded project 'Measuring and managing soil water in Australian agriculture' (CSP00170) contributed a further 250 APSoil PAWC characterisations, nine of which located in the Macquarie-Bogan Floodplain. These were carried out in collaboration with local LLS staff and consultants.

This report documents the results from these new characterisations as well as older existing ones in the area for the benefit of local growers and advisors (Part II). It also describes the methodology used to measure PAWC in the field and how to access the PAWC data in the APSoil database (Part I). As PAWC characterisations are labour intensive, growers and advisors are often not in the position to do a local field characterisation and will instead rely on the existing APSoil characterisations in the APSoil database to estimate the PAWC of their soils. This comes down to finding a soil with similar properties. Given that the nearest APSoil characterisation may be for a completely different soil type, this is not an easy task and one that still challenges researchers as well. The report provides some general guidance for this, but also examines to what extent we can extrapolate or generalise from the combined PAWC characterisations in the Macquarie-Bogan Floodplain drawing on available soil-landscape information (Part III). This is still research in progress and the preliminary results reported here are included to provide directions for future research and development.

The new PAWC characterisations have enhanced the coverage of soil types within the Macquarie-Bogan Floodplain considerably. Most of the soil-landscape units (SLUs) used for dryland cropping now have at least one PAWC characterisation, although (as noted in Part III) it is still difficult to determine to what extent this characterisation represents most of the soils that are relevant to cropping in the SLUs and how to predict the variability within them. Soil texture differences relating to geology and landscape position were found to be the main drivers of magnitude of PAWC. In some of the SLUs subsoil constraints, primarily salinity, resulted in considerable reductions in PAWC. While the use of SLU mapping for selection of characterisation sites and interpretation of results proved worthwhile, more research needs to be carried out to develop methods and tools to capture the within SLU variability in PAWC. This could include terrain analysis and Electromagnetic Induction (EM), or indirectly via yield mapping. The value of the digital mapping contained in the new Soil and Landscape Grid of Australia should also be explored. The increasing availability of regional, state and national soil information on-line opens the way to more soil specific management and digital agriculture, although further research, development and extension is required to make it easily accessible and interpretable by growers and advisors.

Part I Characterising PAWC

Introduction to methodology

Based on: Verburg K, Cocks B, Webster T, Whish J (2016) Methods and tools to characterise soils for plant available water capacity. GRDC Advisor Update paper Nyngan NSW. https://grdc.com.au/Research-and-Development/GRDC-Update-Papers/2016/02/Methods-and-tools-to-characterise-soils-for-plant-available-water-capacity-Nyngan

1 Introduction

A key determinant of potential yield in dryland agriculture is the amount of water available to the crop, either from in-season rainfall or stored soil water. In the northern region the contribution of stored soil water to crop productivity for both winter and summer cropping has long been recognized. The amount of stored soil water influences decisions to sow a crop or wait (for the next opportunity or long fallow), timing of sowing (and associated crop type and variety choice) and the input level of resources such as nitrogen fertiliser.

The amount of stored soil water available to a crop – plant available water (PAW) – is affected by pre-season and in-season rainfall, infiltration, evaporation and crop water use. It also strongly depends on a soil's plant available water capacity (PAWC), which is the total amount of water a soil can store and release to different crops. The PAWC, or 'bucket size', depends on the soil's physical and chemical characteristics as well as the crop being grown.

Over the past 20 years, CSIRO in collaboration with state agencies, catchment management organisations, consultants and farmers has characterised more than 1000 sites around Australia for PAWC. These data are publicly available in the 'APSoil' database, which can be accessed in the 'SoilMapp' application for iPad, on the APSoil website and via a Google Earth file (see Section 10 Resources).

A number of farmers and advisers, especially in southern Australia, are using the APSoil PAWC data in conjunction with Yield Prophet® to assist with crop management decisions. Yield Prophet® is a tool that interprets predictions made by the APSIM cropping systems model. It uses the information on PAWC along with information on pre-season soil moisture and mineral nitrogen, agronomic inputs and local climate data to forecast, at any time during the growing season, the possible yield outcomes. Yield Prophet® first simulates soil water and nitrogen dynamics as well as crop growth with the weather conditions experienced to date, and then uses the long-term historical weather record to simulate what would have happened from this date onwards in each year of the climate record. The resulting range of expected yield outcomes can be compared with the expected outcomes for alternative management options to inform management decisions. Others use the PAWC data more informally in conjunction with assessments of soil water (soil core, soil water monitoring device or depth of wet soil with a push probe) to estimate the amount of plant available water. Local rules of thumb are then used to inform the management decisions.

The APSoil database provides geo-referenced data, but the PAWC characterisations are for points in the landscape. To estimate PAWC at another point in the landscape, one needs to know the soil at that location and then find a similar soil in the APSoil database. This is not a straightforward process and the subject of ongoing research, but a number of soil and landscape data and information sources are available that can assist. If suitable PAWC data are not found, local measurement of PAWC is required. This will often also provide a more accurate estimate although spatial variability may still be an issue.

Part I of this report describes the measurement of PAWC, including practical tips and pitfalls, and outlines where to find existing information on PAWC. It also discusses the principles behind extrapolation from known soil profiles or 'choosing an APSoil characterisation' (Section 7).

During 2015 and 2016 as part of a GRDC funded project 'Measuring and managing soil water in Australian agriculture' (CSP00170) local LLS staff and consultants teamed up with CSIRO to add an additional nine characterisations from the Macquarie-Bogan Floodplain to the APSoil database. The descriptions of these soils as well as those of other existing APSoil characterisations are included in Part II of this report. They are presented along with soil-landscape information for each area. This reflects current research in progress that tries to interpret the PAWC results in a soil-landscape context. Part III examines to what extent we can extrapolate or generalise from the available PAWC characterisations drawing on available soil-landscape information. The preliminary results reported here will be used to determine future directions for research and development to better support growers and advisors who want to estimate the PAWC of their soil.

2 Plant Available Water Capacity (PAWC)

To characterise a soil's PAWC, or 'bucket size', we need to determine (Figure 1a):

- drained upper limit (DUL) or field capacity – the amount of water a soil can hold against gravity;
- crop lower limit (CLL) – the amount of water remaining after a particular crop (wheat, canola, chickpea, etc.) has extracted all the water available to it from the soil; and
- bulk density (BD) – the density of the soil, which is required to convert measurements of gravimetric water content to volumetric water content

In addition, soil chemical data are obtained to provide an indication whether subsoil constraints (e.g. salinity, sodicity, boron and aluminium) may affect a soil's ability to store water, or the plant's ability to extract water from the soil.

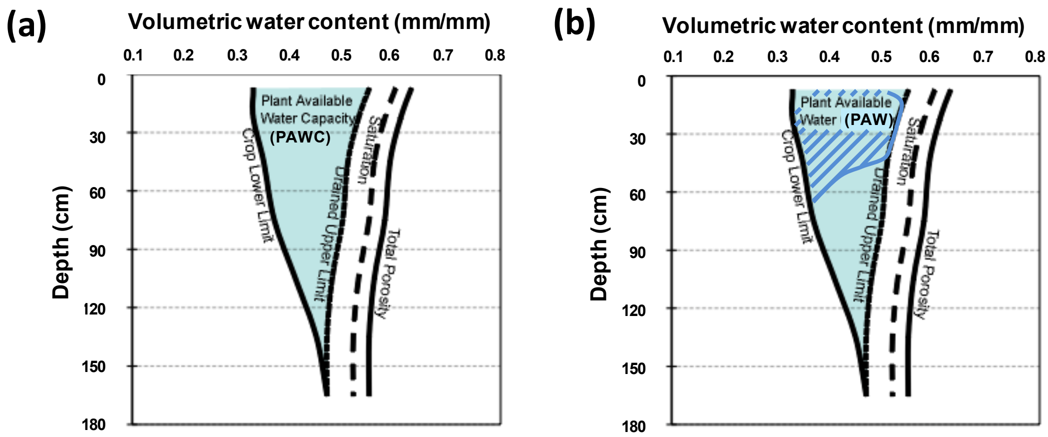


Figure 1. (a) The Plant Available Water Capacity (PAWC) is the total amount of water that a soil can store and release to different crops and is defined by its Drained Upper Limit (DUL) and its crop specific Crop Lower Limit (CLL); (b) Plant Available Water (PAW) represents the volume of water stored within the soil available to the plant at a point in time. It is defined by the difference between the current volumetric soil water content and the CLL.

Source: Verburg et al. (2016) Nyngan Update March 2016

Plant Available Water (PAW)

Plant available water is the difference between the CLL and the volumetric soil water content (mm water / mm of soil) (Figure 1b). The latter can be assessed by soil coring (gravimetric moisture which is converted into a volumetric water content using the bulk density of the soil) or the use of soil water monitoring devices (requiring calibration in order to quantitatively report soil water content).

An approximate estimate of PAW can be obtained from knowledge of the PAWC (mm of available water/cm of soil depth down the profile) and the depth of wet soil (push probe or based on a feel of wet and dry limits using an uncalibrated soil water monitoring device).

Knowledge of PAW can inform management decisions and many in the northern region have, formally or informally, adopted this. Several papers at recent GRDC Updates have illustrated the impact of PAW at sowing on crop yield in the context of management decisions (see e.g. Routley 2010, Whish 2014, Dalgliesh 2014 and Fritsch and Wylie 2015).

3 Factors that influence PAWC

An important determinant of the PAWC is the soil's texture. The particle size distribution of sand, silt and clay determines how much water and how tightly it is held. Clay particles are small (< 0.002 mm in size), but collectively have a larger surface area than sand particles (0.02 to 2 millimetres) occupying the same volume. This is important because water is held on the surface of soil particles, resulting in a clay soil having the ability to hold more water than a sand. Because the spaces between the soil particles tend to be smaller in clays than in sands, plant roots have more difficulty accessing these spaces and the more tightly held water. This affects the amount of water a soil can hold against gravity (DUL) as well as how much of the water can be extracted by the crop (CLL).

The effect of texture on PAWC can be seen by comparing some of the APSoil characterisations from the northern region, as illustrated below (Figure 2). The soil's structure, chemistry and mineralogy affect PAWC as well. For example, sodicity may impede internal drainage and constraints such as salinity, sodicity, toxicity from aluminium or boron and extremely high soil density may limit root exploration, sometimes reducing the PAWC bucket significantly. These constraints are often present in the subsoil, and the depth at which they occur greatly influences the PAWC.

The CLL may differ for different crops due to differences in root density, root depth, crop demand and duration of crop growth. Some APSoil characterisations only determined the CLL for a single crop. The CLL for wheat, barley and oats are often considered the same and that of canola can be found to be similar as well, but care needs to be taken with such extrapolations as different tolerances for subsoil constraints can cause variation between crops.

A detailed explanation of the factors influencing PAWC is included in the '*Soil Matters – Monitoring soil water and nutrients in dryland farming'* book (Dalgliesh and Foale, 2005), a pdf of which is available for free online (see Section 10 Resources).

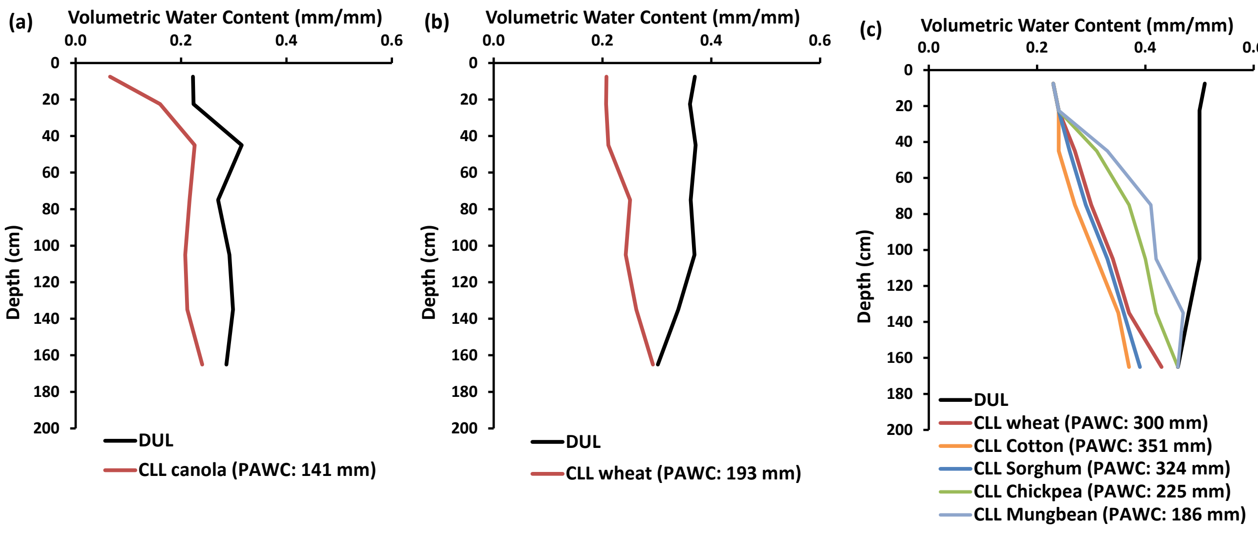


Figure 2. (a) Sandy clay loam (APSoil No683) near Trangie NSW in alluvial sediment formed on a meander plain of the Macquarie River. The higher proportion of sand, particularly in the surface of this soil has resulted in a lower PAWC. (b) Light over medium clay reverting to a sandy clay at depth (APSoil No684) near Trangie NSW in alluvial sediment formed on a back plain of the Macquarie River. The back plains are characterised by large flat areas where finer sediments were deposited from the lower energy flows. These finer sediments produce soils with higher PAWC. (c) Grey-Black Vertosol (APSoil No128) near Spring Ridge NSW on a gently inclined footslope in alluvial fan material of Jurassic Garrawilla volcanics origin. The chart demonstrates how CLL and therefore PAWC is a function of soil and crop.

4 Field measurement of PAWC

Field measurement of DUL, CLL and BD are described in detail in the GRDC PAWC Booklet '*Estimating plant available water capacity*' (Burk and Dalgliesh 2013; see Section 10 Resources). Briefly, to determine the DUL an area of approximately 4 m x 4m is slowly wet up using drip tubing that has been laid out in spiral (see Figure 3 top). The area is covered with plastic to prevent evaporation and after the slow wetting up it is allowed to drain (see GRDC PAWC booklet for indicative rates of wetting up and drainage times). The soil is then sampled for soil moisture and bulk density.

The CLL is measured either opportunistically at the end of a very dry season or in an area protected by a rainout shelter between anthesis/flowering and time of sampling (Figure 3 bottom left). This method assumes the crop will have explored all available soil water to the maximum extent and it accounts for any subsoil constraints that affect the plant's ability to extract water from the soil.

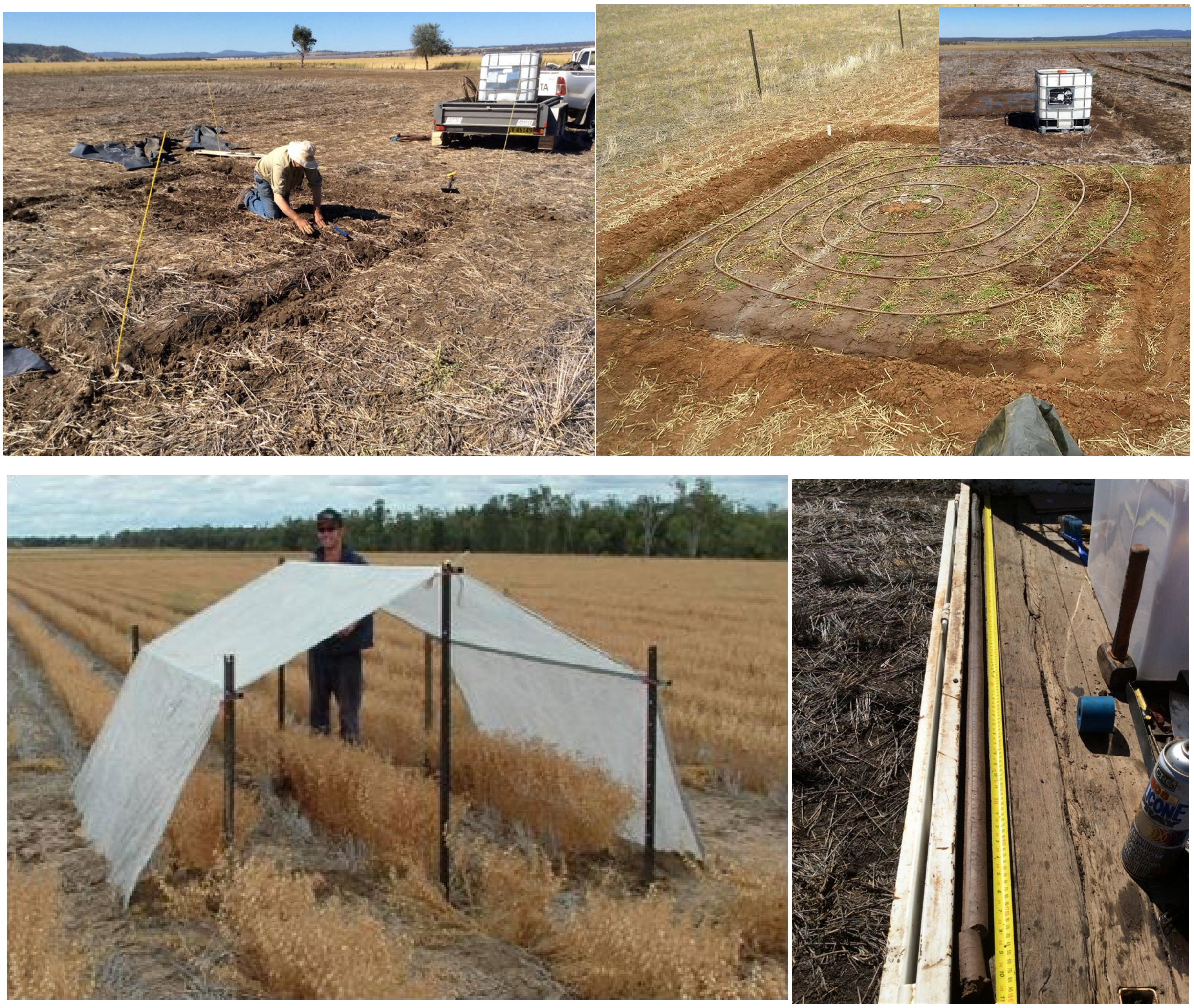


Figure 3. (top) Wetting up site for DUL determination; (bottom) rainout shelter used for CLL determination and soil coring.

Source: Bill Manning, Brett Cocks

Pitfalls and common mischaracterization issues

While the concept of PAWC is simple and the measurement methods for DUL and CLL were developed to be straightforward, not requiring any sophisticated equipment, it is important to consider possible sampling errors. The list below summarises some of the key pitfalls and common mischaracterization issues that we have come across in our collective experience of PAWC characterisations across Australia.

To allow interpretation and use of the data by others, PAWC characterisations should be accompanied by as much extra information as possible, including descriptions of the landscape position, surface condition (e.g. cracking, waterlogging), colour, texture (ideally with a full particle size analysis), Australian Soil Classification (Isbell 1996) and any local classification soil name.

<u>DUL</u>

- Weeds are often seen growing on the side of the plastic cover. It is important that these are strictly controlled throughout the wetting up process until sampling. The crop and all weeds must be removed from a distance away from the plastic to ensure these plants do not 'harvest' water from under the plastic cover.
- In sandy-textured soils the concentric rings of dripper line must be laid sufficiently close to each other to ensure consistent wetting across the whole area.
- Allowing insufficient time for drainage may lead to overestimation of DUL, especially at depth. Heavier soils can take a number of months to drain, although Burk and Dalgliesh (2013) suggest that sampling after one or two months provides a good estimate as drainage rates become very low.
- Insufficient water application or application at too high a rate leads to underestimation of DUL at depth. This is particularly an issue with heavy clay soils, dispersive sodic soils and strong duplex (texture contrast) soils where water may move sideways. Both the GRDC *PAWC booklet* and the *Soil Matters* book provide indicative rates and amounts for different soils. The wetting and drainage processes may be monitored (e.g. using NMM or a moisture probe), but this is not often done due to cost constraints (time, money).
- Bulk density sampling, which is often done in conjunction with DUL sampling, requires a relatively high level of precision as any error in bulk density values will propagate when used to convert gravimetric water contents (including DUL, CLL and PAW) into mm of water. The procedure is described and illustrated in detail in the GRDC *PAWC booklet*.
- Snakes like to hide under the plastic, so take care when wetting and sampling the plot.

<u>CLL</u>

- The CLL method as described above relies on crop roots exploring the soil to the fullest extent. If the crop had insufficient moisture to establish its root system prior to anthesis, the CLL may not reflect maximum soil water extraction. Roots will not grow through a dry layer even if there is moisture underneath. It is, therefore, important to perform CLL measurement in paddocks with a well-established and healthy crop. Wetting up of the CLL site prior to the growing season may help, but requires close attention to weeds and to supplying the right amount of nitrogen fertiliser.
- Rainfall in the weeks just prior to the erection of rainout shelters at anthesis may refill the PAWC 'bucket'. If the PAWC is large, this may prevent the crop from using all soil water and result in an overestimate of CLL (too wet). Ideally CLL is measured over multiple seasons, but this is rarely done in practice. Calibrated moisture probes can be an effective tool to assess a crop's ability to extract moisture over a range of different seasons.

- The CLL measured for one crop type may not apply to a different crop type, especially where growing season length or susceptibility to subsoil constraints differs. It is possible that long-season varieties may extract water from a greater depth than short season varieties because of more extensive root development, and hence result in a different CLL.
- If sampling is not deep enough to capture the full root zone, PAWC will be underestimated. In this case the CLL and DUL do not reach the same value at the bottom of the profile.
- If there is insufficient wetting of the profile prior or during the growing season, the measured CLL may reflect the CLL of a previous crop. If the current crop has a shallower root system this could cause the PAWC to be overestimated. Wetting up of the CLL site prior to the season may help. Taking a soil core when the rainout shelter is installed and comparing values against those determined at the time of final sampling can assist with interpretation of the data.
- Rainout shelters have blown loose or away on occasions, so it is important to make sure the tent corner posts are well braced using star pickets at 45 degrees and using rope to stabilize the central post at each end as well as to secure the sides firmly into the soil (fit in trench and cover up).
- For duplex soils located on hills slopes > 3-5% or soils at the break of slope, subsurface lateral flow can cause soil wetting despite the presence of a well-constructed rain-out shelter. Keep an eye on late season rainfall and note any unusual wetness in samples collected.
- Sampling after harvest when the soils are dry and hard or have hard layers can be tricky. Digging a soil pit can be a better alternative than soil coring from the surface in these situations.
- Drying of the soil surface due to evaporation can be difficult to distinguish from crop extraction. Measurements of CLL at harvest often underestimate the CLL. Correction procedures are available, but these imply that surface CLL values are effectively estimated. Laboratory 15 bar data may form a useful complement.

General:

- Soil variability may mean there is more than one PAWC profile within the paddock. Variability in depth of layers, e.g. texture contrast in duplex soils, can occur over small distances. This makes mixing replicates and selecting a ‘representative soil’ difficult.
- High soil variability can cause the DUL and CLL measurements to effectively be on different soils (even though they are usually only 2-3 m apart). It is essential to measure DUL and CLL on the same soil type. Yield or soil maps may assist in deciding where to sample.
- Despite the use of a rainout shelter for CLL, seasonal climate conditions may affect the measurements. Ideally measurements would be repeated in different seasons, but this is usually not possible. The estimates, while presented in APSoil to the nearest mm, will not be accurate to the nearest mm.
- For instructions how to collect information for a full APSoil characterisation, see the ‘Field protocol for APSoil characterisations’ and ‘Protocol for the development of soil parameter values for use in APSIM’ (see Section 10 Resources).

5 Sampling for soil chemistry

Along with the field characterisation of BD and DUL, samples are collected for soil chemical analysis. These data are used to assist with the interpretation and sensibility checking of the PAWC data. As described in Burk and Dalgliesh (2013) samples are dried for four to five days at 40°C and then analyse for EC, chloride (Cl), cations, CEC, pH (H_2O and $CaCl_2$), boron, aluminium, manganese, organic carbon and particle size.

Details of the analytes included in this report are given below in Table 1

Table 1: Analytes and analysis methods.

Analyte	Unit	Method
OC	%	Walkley Black
EC	dS/m	1:5 H2O
pH water		1:5 H2O
pH CaCl2		1:5 CaCl2
Cl	mg/kg	
CEC	cmol+/kg	Calculation (eCEC)
Ca, Mg, Na, K	cmol+/kg	NH4Cl/ICP
ESP	%	Calculated from the above
Coarse sand	%	Sieve
Fine sand	%	Sieve
Silt	%	Hydrometer
Clay	%	Hydrometer

6 Where to find existing information on PAWC

Characterisations of PAWC for more than 1200 soils across Australia have now been collated in the APSoil database and are freely available to farmers, advisors and researchers. The database software and data can be downloaded from https://www.apsim.info/apsim-model/apsoil/. The characterisations can also be accessed via Google Earth (KML file from APSoil website) and in SoilMapp, an application for the iPad and Android. The yield forecasting tool Yield Prophet® also draws on this database.

In Google Earth the APSoil characterisation sites are marked by white circles with a green shovel symbol (Figure 4), with information about the PAWC profile appearing in a pop-up box if one clicks on a site (Figure 5a). The pop-up box also provides links to download the data in APSoil database or spreadsheet format.

In SoilMapp the APSoil sites are represented by green dots (see Figure 5b). Tapping on the map results in a pop-up that allows one to 'discover' nearby APSoil sites (tap green arrow) or other soil (survey) characterisations. The discovery screens (see Figure 5c,d) then shows the PAWC characterisation as well as any other soil physical or chemical analysis data and available descriptive information.

Most of the PAWC data included in the APSoil database has been obtained through the field methodology outlined above, although for some soils estimates have been used for DUL or CLL. Some generic, estimated profiles are also available. While field measured profiles are mostly geo-referenced to the site of measurement (+/- accuracy of GPS unit), generic soils or those for which geo-referencing was not approved are identified with a regional town.

The report '*PROFILE descriptions – District guidelines for managing soils in north-west NSW*' by Daniells et al. (2002) provides PAWC characterisations for 17 soils in the NW region of NSW drawing on the same methodology. In addition, this report provides valuable soil descriptions for areas around Coonabarabran, Coonamble, Moree, Pilliga, and Walgett.

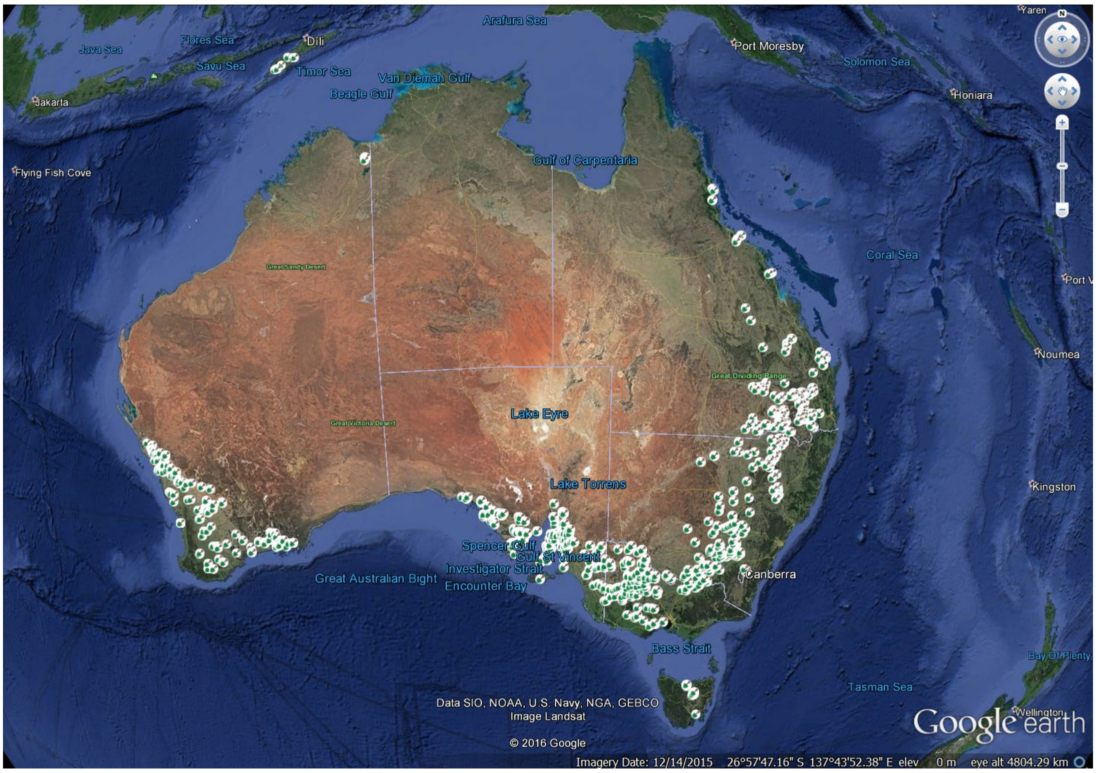


Figure 4. Access to geo-referenced soil PAWC characterisations of the APSoil database via Google Earth

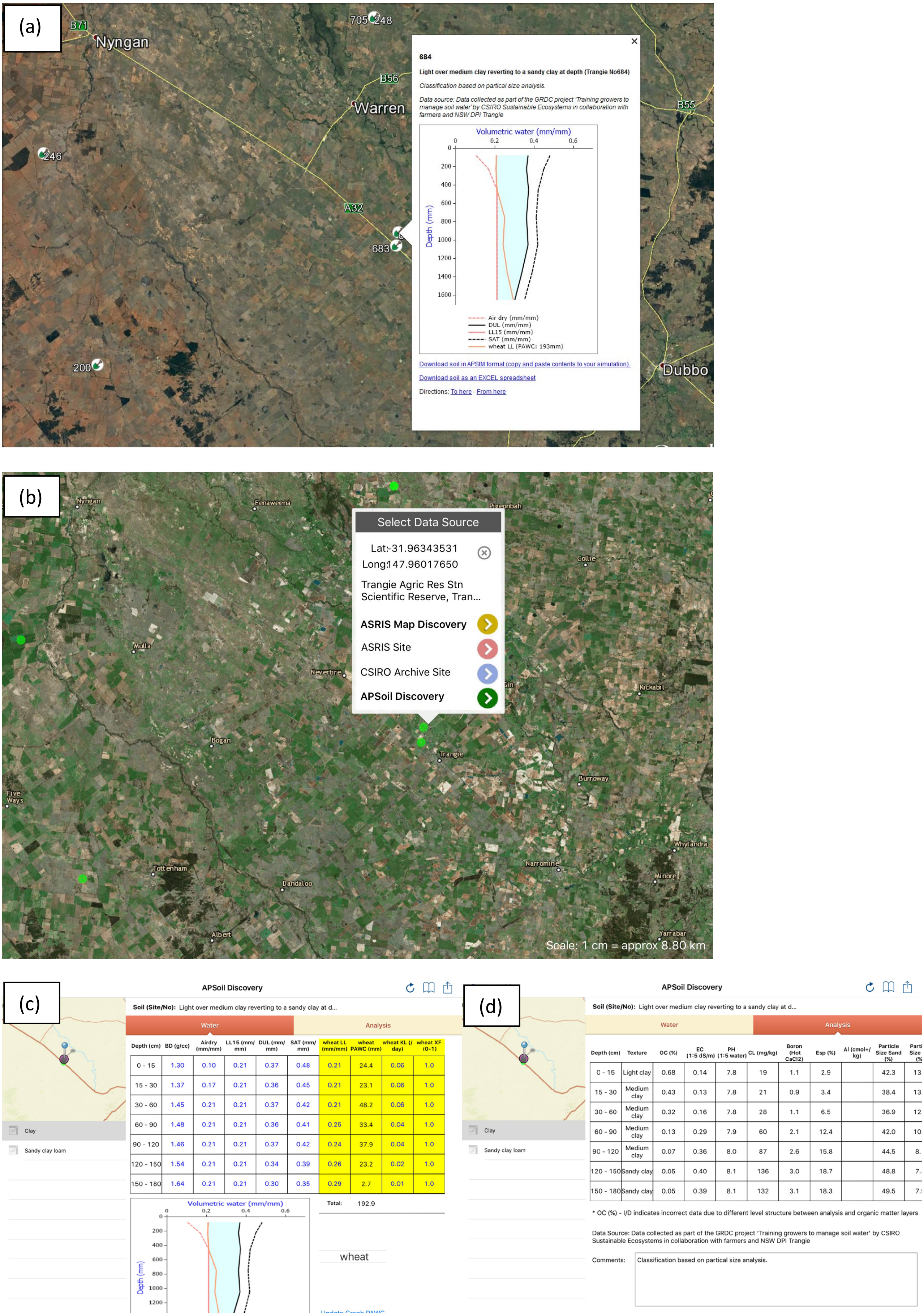


Figure 5. Access to geo-referenced soil PAWC characterisations of the APSoil database via (a) Google Earth and (b) SoilMapp; (c) and (d) APSoil discovery screens.

7 Choosing an APSoil characterisation

As shown in part II of this report, the soil PAWC can vary significantly. How do we choose the most appropriate APSoil characterisation, if we are not in the position to do a local field PAWC characterisation? This is still research in progress, but some guidance can already be provided.

- The nearest APSoil site may not be the most appropriate as its soil, parent material and landscape position could be quite different (cf. Figure 2)
- Compare soil with descriptions of the APSoil sites (texture, colour, soil classification, chemical analysis). More recently collected APSoil characterisations include chemical analysis and particle size. As illustrated in Figure 2 and described for the various soils documented in part II both particle size and subsoil constraints strongly affect the PAWC.
- Dig a hole (soil auger, soil core, backhoe trench, roadside bank or cutting); note surface features (cracking, hard setting), subsoil issues (salinity, sodicity, etc), rooting depth. This can assist with APSoil selection as well as adapting an APSoil profile to local conditions (e.g. if depth of texture change or rooting depth is different).
- A measured sowing soil water profile (convert to volumetric) needs to ‘fit’ between CLL and DUL and can assist with APSoil selection (Figure 1b). If the measured (volumetric) water content profile is below CLL or above DUL then the texture of the soil does not match that of the chosen APSoil.
- Opportunistic CLL (e.g. soil core following a dry finish; convert to volumetric) can be compared with CLL of APSoil characterisations.
- Check for nearby soil survey characterisations (SoilMapp, eSPADE and local soil reports) to help describe soils.
- Seek out soil experts who understand how soils vary across the landscape. In some regions, there are soil and land resource officers in state agencies (usually with a training in pedology) who have the detailed knowledge that can help.
- Draw on soil-landscape mapping (where available) to find APSoil sites in similar landscape positions (see Section 8 and discussion in Part III).
- Native vegetation is often a useful indicator of soil type too and is indeed often included in information about soil-landscape, land resource area and land systems units.

8 Finding soil-landscape information

In many landscapes the soil properties are tightly linked to a soil's development and position in the landscape. These same aspects underpin soil and land resource surveys that have been carried out over the years, which are increasingly becoming available on-line. Many of these present a mapping of so-called soil-landscape units that are based on a combination of geology, landscape features like slope and relief, vegetation and groups of soils. Effectively the distribution of soil types described by these maps and their mapping unit descriptions are based on a conceptual model of the landscape. These descriptions, where available, can be used to interpret and potentially extrapolate APSoil characterisations.

In parts of NSW soil-landscape maps can be accessed through the eSPADE tool (e.g. Figure 6a; see Section 10 Resources), which delineates the units and provides a description and typical soil profiles for each unit. Similar mapping has been undertaken within the area of the Macquarie-Bogan flood plain (covering the Nyngan, Narromine and Walgett map sheets), but unfortunately these maps have not yet been published on-line. In parts of Queensland, similar land resource area (LRA) mappings are used as part of land management manuals (e.g. Harris et al. 1992). Where this information is available, it may be possible to use it to find an APSoil site in a similar landscape position as a first approximation of PAWC.

The concept of using soil-landscape information to classify and inform soil properties relevant to agricultural management is not new. The Queensland land management manuals accompanying the LRA maps draw on the same concept as do the '*Glovebox Guide to Soil of the Macquarie-Bogan Flood Plain*' by Hulme (2003) and several '*Soil Specific Management Guidelines for Sugarcane Production*' in different sugarcane growing areas from northern NSW to northern Queensland (e.g. Wood et al 2003). The availability of these maps on-line makes them more accessible and assists with visualising a location's position in the landscape. Combining these maps with the geo-referenced APSoil PAWC characterisations will increase the value that both resources can provide to farmers and advisors.

Using these resources to inform or predict PAWC profiles is, however, still research in progress. In particular its predictive power for PAWC and spatial accuracy has not been assessed, nor the required level of soil and landscape information. Not all areas within the northern region are covered by soil-landscape maps and the detail of other soil data within these areas varies too.

Another resource that may prove useful in the future but requires further testing for its use in predicting PAWC profiles, is the new Soil and Landscape Grid of Australia (see Section 10 Resources) which provides digital soil and landscape attribute predictions at a spatial resolution of 90 m x 90 m (e.g. Figure 6b).

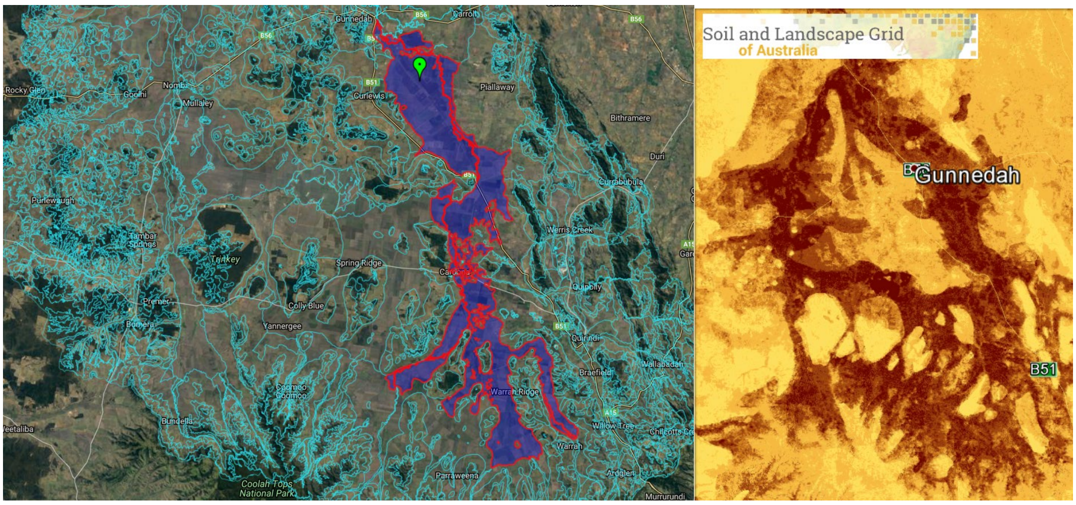


Figure 6. (a) Soil-landscape mapping for the Liverpool Plains available via the on-line tool eSPADE, (b) Predicted % clay in 5-15 cm layer across Liverpool Plains from Soil and Landscape Grid of Australia (SLGA).

Source: Screenshots of eSPADE and Screenshot Google Earth with SLGA layer

9 Soil-landscape information for the Macquarie-Bogan floodplain

Soil landscape mapping for the area of the Macquarie-Bogan flood plain is captured on 1:250,000 Nyngan, Narromine and Walgett map sheets with the geology, landforms, soil types and their land management described in detail in the accompanying reports (Duncan et al. 2012; Forbes et al. 2012a,b). A simplified version is available as the 'Glovebox Guide to Soil of the Macquarie-Bogan Flood Plain' by Hulme (2003).

Parent material was an important driver for the grouping of soil landscapes in this area. At the highest level the maps distinguish the alluvial materials of the current and ancient rivers (Riverine Province) from the in situ, colluvial and adjacent alluvial materials of different geological origin (e.g. Eastern and Western Bedrock Provinces). The Riverine Province on each of the maps is further divided into soil landscape groups on the basis of the age of the alluvial materials, the river system which contributed the materials and the provenance or source of the alluvial materials (Duncan et al. 2012). Alluvium of four different ages are distinguished (Duncan et al. 2012):

- Trangie Soil Landscape Group – Tertiary – 1.6 million to 150 000 years old
- Carrabear Soil Landscape Groups – Quaternary – 150 000 to 15 000 years old
- Bugwah Soil Landscape Groups – Quaternary – 15 000 to 5 000 years old
- Marra Creek Soil Landscape Groups – Quaternary – recent alluvium – less than 5 000 years old

As the river systems lost stream power over time, the materials were deposited under different energy conditions, which affects their particle size distribution. The particle size distribution is also affected by the relative position within the river systems: high-energy bedload in the meander plains and low energy deposition of clays in the back plains. Most of the soil landscape groups in this area, therefore, distinguish soil landscape units for the backplains and the meander plains.

In Part II of this report the APSoil PAWC characterisation sites within the Macquarie-Bogan floodplain are associated with soil landscape units from these soil-landscape maps. Some of the soil-landscape units are described in the context of the PAWC information in Part III of this report. For further information about the soil-landscape units and groups as well as other soil properties and their management see the original reports by Duncan et al. (2012) and Forbes et al. (2012a,b) as well as Hulme (2003).

10 Resources

APSoil, PAWC methodology and national information:

APSoil database: https://www.apsim.info/apsim-model/apsoil/ (includes link to Google Earth file)

SoilMapp (soil maps, soil characterisation, soil archive and APSoil sites): available for iPad and Android; documentation: https://confluence.csiro.au/display/soilmappdoc/SoilMapp+Home

GRDC PAWC booklet: https://grdc.com.au/resources-and-publications/all-publications/publications/2013/05/grdc-booklet-plantavailablewater

Soil Matters book: https://www.apsim.info/wp-content/uploads/2019/10/Soil-matters.pdf

Field protocol APSoil characterisations: https://www.apsim.info/wp-content/uploads/2019/10/Field-protocol-v5.pdf

Protocol for the development of soil parameter values for use in APSIM: https://www.apsim.info/wp-content/uploads/2019/10/Parameters-for-soil-water-Ver24.pdf

Soil and Landscape Grid of Australia: http://www.csiro.au/soil-and-landscape-grid

Yield Prophet®: http://www.yieldprophet.com.au

Google Earth: https://www.google.com/earth/

NSW:

eSPADE: http://www.environment.nsw.gov.au/eSpade2Webapp (with soil-landscape and land systems mapping and reports, location and reports of soil characterisation sites from various surveys, and a number of other derived layers)

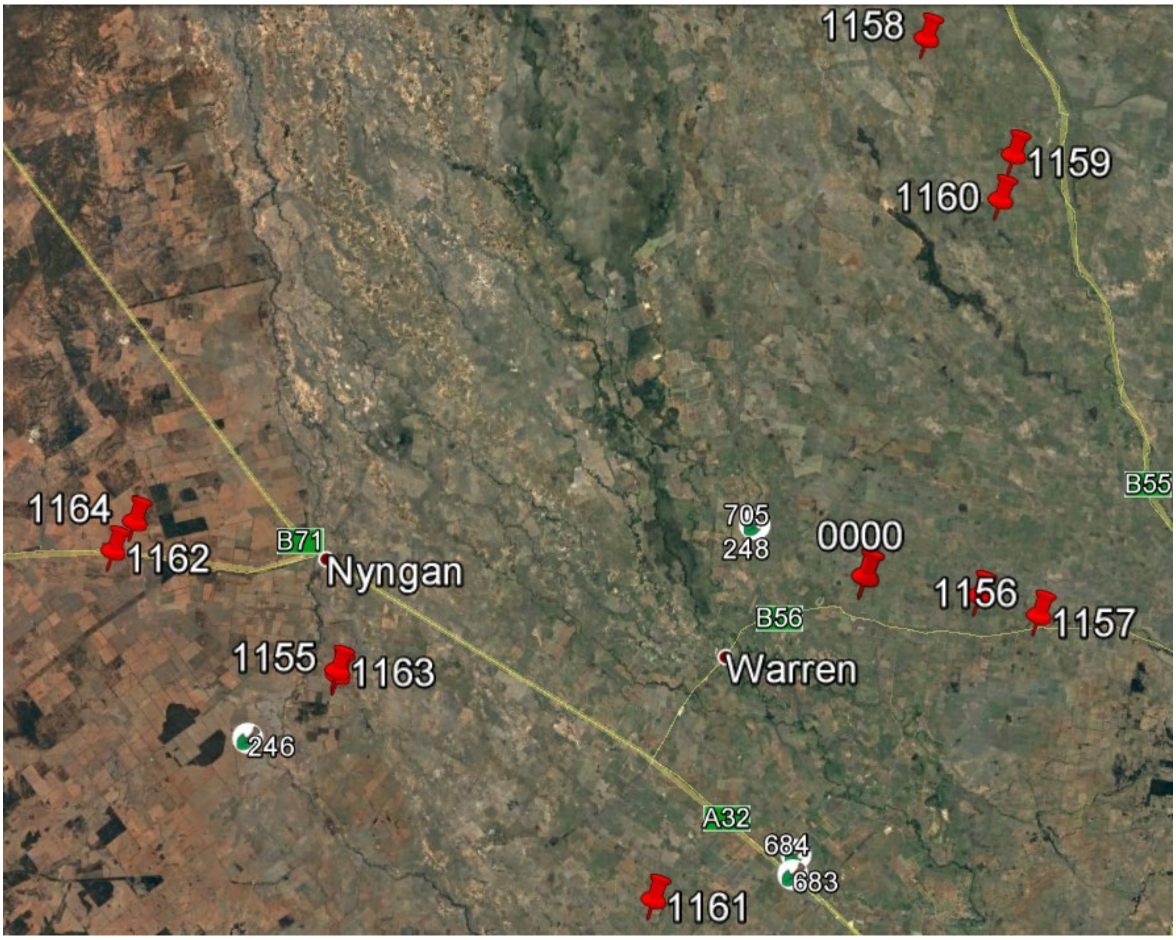
Geology maps: http://www.resourcesandenergy.nsw.gov.au/miners-and-explorers/geoscience-information/products-and-data/maps/geological-maps (includes links to Google Earth files)

NSW Geology phone maps: https://www.geoscience.nsw.gov.au/phonemaps/ (with link to NSW Geology Maps Apple instructions for iPad and iPhone app, and instructions for using NSW Geology maps within Locus Map Free or Locus Map Pro)

Soil Profile Descriptions - District guidelines for managing soils in north-west NSW (Daniells et al. 2002)

Glovebox guide to Soil of the Macquarie-Bogan Flood Plain (Hulme 2003)

Part II PAWC of soils of the Macquarie-Bogan Flood Plain and their landscape context



11 Trangie NSW area

New APSoil characterisation:

None

Existing APSoil characterisations:

Sandy Clay Loam (loam over clay) (Trangie No683) – TFm (Trangie Meander Plains)

Light over medium clay reverting to a sandy clay at depth (Trangie No684) – TFb (Trangie Backplains)

The two existing APSoil sites No683 and No684 are located near the Trangie Research Station and are 3 km apart (Figure 7). The two sites fall within the Trangie soil-landscape group and represent two contrasting positions within this landscape: APSoil No683 falls within the TFm unit, representing meander plains and APSoil No684 falls within the TFb unit, representing backplains. While the two APSoil sites were not formally classified, their texture-based descriptions (see above) do match those of a duplex soil in the meander plains and a Vertosol in the backplains. The Trangie alluvial sediments were laid down under a high energy environment that carried large amounts of sand and gravel, but with sharp boundaries between the meander plains and backplains.

Soils on the northern part of Trangie Research Station fall within the Bugwah soil-landscape group, which is formed in younger sediments that were deposited in calmer conditions, dominated by silt and fine sand. This gives rise to different soil characteristics – see discussion in Part III of this report. Northeast of Trangie is also the Cobboco soil-landscape group, which is a residual and colluvial landscape. There are currently no APSoil characterisations in these two soil-landscape groups.

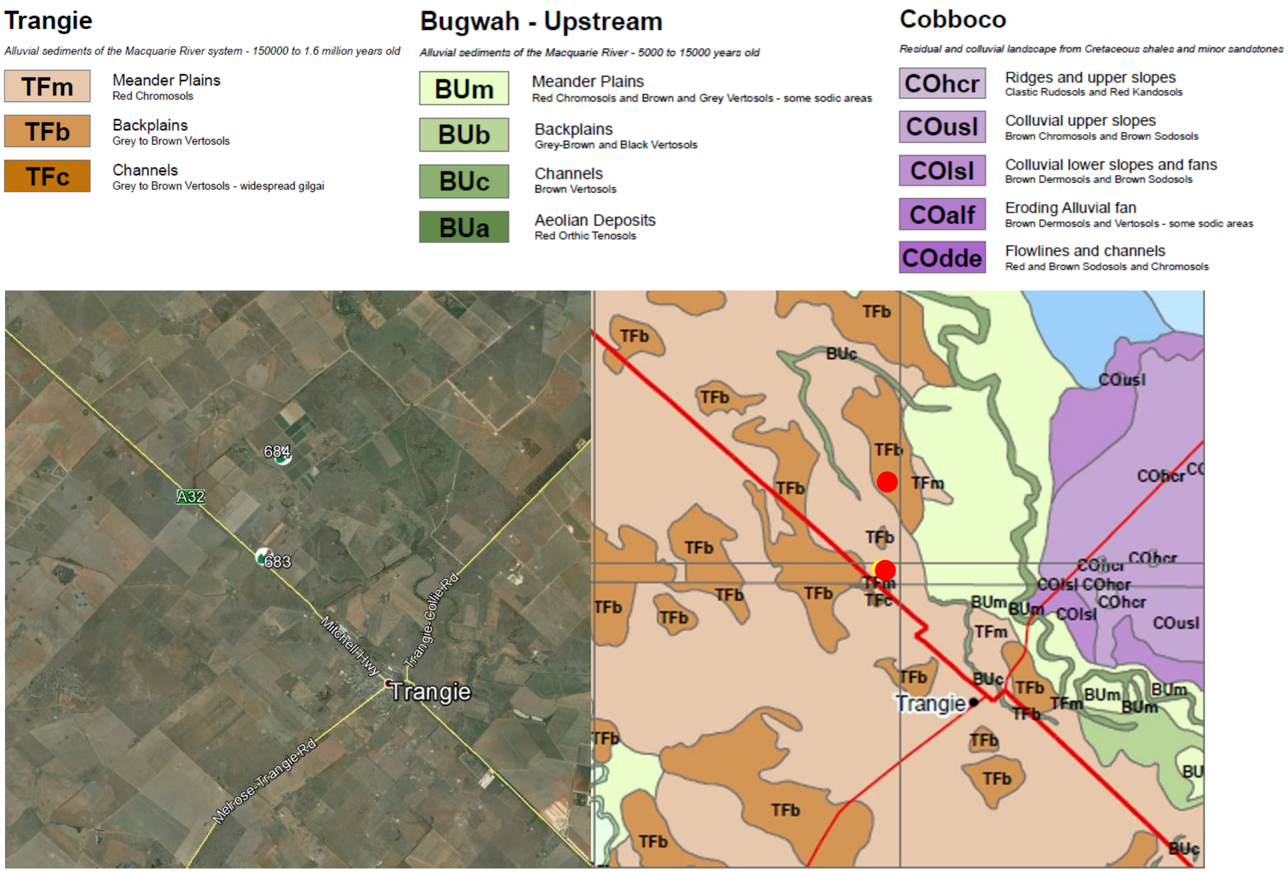


Figure 7: (a) APSoil sites in Trangie NSW area (symbols with shovels) and (b) soil-landscape mapping (Nyngan and Narromine soil-landscape maps (unpublished) Duncan et al. 2008, 2010a) with APSoil sites marked by red circles.

As described in Part I, the meander plain positions are characterised by loamy sand to clay loam surface soils over clay subsoils, whereas the backplain positions are characterised by cracking clay soils. With texture a major determinant of PAWC, the meander plain soils typically have a smaller PAWC than the backplain soils, although subsoil constraints to rooting (salinity, sodicity) can influence the magnitudes.

The soil properties and PAWCs of APSoil No683 and No684 illustrate the description of this distinction well (Figure 8, Table 2). The PAWC profile of APSoil No683 is relatively narrow and shifted to lower water contents for the lighter surface soil. Total PAWC to 180 cm, measured for a canola crop in 2008, was 141 mm. APSoil No684 had a much wider PAWC profile matching its higher clay content, with a total PAWC of 193 mm (measured in 2008 for wheat).

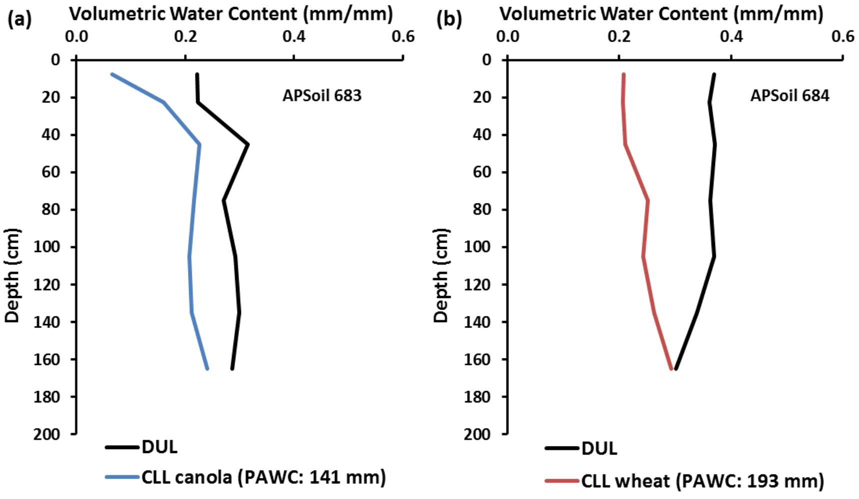


Figure 8: PAWC profiles for (a) APSoil No683 in a meander plain position and (b) APSoil No684 in a backplain position of the Trangie soil-landscape group.

Table 2: Select soil properties for APSoil No683 and No684 (data on coarse and fine sand not available)

APSoil No683																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.82	0.0	5.1	14	9	37	7	1	0	1	1			56	21	24	0.22	0.07
15-30	0.32	0.0	5.8	20	10	32	8	2	0	0	0			53	17	30	0.22	0.16
30-60	0.17	0.0	6.1	9	16	32	12	4	0	0	1			39	10	51	0.32	0.23
60-90	0.09	0.0	6.7	12	15	35	11	4	0	0	1			47	9	44	0.27	0.22
90-120	0.11	0.0	6.7	20	15	32	11	4	0	1	1			45	7	48	0.29	0.21
120-150	0.07	0.1	6.9	25	16	33	11	4	0	1	1			45	6	48	0.30	0.21
150-180	0.05	0.1	6.9	25	17	32	12	4	0	1	1			43	5	52	0.29	0.24

APSoil No684																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.68	0.1	7.8	19	29	65	20	8	1	1	3			42	13	44	0.37	0.21
15-30	0.43	0.1	7.8	21	27	56	18	8	1	0	3			38	13	48	0.36	0.21
30-60	0.32	0.2	7.8	28	28	56	15	11	2	0	6			37	12	51	0.37	0.21
60-90	0.13	0.3	7.9	60	27	57	11	12	3	0	12			42	10	48	0.36	0.25
90-120	0.07	0.4	8	87	26	54	9	12	4	0	16			44	8	47	0.37	0.24
120-150	0.05	0.4	8.1	136	23	54	7	12	4	1	19			49	7	44	0.34	0.26
150-180	0.05	0.4	8.1	132	23	54	7	11	4	1	18			50	8	43	0.30	0.29

12 Cathundral NSW area

New APSoil characterisation:

Grey Vertosol (Cathundral No1161) - – CWb (Western Carrabear backplains)

Existing APSoil characterisations:

None

The new APSoil site west of Trangie NSW, near Cathundral NSW, falls within a different soil-landscape group. This new site is in a backplain position of the Western Carrabear soil landscape group: CWb – backplain (Figure 9). The Western Carrabear soil-landscape group stretches for approximately 75 km in north-westerly direction from this site to Nyngan NSW. The location of the site is on a small wedge of the Western Carrabear soil landscape surrounded by the meander plains of the Upstream Bugwah soil-landscape group.

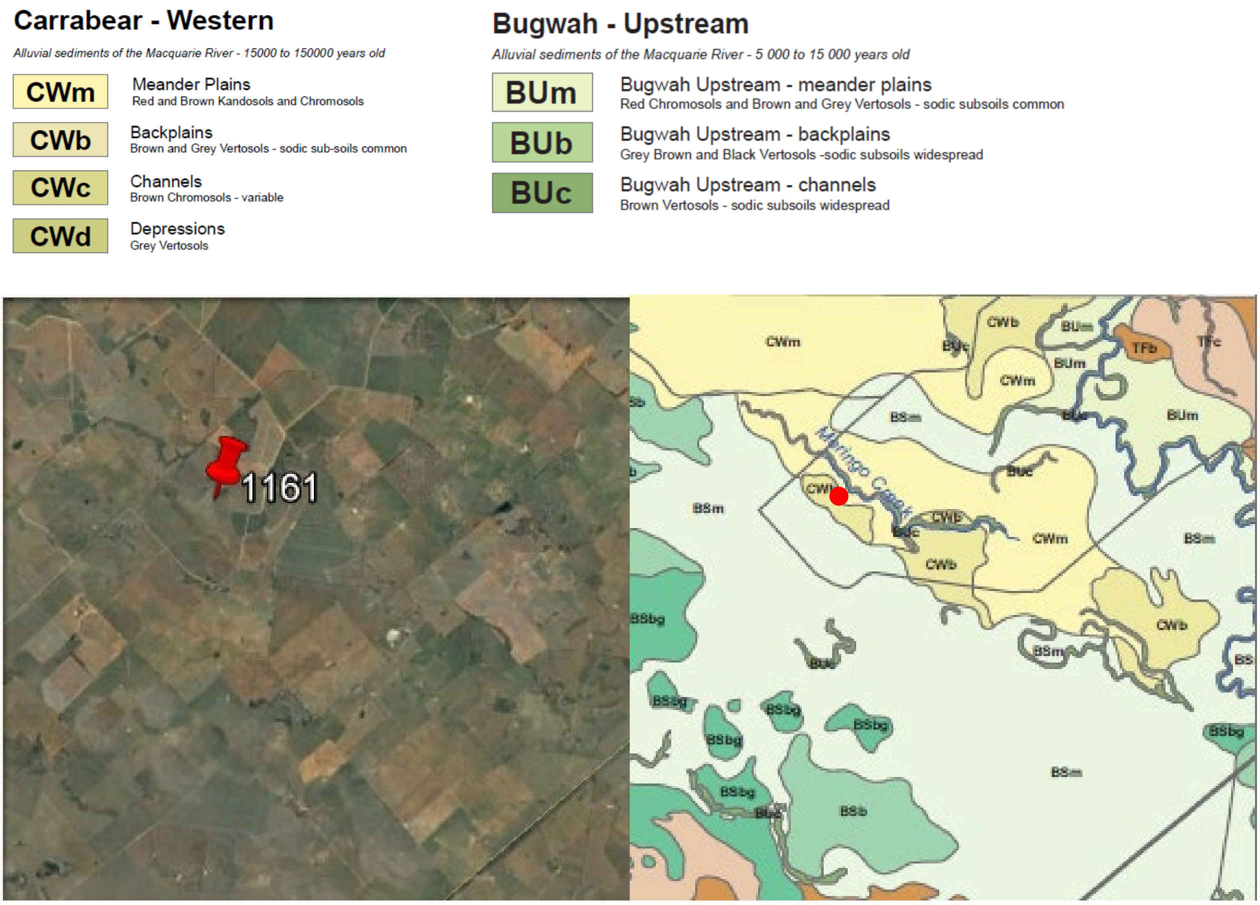


Figure 9: (a) APSoil site No1161 in Cathundral NSW area and (b) soil-landscape mapping (Narromine soil-landscape map (unpublished) Duncan et al. 2010a) with APSoil site marked by red circle.

This soil has been classified as a Vertosol, matching that of the indicative soils of the CWb unit. Sodicity and salinity in the subsoil, as indicated by ESP, EC and Cl, is slightly higher than that of APSoil No684 (Table 3).

The backplain soil formed on the Western Carrabear formation (APSoil No1161) has a lower sand and higher silt content than the backplain soil on the Trangie formation (APSoil No684) (cf. Tables 3 and 2). ESP was higher in APSoil profile No1161, with other chemistry being similar. Both soils have a similar PAWC profile and size (cf. Figure 8b and Figure 10). The slightly higher clay activity (CEC/Clay) of APSoil No1161 compared with APSoil No684 indicates more basaltic influence and more shrink-swell, but the effect on PAWC is marginal. Most of the (small) difference in total PAWC stems from the different DUL in the bottom later (150-180 cm). This may reflect the slightly lower clay content in that layer in APSoil No684 or could be caused by insufficiently deep wetting prior to DUL measurement in that characterisation.

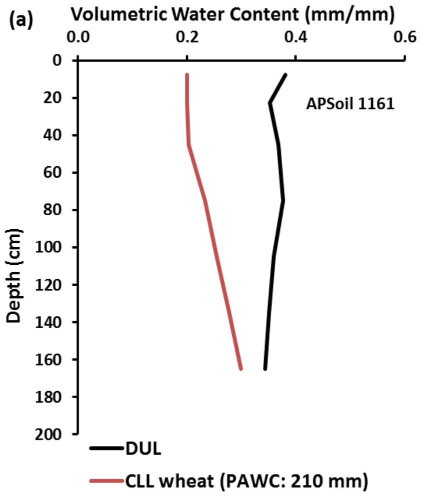


Figure 10: PAWC profile for APSoil No1161 in a backplain position of the Western Carrabear soil-landscape group.

Table 3: Select soil properties for APSoil No1161

APSoil No1161																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.57	0.1	8.3	15	27	69	19	7	1	1	4	10	26	36	24	40	0.38	0.20
15-30	0.48	0.1	8.8	14	29	73	19	8	2	1	7	10	25	35	25	40	0.35	0.20
30-60	0.42	0.2	9.2	17	30	72	18	9	3	0	11	11	22	33	25	42	0.37	0.20
60-90	0.28	0.3	9.1	41	32	73	17	9	5	1	16	8	23	31	25	44	0.38	0.23
90-120	0.17	0.9	8.5	75	32	59	17	9	6	1	19	6	23	29	16	55	0.36	0.26
120-150	0.11	0.9	8.7	133	32	83	14	9	8	1	24	7	27	34	27	39	0.35	0.28
150-180	0.26	0.6	9.1	183	32	68	14	9	9	1	27	6	21	27	25	48	0.34	0.30

13 Collie NSW area

New APSoil characterisation:

Vertosol (Collie No1156) – CEb (Eastern Carrabear backplains)

Vertosol (Collie No1157) – BAIsl (Berakee Lower slopes – transition to riverine plain)

Existing APSoil characterisations:

None

The two new APSoil sites near Collie NSW are less than 10 km apart but fall in different soil-landscapes (Figure 11). APSoil No1156 falls within a backplain position of the Eastern Carrabear formation (CEb), while that of APSoil No1157 falls within the the lower slopes of the erosional and weathering landscape of Berakee where it transitions to the riverine plain (BAIsl).

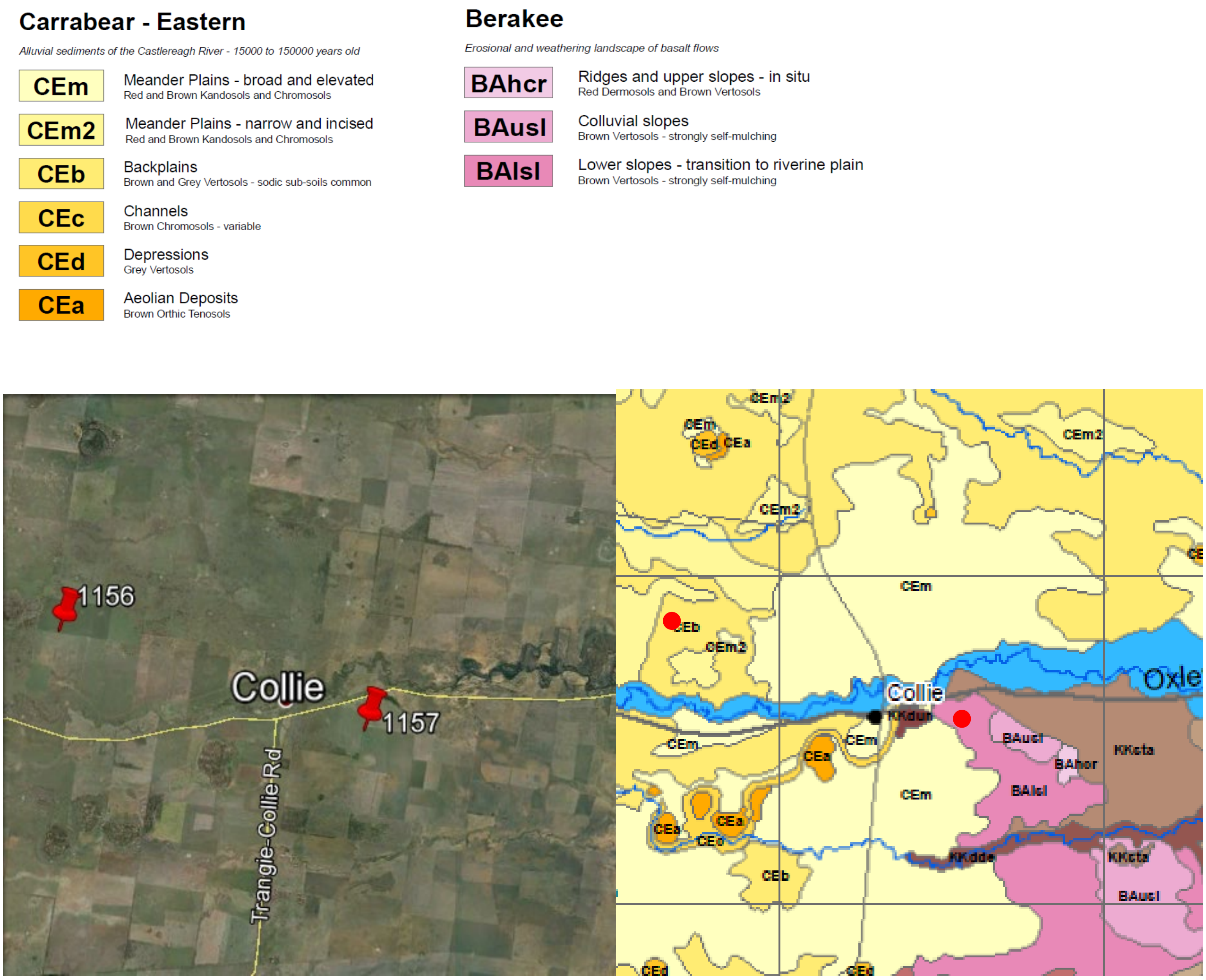


Figure 11: (a) APSoil sites No1156 and No1157 in Collie NSW area and (b) soil-landscape mapping (Nyngan soil-landscape map (unpublished) Duncan et al. 2008)

Both soils are Vertosols, matching with the indicative soils for these units. The backplain APSoil No1156 has a smaller PAWC (153 mm, measured for wheat in 2015; Figure 12) than the two previous backplain soils (APSoil No684 near Trangie (193 mm) and No1161 near Cathundral (210 mm)). The DUL is similar, but the CLL is increased (and hence PAWC decreased) more strongly and at shallower depth than in these other two backplain soils, most likely due to the higher EC and Cl below 60 to 90 cm depth (Table 4).

APSoil No1157 has a higher PAWC (194 mm, measured for wheat in 2015), due to being slightly less constrained at depth. EC and Cl are similar, but ESP is slightly lower at the 60-120 cm depth. While the site is in a different landscape group and formation, it is a transitional unit "lower slopes – transition to alluvial plain" on material of basaltic origin. The Ca/Mg ratio is slightly lower and clay activity (CEC/clay) slightly higher than that of APSoil No1156. The lower pH in APSoil No1157 at depth possibly supports the change in landform.

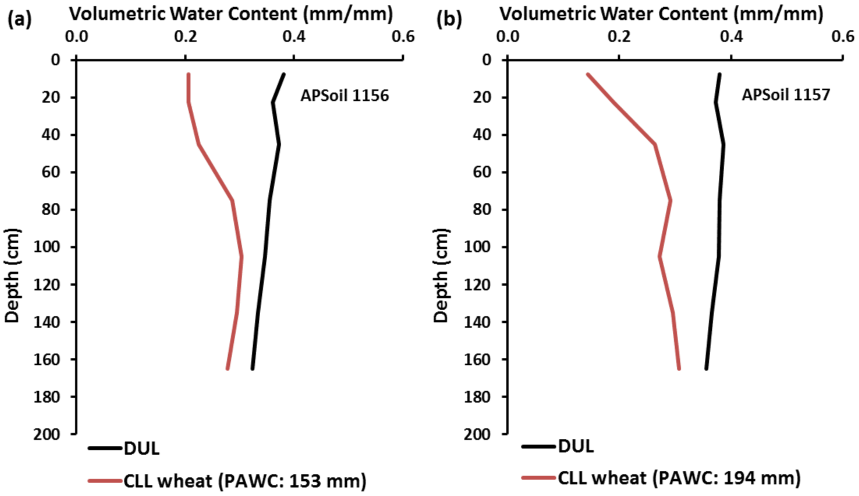


Figure 12: PAWC profiles near Collie, NSW for (a) new APSoil No1156 in backplain position of the Eastern Carrabear soil-landscape group and (b) APSoil No1157 on the lower slopes reflecting a transition to riverine plain of the Berakee soil-landscape group.

Table 4: Select soil properties for APSoil No1156 and No1157

APSoil No1156																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.90	0.2	7.9	17	27	71	21	4	1	1	3	21	22	43	19	37	0.38	0.21
15-30	0.60	0.2	8.8	34	29	68	21	6	2	0	8	21	19	39	17	43	0.36	0.21
30-60	0.48	0.2	9.3	26	31	71	19	7	5	0	15	23	15	38	19	43	0.37	0.22
60-90	0.26	0.9	8.7	58	32	66	18	6	7	0	22	21	15	36	16	48	0.36	0.29
90-120	0.24	2.3	8	297	37	*	20	7	10	0	27	18	25	43	*	*	0.35	0.30
120-150	0.16	3.4	8	744	38	*	22	6	10	0	25	15	19	34	*	*	0.33	0.29
150-180	0.14	0.9	8.5	849	32	64	15	7	10	0	31	15	19	33	18	49	0.32	0.28
APSoil No1157																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.79	0.2	8.1	15	27	85	20	5	1	1	3	21	14	35	33	32	0.38	0.14
15-30	0.51	0.2	8.5	24	30	72	20	7	2	1	6	19	20	39	19	42	0.37	0.19
30-60	0.43	0.2	9.3	18	33	79	19	10	4	1	11	18	17	35	23	42	0.39	0.26
60-90	0.28	0.9	8.6	55	33	72	16	10	6	0	17	20	17	37	17	46	0.38	0.29
90-120	0.21	3.5	7.1	259	44	*	24	11	8	0	19	15	21	36	*	*	0.38	0.27
120-150	0.18	2.0	5.2	721	38	76	18	10	9	0	24	13	19	32	18	50	0.37	0.30
150-180	0.16	0.6	5.1	891	27	50	8	9	9	0	33	12	22	34	13	53	0.36	0.31

* data missing – insufficient dispersion during analysis

West of the APSoil No1156 site and in the same Eastern Carrabear landscape was another APSoil characterisation planned (marked ‘0000’ in Figure 13). Only the CLL was measured. The location was in a backplain position, but close to the meander plain. The site has a CLL gravimetric water content profile very similar to that of APSoil No1156 (Figure 14).

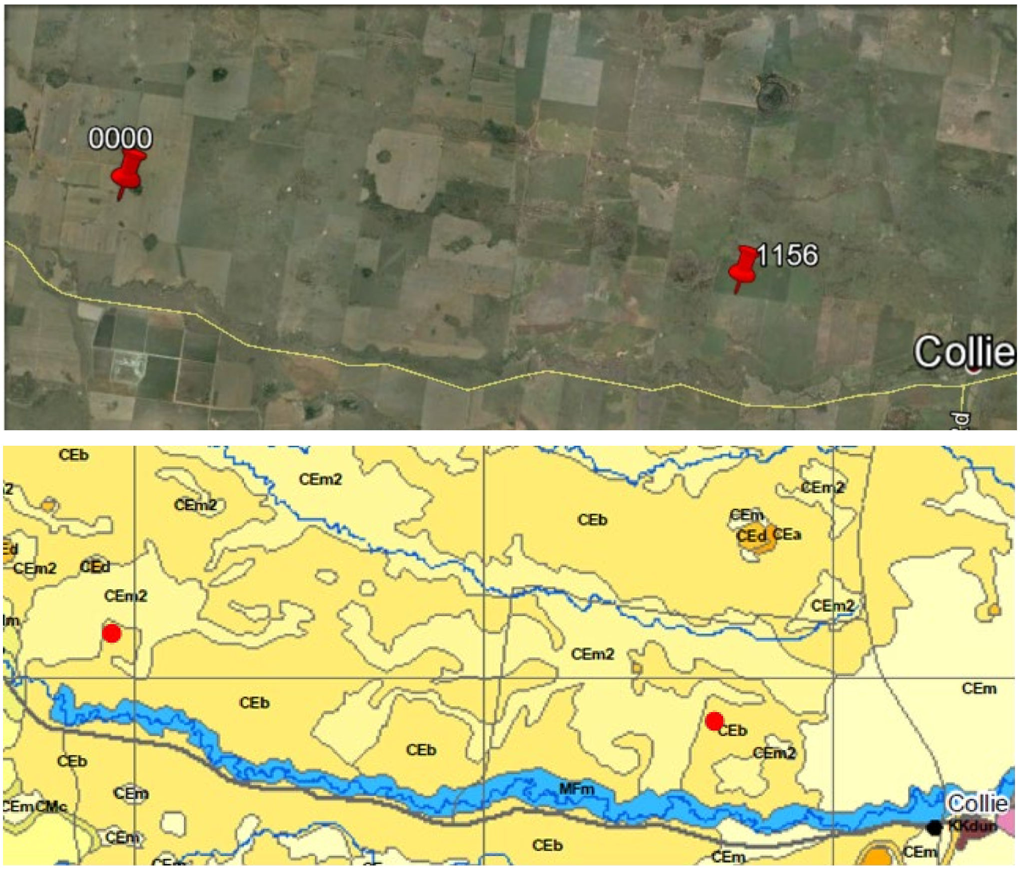


Figure 13: (a) APSoil sites in Carrabear – Eastern landscape and (b) soil-landscape mapping (Nyngan soil-landscape map (unpublished) Duncan et al. 2008)

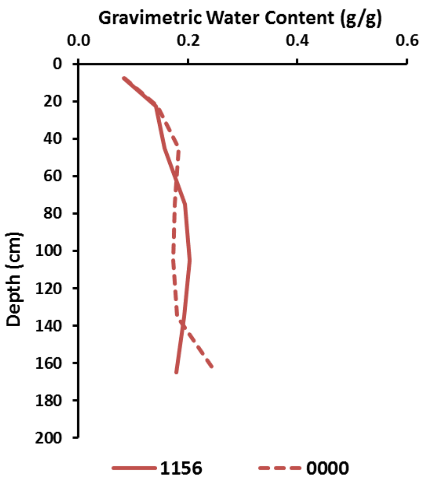


Figure 14: Gravimetric water content profiles measured under CLL rainout shelters over wheat at APSoil site No1156 and planned APSoil site No0000. Note that these profiles have not been corrected for the effect of surface evaporation near the surface.

14 Area north of Warren NSW

New APSoil characterisation:

None

Existing APSoil characterisations:

Sandy clay loam over light clay changing to clay loam at depth (Warren No248) – CMm (Macquarie Carrabear meander plains)

Medium clay (Warren No705) – (likely) CMb (Macquarie Carrabear backplains) or CMd (Macquarie Carrabear depressions)

North of Warren NSW two existing APSoil characterisations fall within the Macquarie Carrabear soil-landscape group (Figure 15). The exact location of the characterisations is unknown, although it is understood they were in the same paddock. Both are pinned to the same location in Google Earth, which matches with the CMm, meander plain unit.

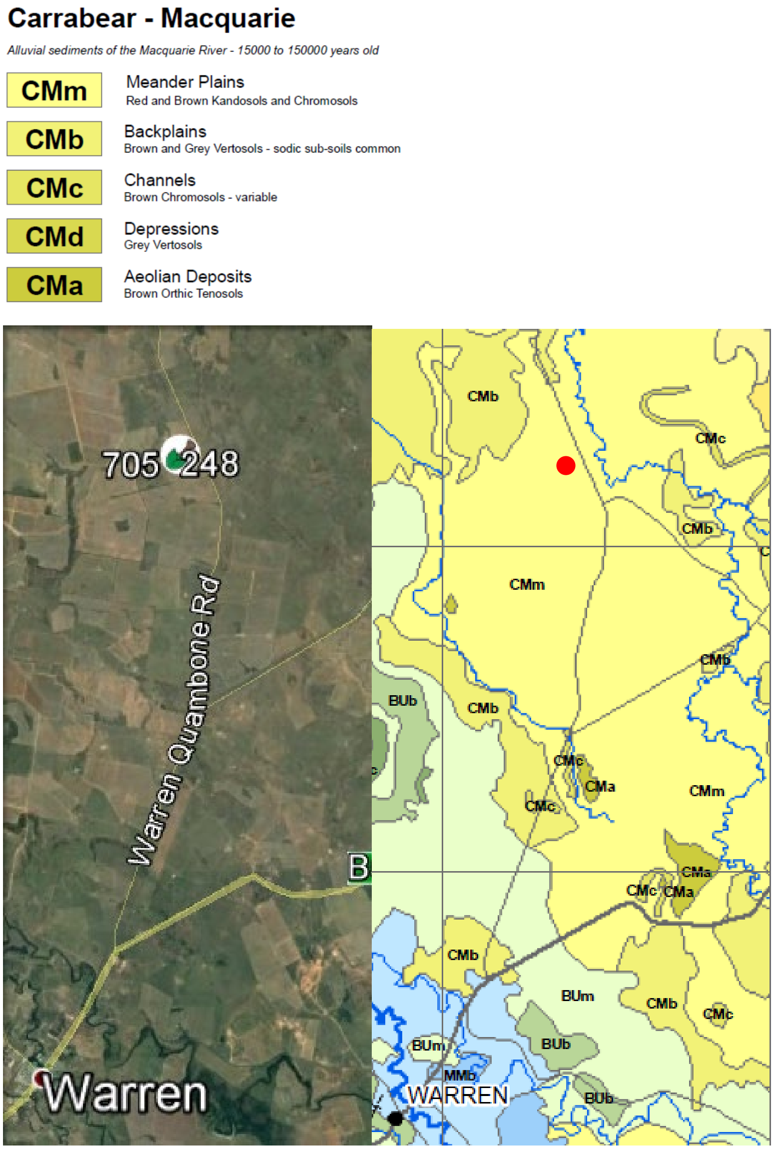


Figure 15: (a) APSoil sites north of Warren NSW (overlapping symbols with shovels) and (b) soil-landscape mapping (Nyngan soil-landscape map (unpublished) Duncan et al. 2008).

The soil properties and PAWCs of these soils (Figure 16, Table 5) differ and strongly suggest a meander plain position (CMm, APSoil No248) and a backplain (CMb) or local depression position (CMd) (APsoil No705). While it is possible that the APSoil site No 705 was located further north in the CMb unit or that the CMb unit extended further south than mapped, it is also possible that within the meander plain unit there are variations that were not mappable at the 1:250,000 scale of these maps. Indeed, a close-up view in Google Earth of the paddock suggested some within paddock variability (data not shown). An important lesson from that is to not automatically associate location within a mapping unit to a classification but corroborate this with local observations and evidence.

Compared with APSoil No 684 (Trangie), APSoil No1161 (Western Carrabear) and APSoil No1156 (Eastern Carrabear) the clay activity (CEC/Clay) of APSoil No705 is lower, meaning reduced shrink-swell is likely responsible for the slight shift in DUL to lower water contents, despite its slightly higher clay content. Dispersion (high ESP along with low EC) may also have contributed to the narrowing of PAWC at depth.

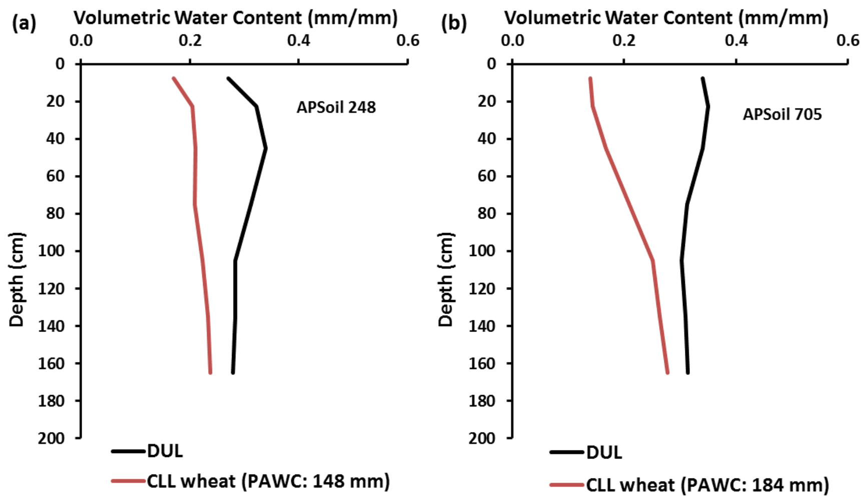


Figure 16: PAWC profiles north of Warren, NSW for (a) APSoil No248 in a meander plain position and (b) APSoil No705 in a backplain or (local) depression position of the Macquarie Carrabear soil-landscape group.

Table 5: Select soil properties for APSoil No248 and No705 (coarse and fine sand fractions not available)

APSoil No 248																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	1.03	0.1	4.9	27	11	38	7	3	0	1	1			49	22	29	0.27	0.17
15-30	0.53	0.0	4.8	21	12	38	7	4	0	0	2			48	21	31	0.32	0.21
30-60	0.38	0.1	6.5	11	24	51	13	9	1	0	5			36	17	47	0.34	0.21
60-90	0.19	0.2	7.7	13	23	51	11	10	2	0	7			36	18	45	0.31	0.21
90-120	0.09	0.2	8	75	22	50	10	9	2	0	8			35	21	44	0.28	0.22
120-150	0.05	0.3	7.9	231	18	46	9	7	1	0	7			37	24	39	0.28	0.23
150-180	0.03	0.3	7.9	273	19	48	10	8	1	0	6			37	23	40	0.28	0.24

APSoil No 705																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.74	0.0	6.1	13	21	48	14	6	0	1	1			36	19	45	0.34	0.14
15-30	0.47	0.1	6.8	14	21	48	14	6	0	0	2			36	20	43	0.35	0.14
30-60	0.28	0.1	7.8	9	26	52	15	9	2	0	7			30	19	51	0.34	0.17
60-90	0.24	0.2	7.9	16	24	49	11	10	3	0	13			32	19	49	0.31	0.21
90-120	0.19	0.3	7.9	59	25	47	10	10	5	0	18			28	19	53	0.30	0.25
120-150	0.07	0.3	7.7	135	26	51	10	11	5	0	20			29	20	51	0.31	0.26
150-180	0.05	0.4	7.5	165	26	47	9	10	5	0	20			26	19	54	0.31	0.28

15 Area west of Combara NSW

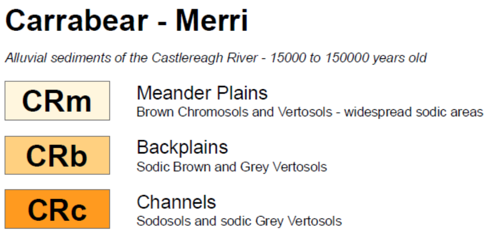
New APSoil characterisation:

Grey Vertosol (Coonamble) No1160) – CRb (Merri Carrabear backplains)

Existing APSoil characterisations:

None

This new APSoil characterisation west of Combara NSW is located in a backplain position of the Merri Carrabear soil-landscape group (CRb) (Figure 17). The classification Vertosol matches that of the indicative soil profiles for this unit.



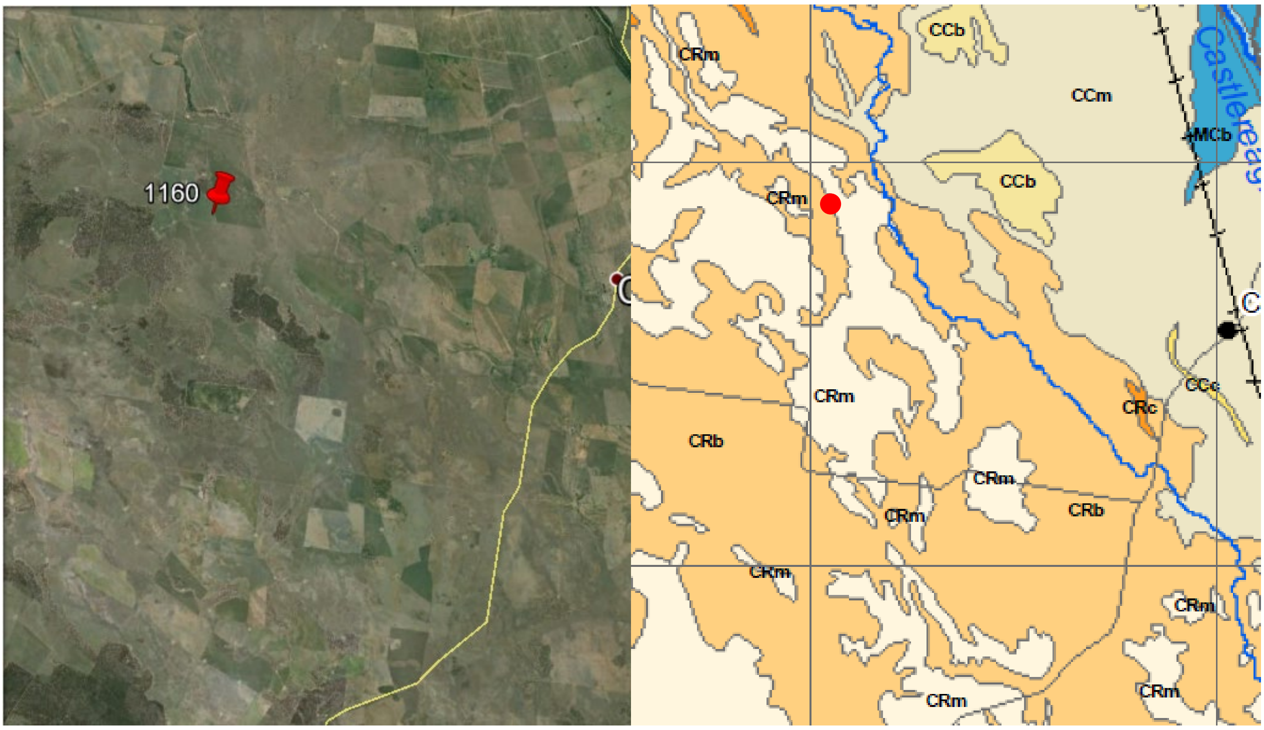


Figure 17: (a) APSoil site No1160 west of Combara NSW, and (b) soil-landscape mapping (Nyngan soil-landscape map (unpublished) Duncan et al. 2008)

The Grey Vertosol APSoil No1160 has high EC, Cl and ESP in the subsoil from about 60 cm depth (Table 6) limiting the total PAWC to 126 mm (Figure 18; measured for barley in 2015), well below that of other backplain soils that are less constrained. The reduced PAWC is in part due to DUL being relatively low compared with the other backplain soils. Sodicity may have contributed to this, although the high salinity would likely reduce dispersion, or it may be due to the low percentage of silt and high percentage of coarse sand (Table 6).

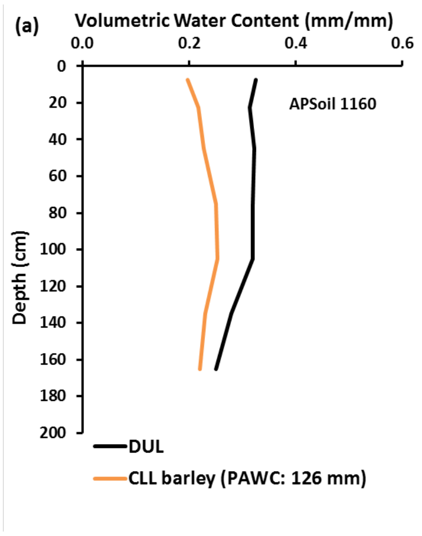


Figure 18: PAWC profile for (a) APSoil No1160 – in backplain position of Merri Carrabear soil-landscape group

Table 6: Select soil properties for APSoil No1160

APSoil No1160																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.60	0.3	8.2	9	24	61	17	5	1	1	5	32	15	47	14	39	0.32	0.20
15-30	0.39	0.3	8.9	5	28	66	19	6	3	0	9	29	15	44	14	42	0.31	0.22
30-60	0.39	0.3	9.2	72	26	59	15	6	4	0	17	31	13	43	13	44	0.32	0.23
60-90	0.27	0.6	9.2	319	25	59	13	6	6	0	24	32	14	46	11	43	0.32	0.25
90-120	0.19	0.9	9	517	28	62	14	6	8	1	27	29	15	44	11	45	0.32	0.25
120-150	0.13	0.9	9.2	627	25	67	12	5	7	1	27	34	18	52	12	36	0.28	0.23
150-180	0.10	0.9	9.1	668	23	64	11	5	6	0	28	38	17	55	10	35	0.25	0.22

16 Coonamble NSW area

New APSoil characterisation:

Brown Vertosol (Coonamble No1158) – CCb (Combara Carrabear backplains)
Sandy Clay Loam (Coonamble No1159) – CCm (Combara Carrabear meander plains)

Existing APSoil characterisations:

None

Further north two more new APSoil sites were characterised. Both of these fell within the Combara Carrabear landscape, with APSoil No1158 in a backplain position (CCb) and APSoil No1159 in a meander plane position (CCm) (Figure 19).

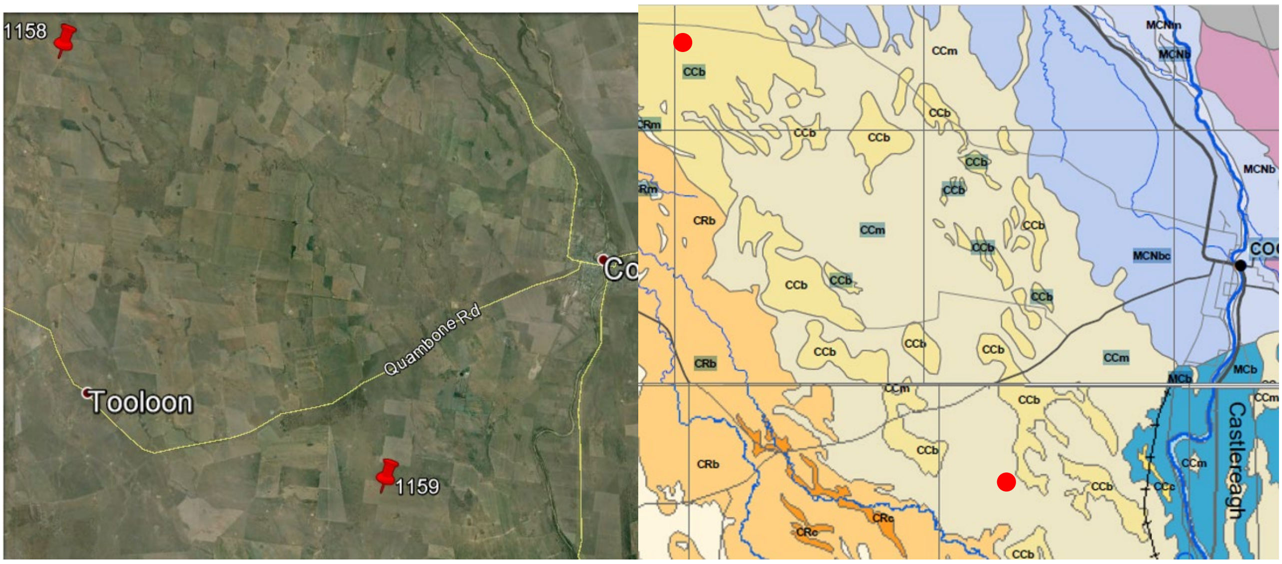


Figure 19: (a) APSoil sites in Combara Carrabear landscape near Coonamble NSW, and (b) soil-landscape mapping (Nyngan and Walgett soil-landscape maps (unpublished) Duncan et al. 2008, 2010b)

The Brown Vertosol classification of APSoil No1158 matches the indicative soils for the CCb unit. It has a classic Vertosol PAWC profile with slight subsoil constraints (Figure 20a), although we need to note this characterisation was done in chickpea, which tends to be shallower rooting and more susceptible to subsoil constraints. Wheat or barley may root deeper and have a larger PAWC. On the assumption that wheat would root deeper, the PAWC is large given the high ESP and EC for this profile. This could be due to the fact that the high EC is not due to salinity (Cl low). In addition, the percentage silt is high compared with backplain soils in the other soil-landscape groups.

The uniform texture profile – loam to sandy loam – of APSoil No1159 matches with the main soil within CCm having a Kandosol classification. Its deep uniform PAWC profile (Figure 20b) and no subsoil constraints matches with that classification and the associated chemistry (Table 7).

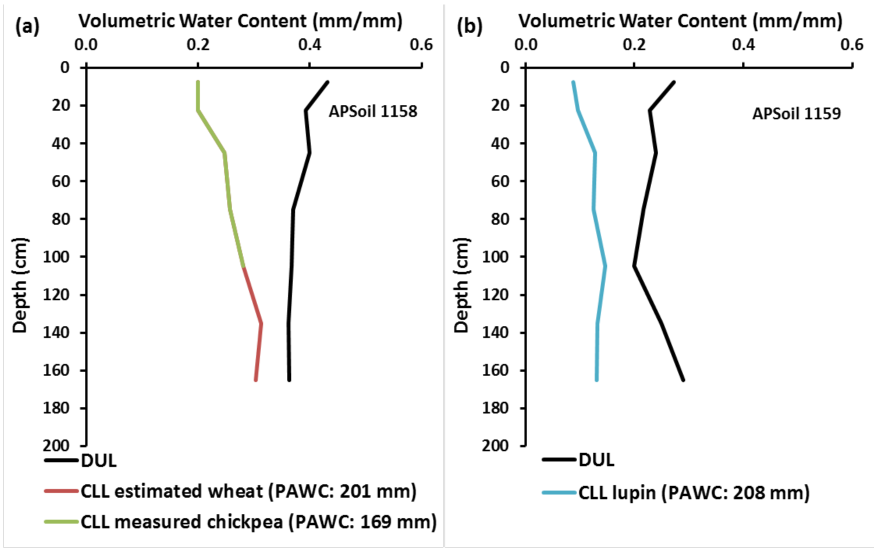


Figure 20: PAWC profiles near Coonamble NSW for (a) APSoil No1158 in a backplain position and (b) APSoil No1159 in a meander plain position of the Combara Carrabear soil-landscape group.

Table 7: Select soil properties for APSoil No1158 and APSoil No1159; APSoil 1158 CLL for chickpea.

APSoil No1158																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.60	0.5	8.5	27	32	65	19	7	5	1	15	14	13	27	25	49	0.43	0.20
15-30	0.59	0.3	8.6	26	34	62	21	8	3	1	10	13	10	23	23	55	0.39	0.20
30-60	0.43	0.2	9	23	33	70	19	8	5	1	15	11	13	24	30	46	0.40	0.25
60-90	0.42	1.0	7.4	20	33	*	18	7	6	1	18	7	13	20	*	*	0.37	0.26
90-120	0.39	0.9	7.9	18	33	66	14	9	9	1	28	5	9	14	36	50	0.37	0.28
120-150	0.18	0.9	7.9	19	32	59	13	9	10	1	30	8	11	19	28	54	0.36	
150-180	0.20	0.7	7.9	24	31	57	13	9	9	1	29	10	12	22	24	55	0.36	
APSoil No1159																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.52	0.1	7.2	8	10	60	6	2	1	1	13	28	39	67	16	17	0.27	0.09
15-30	0.48	0.1	7.4	6	12	67	8	2	1	1	9	29	40	69	13	18	0.23	0.10
30-60	0.37	0.1	7.7	7	13	60	10	2	1	0	7	33	33	66	12	22	0.24	0.13
60-90	0.21	0.1	8.6	3	14	77	12	2	0	0	3	36	34	70	12	18	0.22	0.12
90-120	0.17	0.1	8.5	6	12	74	10	2	0	0	3	42	31	73	10	17	0.20	0.15
120-150	0.17	0.1	8.6	8	16	74	11	4	0	0	2	29	33	62	17	21	0.25	0.13
150-180	0.17	0.1	8.7	12	15	64	10	4	0	0	3	25	43	68	9	23	0.29	0.13

* data missing due to incomplete dispersion

17 Mulla - Nyngan NSW area

New APSoil characterisation:

Brown Vertosol (Nyngan No1155) – MUalp (Mulla Cowal Alluvial plain)

Clay loam over light clay (Nyngan No1163) – MUalp (Mulla Cowal Alluvial plain)

Existing APSoil characterisations:

Sandy clay loam over sandy clay (Nyngan No246)

The two new APSoil characterisations are located in the alluvial plain between the Bogan River and the Western Carrabear soil-landscape group (Figure 21). Both sites are located within the (MUalp) unit within the Mulla Cowal alluvial plain soil-landscape where backplain and meander plain units are not mapped further.

NSW eSPADE shows some survey profile points nearby. Those away from the river like APSoil No1163 are classified as Red Chromosols and those closer to the river like APSoil No1155 as Brown Vertosols. For one of these it is indicated the location was in ‘oxbow’ physiography, which would explain the heavier nature of the soil, and by inference maybe also that of APSoil No1155.

The existing APSoil site No246 is located about 15 km away on the other side of the Bogan River. This is a different landscape, consisting of alluvial fan, plains and channels of Pangee Creek, with the site located on the old alluvial plain (PFsta).

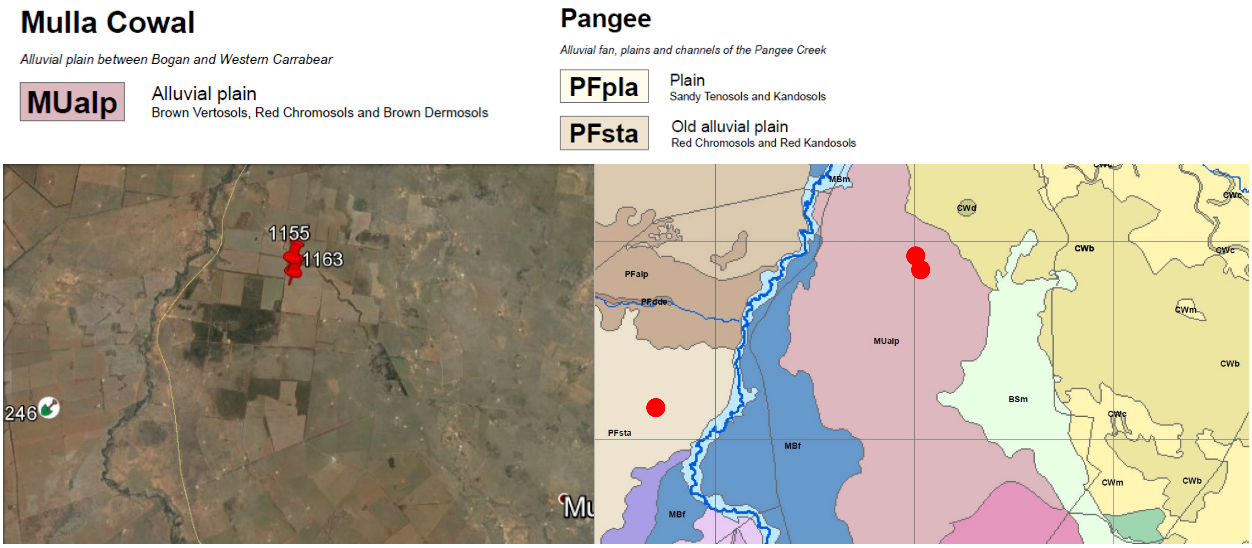


Figure 21: (a) Location of sites in the Mulla – Nyngan NSW area, and (b) soil-landscape mapping (Nyngan soil-landscape maps (unpublished) Duncan et al. 2008).

While being located within one paddock about 750 m apart, the new APSoil sites No1155 and 1163 have strongly contrasting soil properties and PAWC (Table 8, Figure 22). They reflect different alluvial plain positions, with No1163 being a duplex soil with a smaller PAWC (measured under wheat in 2015 as 177 mm to 180 cm depth) and No1155 being a clay soil with larger PAWC (209 mm under wheat in 2015 to 180 cm). Contrary to typical meander and backplain positions, the clay soil is closest to the current creek. It is possibly located in an oxbow position. Such local differences are not mapped in this soil-landscape unit and are difficult to pick up in Google Earth and the Soil and Landscape Grid, so a local assessment of texture (at least surface 0-30 cm) will be needed to be made when choosing between the two profiles. APSoil site No 248 has a granitic origin as supported by its much lower clay activity (CEC/clay). Its texture becomes heavier gradually with depth (sandy clay loam to clay), which is reflected in the position of the PAWC profile. Total PAWC (to 150 cm) is only 108 mm.

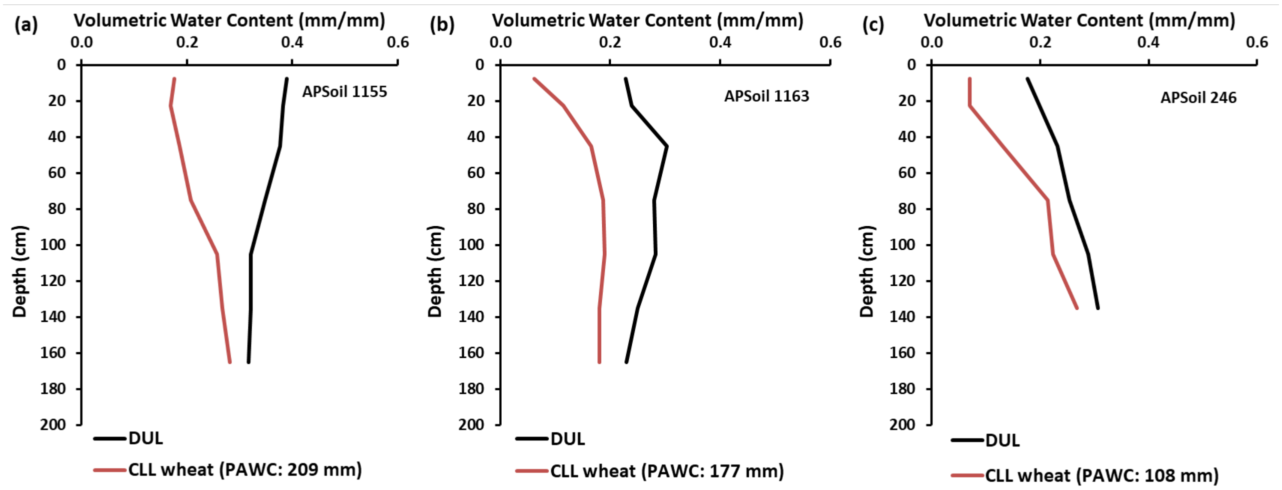


Figure 22: PAWC profiles in the Mulla – Nyngan NSW area for (a) APSoil No1155 suspected depression position and (b) APSoil No1163 in a meander plain position of the Mulla Cowal soil-landscape group and (c) APSoil No248 on an old alluvial plain of the Pangee soil-landscape group.

Table 8: Select soil properties for APSoil No1155, APSoil No1163 and APSoil No246 (*marked data in doubt due to suspected inclusion of carbonate)

APSoil No1155																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.63	0.1	7.1	17	19	50	10	6	1	1	7	7	37	44	19	37	0.39	0.18
15-30	0.48	0.3	8.9	14	27	60	15	8	3	1	12	5	32	37	18	45	0.38	0.17
30-60	0.28	0.3	9.3	182	26	61	12	7	5	1	21	8	31	39	18	43	0.38	0.19
60-90	0.15	0.7	9.1	744	27	67	11	8	8	1	29	6	34	40	19	41	0.35	0.21
90-120	0.16	2.5	8.0	966	31	80	14	7	8	1	27	7	33	40	22	38	0.32	0.26
120-150	0.11	1.1	8.8	1015	29	72	11	8	10	1	33	5	31	37	23	40	0.32	0.27
150-180	0.11	1.4	8.9	1351	29	68	9	8	10	1	35	4	30	35	23	42	0.32	0.28
APSoil No1163																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.87	0.1	6.5	5	11	43	7	2	0	2	0	15	47	61	14	24	0.23	0.06
15-30	0.58	0.1	7.8	6	21	55	15	4	0	2	1	11	35	46	15	39	0.24	0.11
30-60	0.33	0.1	8.3	5	22	54	15	6	0	2	2	9	30	39	20	41	0.30	0.16
60-90	0.17	0.1	8.9	8	22	49	13	6	1	1	4	11	28	39	17	44	0.28	0.19
90-120	0.16	0.2	9.1	6	22	52	11	7	1	2	7	9	29	38	20	42	0.28	0.19
120-150	0.12	0.2	9.3	10	21	50	10	7	2	1	9	8	26	34	25	41	0.25	0.18
150-180	0.10	0.2	9.3	17	20	50	9	7	2	2	12	7	28	35	25	40	0.23	0.18
APSoil No246																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.57	1.2	7.1	31	26*	124*	21*	3	1	1	4			71	8	21	0.18	0.07
15-30	0.32	0.0	7	17	8	41	6	1	0	1	1			72	10	18	0.20	0.07
30-60	0.15	0.0	7.1	14	8	33	5	2	0	1	0			67	9	24	0.23	0.13
60-90	0.11	0.1	7.1	10	15	37	7	6	0	2	2			49	9	41	0.25	0.21
90-120	0.07	0.1	7.4	11	20	39	9	8	1	2	3			42	8	51	0.29	0.22
120-150	0.05	0.2	7.8	16	20	45	8	8	1	2	5			46	9	45	0.31	0.27

18 Hermidale NSW area

New APSoil characterisation:

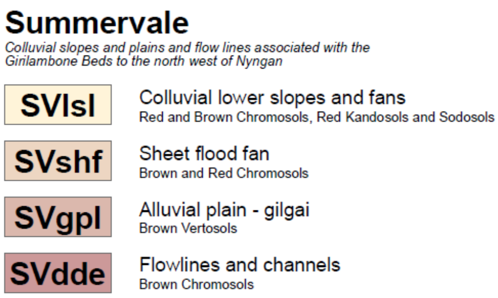
Sandy Clay Loam (Nyngan No1162) – (SVlsl) Colluvial lower slopes and fans

Loam over clay loam – nearby soil pit

Existing APSoil characterisations:

None

One new site, APSoil No1162, and a demonstration soil pit site nearby are located north and south of the road from Nyngan to Hermidale, just past Miandetta (Figure 23). This area falls just outside the Nyngan soil-landscape map, but extrapolation of the units using the underlying 1:250 000 Cobar Geology map (Brunker 1969) places both sites on the colluvial lower slopes and fans (SClsl) of the Summervale soil-landscape group, which is associated with the Girilambone Beds.



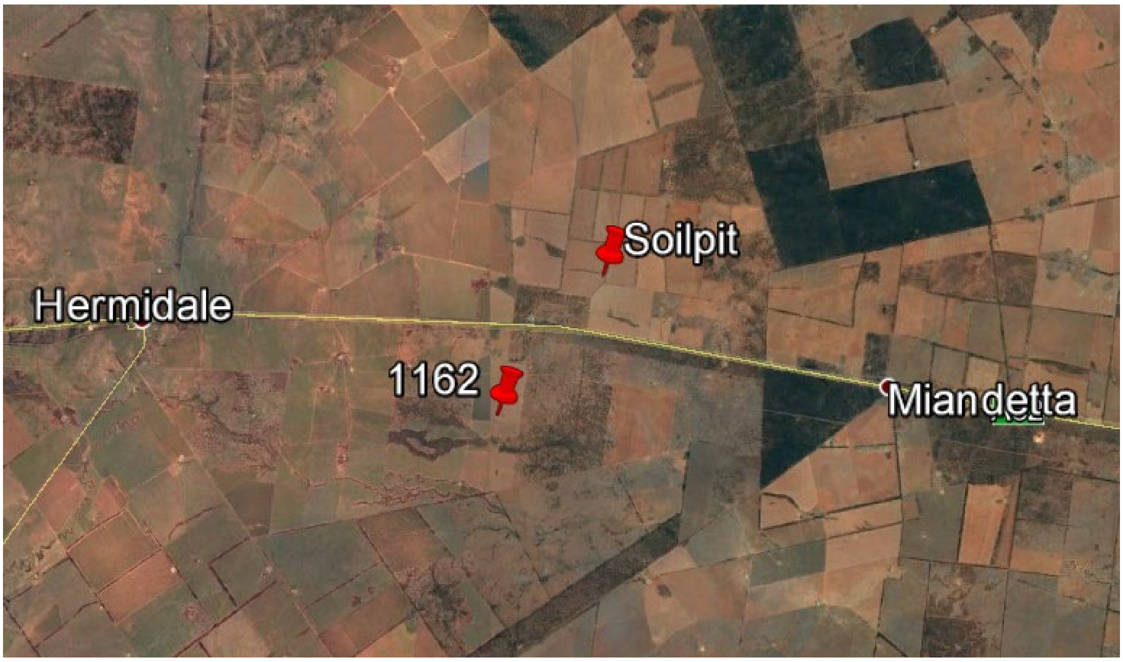


Figure 23: Location of sites in the Hermidale NSW area.

APSoil No1162 is a gradational soil with texture (based on PSA) gradually increasing from sandy clay to loam and light clay. This texture change is reflected in the PAWC profile (Figure 24). The surface soil was high in Cl, but otherwise there were no apparent constraints on PAWC, except for the soil being relatively shallow compared with soils on the alluvial plains.

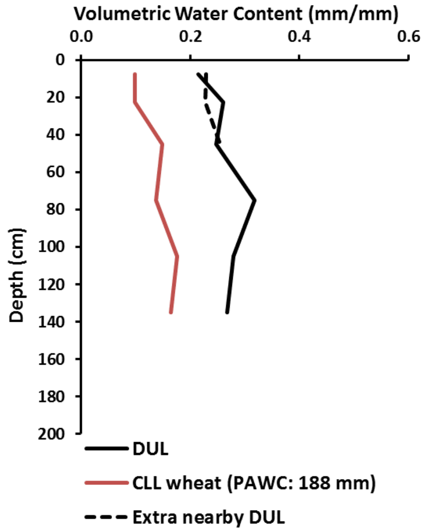


Figure 24: PAWC profiles in the Hermidale NSW area for APSoil No1162 in a position of lower colluvial slopes with (dashed line) additional data from the nearby soil pit site.

Table 9: Select soil properties for APSoil No1162 and the nearby soil pit.

APSoil No1162																		
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay	DUL	CLL
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)					(mm/mm)	
0-15	0.67	0.1	6.4	859	6	30	4	1	0	1	1	39	35	74	5	22	0.21	0.10
15-30	0.49	0.1	7.3	70	7	28	5	1	0	1	1	32	36	67	9	24	0.26	0.10
30-60	0.26	0.0	7.5	11	8	27	5	1	0	1	1	27	35	62	8	30	0.25	0.15
60-90	0.17	0.0	7.9	4	9	27	6	2	0	1	1	22	35	57	9	34	0.32	0.14
90-120	0.20	0.1	7.8	4	11	26	6	4	0	1	1	15	31	46	11	43	0.28	0.18
120-150	0.15	0.0	7.9	3	10	26	6	4	0	1	1	16	38	53	7	40	0.27	0.16

Nearby soil pit																
Depth	OC	EC	pH	Cl	CEC	CEC/ Clay	Ca	Mg	Na	K	ESP	Coarse Sand	Fine Sand	Sand	Silt	Clay
(cm)	(%)	(1:5 dS/m)	(1:5 water)	(mg/ kg)	(cmol+/kg)						(%)	(%)				
0-10	0.80	0.1	7.2	9	10	52	8	1	0	1	1	19	45	64	17	19
10-30	0.50	0.1	7.4	9	11	46	9	1	0	1	1	18	43	61	16	24
30-60	0.30	0.1	7.6	9	12	39	9	2	0	1	1	16	39	56	13	32
60-90	0.10	0.1	8.1	9	15	41	10	3	0	1	1	15	35	49	15	36
90-120	0.10	0.1	7.0	10	13		6	5	1	1	5					
120-150																

Part III Discussion

19 Extrapolating from the APSoil characterisations

In Section 7 of this report general guidance was provided for choosing an APSoil characterisation based on comparing soil properties and finding a soil that is similar. As soil surveys also group soils on the basis of similarities in properties and, in the case of soil-landscape mapping, geology and position in the landscape, we hypothesised in Section 8 that soil-landscape mapping may provide a means to extrapolate from the APSoil characterisations.

Presenting the existing and new APSoil characterisations in Part II in the context of the available soil-landscape mapping (Duncan et al. 2008, 2010a, 2010b) was a first attempt to link APSoil characterisations with their soil-landscape mapping units. As indicated in the individual sections, the PAWC and descriptions of the APSoil characterisations often matched the description of key soils of the soil-landscape mapping units they were located in.

In this section we take this a step further and explore whether these APSoil characterisations are likely representative of the main soils within these soil-landscape units and whether enough soils are captured to allow extrapolation and prediction of PAWC. We do this by comparing the soil properties of the APSoil characterisations with those of soil profiles collected during the course of the soil survey program for the development of the soil-landscape maps for the 1:250 000 sheets of Nyngan, Narromine and Walgett (Duncan et al. 2008, 2010a, 2010b). These profiles were collected using a 50 or 75 mm soil corer, usually on roadsides or on landholders' paddocks under agricultural production. The soils were analysed using standard laboratory methods as described in http://www.environment.nsw.gov.au/soils/testmethods.htm. The data is summarised, along with detailed descriptions of the soil landscape mapping units, in Duncan et al. (2012) and Forbes et al. (2012a,b) and also available through eSPADE.

The comparisons are, at this stage, limited to descriptive physical and chemical properties and do not extent to the PAWC itself. While 'field capacity' (FC; -100 cm matric potential) and 'permanent wilting point' (PWP; -15 bar matric potential) were determined for many of the soil profiles in the soil-landcape surveys, it can be difficult to compare these results with the in-situ, field measured DUL and CLL of APSoil characterisations. The laboratory-based measures of FC and PWP were determined using disturbed samples. In addition, and unlike the field based DUL and CLL, they do not capture effects of soil structure or limitations of physical or chemical constraints like high bulk density, salinity or sodicity on rooting density or effectiveness. They may, however, still provide an indication of the likely variability within the mapping units of the unconstrained PAWC – also referred to as the soil available water capacity (AWC).

An approach that may provide insights into variability of PAWC within mapping units as well as determining how representative the APSoil characterisations are, is by predicting PAWC on the basis of measured physical and chemical properties. In Australia the prediction of soil hydraulic properties has been subject of investigation on and off since the early 1990s (see review by McKenzie and Cresswell 2002), including several studies that captured a wide variety of soils (among others, Williams et al. 1992; Minasny et al 1999). There have also been a few attempts to characterise the effects of subsoil constraints on CLL (Hochman et al. 2001, 2007; Burk and Dalgliesh 2012). These have, however, not been tested widely and hence 'universal' equations are still subject of further research.

Here we have included a preliminary analysis where FC, PWP and the resulting AWC are predicted for a number of the APSoil and soil survey profiles based on particle size analysis using the Neuroman model (Minasny et al. 1999; Minasny and McBratney 2002). The New South Wales data set within Neuroman was used to predict the water holding properties. In the tables the mean value and the standard error of the predictions are given. A full analysis would require verification that the predictive algorithms apply to the local soils. The analysis is, therefore, only a first step to determine whether this may be a suitable approach to pursue. In addition, it should be noted that a particle size-based prediction of PAWC ignored other factors that affect the PAWC (see Section 3). Like the above laboratory-based measures, the effects of subsoil constraints that limit crop rooting or its effectiveness are not considered in these predictions. These may have an overriding effect on PAWC and be difficult to predict. Hence, the predictions are for AWC.

Trangie Backplains (TFb)

According to Duncan et al. (2012) the main soils of the backplains of the Trangie soil-landscape group (TFb) are "Grey Vertosols with weakly self-mulching surfaces. Some surface soils are weakly sodic and have coarse structured clay surface soils. There are some more strongly self-mulching surface soils."

Comparing the properties of APSoil No684 with soil survey profiles of TFb soils (Table 10), suggests that APSoil No684 is representative of the modal soil profile for the Trangie backplains, although it is slightly less saline and sodic in the deep subsoil (> 75 cm). At the extremes within the Trangie backplains there are profiles that have slightly different properties. For example, TFb profile 53 had a more clayey subsoil which may increase PAWC, and TFb profile 44 had higher levels of sodicity and salinity in the subsoil which are likely to reduce the PAWC. Despite these differences, the measured FC and PWP for the soil survey profiles were similar (Figure 25a).

Particle size analysis-based predictions of AWC (i.e. unconstrained PAWC profiles) suggest that profile APSoil No684 represents the Trangie backplain soils reasonably well, with AWC being between 1.1 and 1.3 mm/cm across the profile (Table 10) and positions of FC and PWP predicted to be similar to those of the survey profiles (Figure 25b). The lower predicted FC and PWP for TFb profile 44 at 27.5 cm in (Figure 25b) relates to an unexpected low clay content in this layer. This could be a lighter texture layer or it could be an error given the unusually high CEC/clay (Table 10).

Comparison of the laboratory FC and PWP (Figure 25a) with the predicted FC and PWP (Figure 25b) and field measured DUL and CLL (Figure 25c) suggest that the laboratory method with disturbed soil samples may have overestimated the FC. The measurement at -100 cm suction would be sensitive to changes in pore structure. In addition, there is a lack of overburden pressure, which may affect swelling clay samples. The laboratory measurement of PWP (15 bar suction) appears to provide a better estimate of (unconstrained) CLL.

Further research will be needed to assess the variability of subsoil constraints within this soil-landscape as that will modify the AWC and determine the actual PAWC. The low levels of salinity and sodicity observed in APSoil No684 mean that its PAWC is unconstrained. The predicted AWC indeed compared well with the field measured PAWC (Figure 25c), except in the 15-60 cm layer where the CLL obtained in the field was lower than the predicted PWP. The prediction method is based on calibration against datasets of laboratory based 15 bar measurements. The relationship between maximum field water extraction and 15 bar measurements is subject of further research in another project.

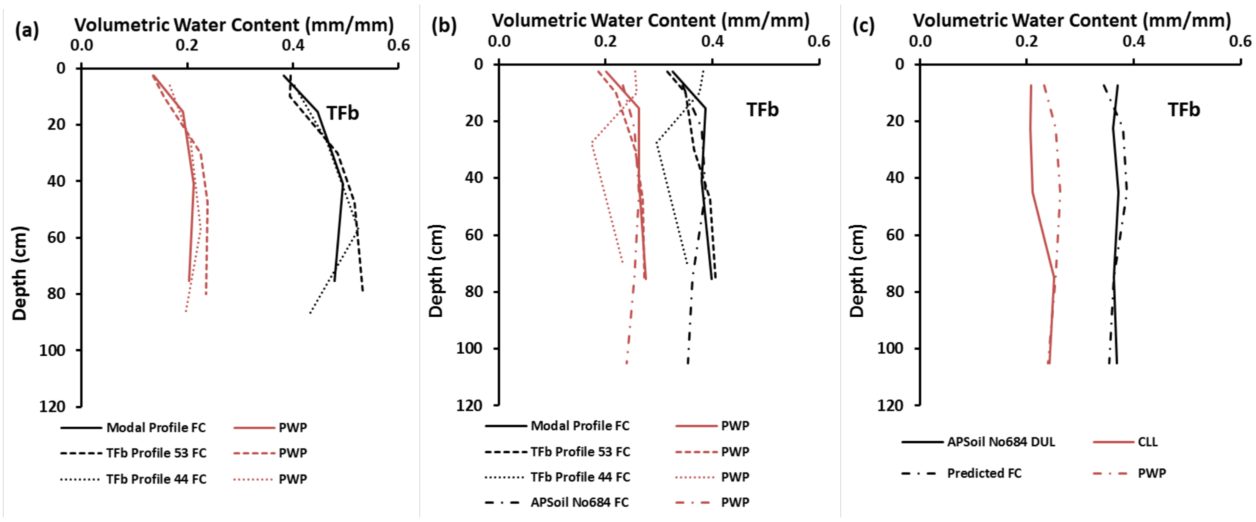


Figure 25: (a) Laboratory measured FC and PWP for modal and select TFb soil survey profiles; (b) predicted volumetric FC and PWP based on particle size data for APSoil No684, modal and select TFb survey profiles; (c) comparison of predicted volumetric FC and PWP with field measured CLL and DUL for APSoil No684.

Table 10: Soil properties relevant to PAWC for Trangie Backplains (TFb) comparing APSoil No 684 with modal and select profiles describing the TFb unit (data with permission from Duncan et al. 2012). Predicted values for unconstrained profiles from Neuroman program with mean and standard error given.

Horizon	Depth	Clay	Silt	Fine sand	Coarse Sand	Total sand	Gravel & stones	EC 1:5	CEC	CEC/ Clay	Ca	Mg	Na	Ca/ Mg	ESP	Lab measured FC	Lab measured PWP	Predicted (unconstrained) FC	Predicted (unconstrained) PWP	Predicted (unconstrained) AWC	SOC	pH 1:5
	cm	%	%	%	%	%		dS/cm	cmol+/kg						%	mm/mm		mm/mm		mm/cm	%	water
Modal profile, TFb, mean soil properties (4 profiles)																						
A	0 – 5	38.5	12.8	31.8	17.0	48.8	0	0.12	20.1	52	13.7	5.4	0.5	2.5	2.5	38.3	13.6	32.6 (1.2)	20.1 (1.4)	1.3	1.69	7.0
	SD	*7.7*	*1.9*	*5.9*	*3.4*	*5.9*	*0*	*0.04*	*5.2*		*6.8*	*0.5*	*0.3*		*1.1*	*2.1*	*2.2*				*0.45*	*0.97*
B21	5 – 26	50.0	12.0	24.3	13.8	38.1	0	0.19	27.3	55	19.5	8.5	2.4	2.3	8.6	44.6	19.2	38.7 (2.6)	26.2 (3.3)	1.3	0.81	8.4
	SD	*2.5*	*2.1*	*2.7*	*3.1*	*1.6*	*0*	*0.13*	*2.2*		*4*	*0.6*	*1.3*		*4.2*	*2*	*1.3*				*0.21*	*0.8*
B22	26 – 56	49.0	13.0	22.8	15.3	38.0	0	0.43	30.9	63	21.1	9.8	5.1	2.2	17.2	49.4	21.2	38.0 (2.9)	26.3 (3.9)	1.2	0.63	9.3
	SD	*12.7*	*1.6*	*9.7*	*4.5*	*13.3*	*0*	*0.24*	*2.6*		*3.5*	*0.9*	*2.6*		*10.2*	*3.1*	*2.4*				*0.24*	*0.2*
B23	56 – 95	53.8	12.0	19.3	15.0	34.3	0	1.05	30.9	57	21.8	9.8	7.1	2.2	23.4	47.8	20.4	39.8 (3.7)	27.5 (3.1)	1.2	0.61	9.1
	SD	*6.9*	*1.8*	*1.7*	*4.6*	*6.1*	*0*	*0.7*	*2.3*		*3.1*	*1.3*	*2.9*		*10*	*4.2*	*2.1*				*0.32*	*0.28*
Properties of APSoil No 684																						
	0 – 15	44	13	na	na	42	na	0.14	29	66	20	8	1	2.5	3			34.4 (2.7)	23.2 (2.6)	1.1	0.68	7.8
	15 – 30	48	13	na	na	38	na	0.13	27	56	18	8	1	2.3	3			38.0 (2.5)	25.4 (2.0)	1.3	0.43	7.8
	30 – 60	51	12	na	na	37	na	0.16	28	55	15	11	2	1.4	6			38.7 (2.9)	26.2 (2.7)	1.3	0.32	7.8
	60 – 90	48	10	na	na	42	na	0.29	27	56	11	12	3	0.9	12			36.3 (4.1)	25.4 (5.8)	1.1	0.13	7.9
	90 - 120	47	8	na	na	44	na	0.36	26	55	9	12	4	0.8	16			35.4 (4.1)	23.9 (3.5)	1.2	0.07	8.0
Profile 45, TFb Type profile																						
A1	0 - 5	35	13	31	21	52	0	0.10	16	47	9	5	0	1.8	2	37.7	12.6				1.79	6.3
B21	5 - 35	53	11	22	14	36	0	0.26	29	55	24	9	3	2.7	10	44.1	19.0				0.61	8.9
B22	35 - 65	52	11	19	18	37	0	0.44	30	58	23	9	6	2.4	18	46.3	18.9				0.44	9.4
B3	65 - 100	54	10	20	16	36	0	0.65	28	52	18	9	7	2.0	23	46.6	19.1				0.30	9.3
Profile 53, TFb, estimated about 20th percentile																						
A1	0 – 5	35	14	38	13	51	0	0.10	20	57	13	6	0	2.3	1	39.5	13.5	31.6 (1.0)	18.7 (1.2)	1.3	2.28	6.4
B21	5 – 15	42	14	31	13	44	0	0.05	22	52	15	7	1	2.2	3	39.4	15.6	35.0 (1.6)	22.0 (1.4)	1.3	0.99	7.3
B22	25 – 35	59	17	18	6	24	0	0.06	31	53	20	11	2	1.8	6	48.4	22.6	36.6 (3.4)	25.5 (3.3)	1.1	1.01	8.1
B22	35 – 60	61	15	15	9	24	0	0.19	34	56	23	11	3	2.1	8	51.6	23.8	39.5 (4.1)	26.9 (3.9)	1.3	0.94	9.0
B23	60 – 90	59	13	17	11	28	0	0.30	33	56	22	11	4	2.0	11	53.2	23.6	40.6 (3.7)	27.3 (2.3)	1.3	0.84	9.3
Profile 44, TFb, estimated about 80th percentile																						
A1	0 – 5	50	10	24	16	40	0	0.18	28	56	23	6	1	3.8	3	40.3	16.7	38.3 (2.8)	25.5 (2.9)	1.3	1.33	8.4
B21	5 – 15	50	10	22	18	40	0	0.33	29	58	22	8	4	2.7	14	46.4	20.7	37.6 (3.3)	25.8 (3.8)	1.2	0.65	9.2
B22	15 – 40	31*	13	37*	19	46*	0	0.75	28	90*	16	9	9	1.8	31	52.4	22.5	29.6 (1.1)	17.3 (1.5)	1.2	0.42	9.5
B23	40 – 100	44	14	21	21	42	0	1.84	30	68	25	9	11	2.9	36	43.0	19.6	35.3 (2.5)	23.3 (1.8)	1.2	0.93	9.1

* original reported, typo in total sand content or in fine sand and clay contents given the unusually high CEC/clay

Backplains of the Western Carrabear, Eastern Carrabear and Macquarie Carrabear soil-landscape groups

Duncan et al. (2012) describe that the main soils on the backplains of the Carrabear Formation are Grey and Brown Vertosols usually with weakly self-mulching surface soil and occasional weakly sodic surface soils. There are also some Brown Dermosols and Black Vertosols. While the alluvial materials of the Carrabear Formation were deposited over a period of 15 000 to 150 000 years ago, the source (provenance) varied, leading to the distinction of different soil landscape groups within Carrabear (see Duncan et al. 2012).

The available laboratory data and results of the predictions of hydraulic properties in the backplains of the Eastern Carrabear (CEb), Western Carrabear (CWb) and Macquarie Carrabear (CMb) indicate that the hydraulic soil properties are very similar (Table 11; Figure 26a,b). There are some variations in the amounts of silt, fine sand and coarse sand, but these differences appear overshadowed by the effect of clay. As for the Trangie backplain the laboratory FC method obtains higher values than the field derived DUL (cf. Figure 26a,c).

APSoil No1161 in the Western Carrabear backplain is probably more sodic than the type profile for this soil landscape (Table 11). The location of the site is in a small wedge of the Western Carrabear soil landscape in close proximity to one of the Bugwah soil landscapes, which is of concern. The Bugwah soil landscapes are often higher in salinity and sodicity.

APSoil No1156 in the Eastern Carrabear backplain probably has properties close to the type profile for the Eastern Carrabear backplains (Table 11). Within this soil landscape there is some variation with more sodic surface soils and perhaps less salinity in the deep subsoil, but generally profile 1156 was assessed to be a good representative profile for the Eastern Carrabear backplains.

The Vertosol in the Macquarie Carrabear backplain, APSoil No705 probably has properties close to the type profile for the Macquarie Carrabear backplains, although it has less salinity at depth and sodicity increases more slowly with depth. Generally, this APSoil profile seems a good representative profile for the Macquarie Carrabear backplains.

The salinity levels of the Vertosols can vary considerably within the backplain landscapes. Data from the soil surveys suggests that the variation occurs within all the landscapes. It may hence be necessary to assess the salinity levels at each site to predict the PAWC accurately. For example, APSoil No1156 and survey profiles 35 and 124 have EC 1:5 levels that potentially can affect the PAWC.

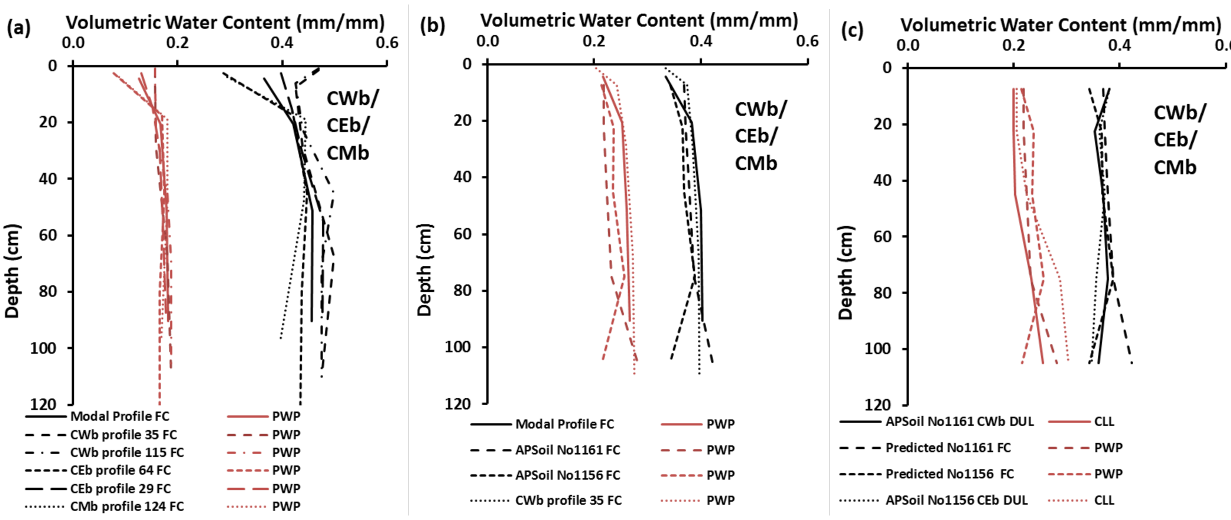


Figure 26: (a) Lab measured FC and PWP for modal and select CWb, CEb and CMb soil survey profiles; (b) predicted volumetric FC and PWP based on particle size data for APSoil No1161 and 1156, CWb/CEb/CMb modal and CWb survey profiles; (c) comparison of the predicted FC and PWP profiles with field measured CLL and DUL for APSoil No1161 and 1156.

The predicted FC and PWP match reasonably well with the field observed DUL and CLL (Figure 26c). However, CLL tends to be slightly lower than predicted PWP in the surface 60 cm. Below that, subsoil constraints (Cl, ESP) in APSoil No1156 cause its CLL to become higher than predicted PWP and its DUL to become lower than predicted FC. A very high clay content in the 90-120 cm layer of APSoil No1161, which is not seen below that (Table 3), is cause of predicted PWP exceeding DUL in that layer.

On comparing the data for the Carrabear backplain soils with the data from the Trangie backplain soils, the two groups of soils have a lot of properties in common. Indeed, the soil hydrological properties of the two soil groups appear to be reasonably similar, as shown by the comparison of APSoil profiles (Figure 27). The DUL profiles of APSoil No684, No1161 and No1156 largely overlap. That of APSoil No705 is, however, considerably lower. It is not clear what caused this. Its clay content is similar, and ESP is lower than that of the other profiles. As information on fine versus coarse sand is missing for this older APSoil characterisation, it is uncertain whether that may have contributed. It could also have been a characterisation issue of insufficient wetting up of the profile.

The CLL of APSoil No684 and No 1161 were again very similar. The CLL of No1156 increases relative to the others from the 60-90 cm layer down. From this layer its EC and Cl values reach levels that affect crop root growth and performance. The low CLL observed in APSoil No705 is more difficult to explain.

The PAWC for the unconstrained APSoil No684 and No1161 are around 210 mm, whereas the subsoil constraints of APSoil No1156 reduce its PAWC by about 30 mm to ~180 mm.

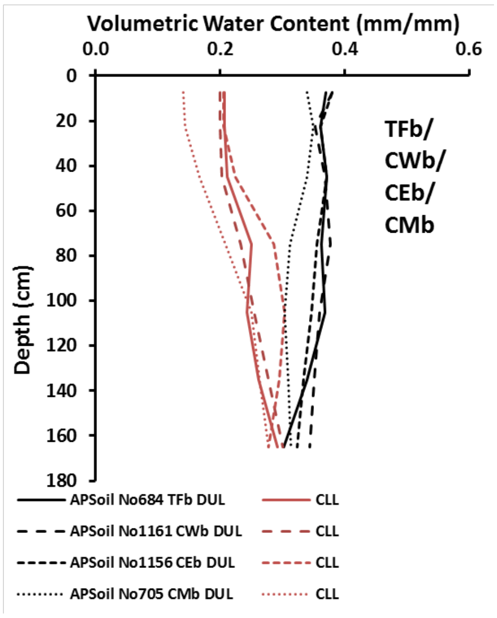


Figure 27: Comparison field measured CLL and DUL for APSoil characterisations across TFb, CWb, CEb, and CMb.

Table 11: Soil properties relevant to PAWC for Carrabear backplains (CEb, CWb and CMb) comparing various APSoils with modal and select profiles underpinning the soil survey (data with permission from Duncan et al. 2012). Predicted values for unconstrained profiles from Neuroman program with mean and standard error given.

Horizon	Depth	Clay	Silt	Fine sand	Coarse Sand	Total sand	Gravel & stones	EC 1:5	CEC	CEC/ Clay	Ca	Mg	Na	Ca/ Mg	ESP	Lab measured FC	Lab measured PWP	Predicted unconstrained FC	Predicted unconstrained PWP	Predicted unconstrained AWC	SOC	pH 1:5
	cm	%	%	%	%	%		dS/cm	cmol+/kg						%	mm/mm		mm/mm		mm/cm	%	water
Mean soil properties (9 profiles) – from Eastern, Western and Macquarie																						
A	0 – 9	38.2	14.1	21.1	25.5	47.7	0	0.12	20.2	53	12.7	5.7	0.6	2.2	2.7	36.5	12.7	33.4 (2.3)	21.7 (2.2)	1.2	1.69	7.0
	SD	*8.8*	*3.4*	*8.6*	*13.2*	*8.2*	*0*	*0.08*	*4.5*		*4.6*	*1.5*	*0.6*		*2.3*	*8.3*	*3.2*				*0.45*	*0.97*
B21	9 - 32	48.2	13.7	16.1	21.9	38.0	0	0.24	28.2	59	20.8	8.9	2.4	2.3	8.2	42.1	16.8	38.3 (2.6)	25.2 (2.5)	1.3	0.81	8.4
	SD	*4.4*	*2.2*	*6.3*	*10.3*	*5.8*	*0*	*0.13*	*3.2*		*4.4*	*4.4*	*1.4*		*4.9*	*4.2*	*1*				*0.21*	*0.8*
B22	32 – 71	49.6	14.9	15.4	20.1	35.6	0	0.55	29.8	60	20.4	10.1	4.7	2.0	15.4	45.8	17.9	40.0 (2.5)	26.1 (2.6)	1.4	0.63	9.3
	SD	*3.1*	*3.0*	*5.6*	*9.2*	*5.3*	*0*	*0.49*	*3.5*		*3.5*	*1.2*	*1.8*		*5.2*	*4*	*1.3*				*0.24*	*0.2*
B23	71 - 110	50.7	15.0	16.0	18.3	34.3	0	1.31	29.3	58	19.5	10.1	6.1	1.9	20.4	45.6	18.2	40.3 (2.7)	26.7 (2.5)	1.4	0.61	9.1
	SD	*5.1*	*3.4*	*6.3*	*9.0*	*6.1*	*0*	*0.94*	*3.9*		*3.4*	*1.1*	*1.8*		*4.1*	*3.4*	*1.4*				*0.32*	*0.28*
Properties of APSoil No 1161 – Carrabear West																						
	0 – 15	40	24	26	10	36	na	0.11	27	68	19	7	1	2.7	4			36.9 (2.6)	21.8 (1.8)	1.5	0.57	8.3
	15 – 30	40	25	25	10	35	na	0.14	29	73	19	8	2	2.4	7			37.1 (2.6)	21.8 (1.9)	1.5	0.48	8.8
	30 – 60	42	25	22	11	33	na	0.20	30	71	18	9	3	2.0	11			37.8 (2.6)	22.4 (2.6)	1.5	0.42	9.2
	60 – 90	44	25	23	8	31	na	0.29	32	73	17	9	5	1.9	16			38.7 (3.0)	23.2 (2.7)	1.5	0.28	9.1
	90 - 120	55	16	23	6	29	na	0.86	32	58	17	9	6	1.9	19			42.2 (3.0)	28.1 (2.5)	1.4	0.17	8.5
Properties of APSoil No 1156 – Carrabear East																						
	0 – 15	37	19	22	21	43	na	0.17	27	73	21	4	1	5.3	3			34.3 (2.2)	21.4 (2.3)	1.3	0.9	7.9
	15 – 30	43	17	19	21	39	na	0.19	29	67	21	6	2	3.5	8			36.6 (2.2)	23.7 (2.0)	1.2	0.6	8.8
	30 – 60	43	19	15	23	38	na	0.2	31	72	19	7	5	2.7	15			36.8 (2.7)	23.5 (2.1)	1.3	0.48	9.3
	60 – 90	48	16	15	21	36	na	0.85	32	67	18	6	7	3.0	22			38.8 (2.8)	25.7 (2.0)	1.3	0.26	8.7
	90 - 120	*	*	25	18	43	na	2.34	37	*	20	7	10	2.9	27			34.2 (2.3)	21.5 (2.2)	1.3	0.24	8
Properties APSoil No 705 – Carrabear Macquarie																						
	0 – 15	45	19	na	na	36	na	0.05	21	47	23	14	6	1.6	1			33.4 (1.1)	20.4 (1.1)	1.3	0.74	6.1
	15 – 30	43	20	na	na	36	na	0.07	21	49	22	14	6	1.6	2			37.4 (2.6)	24.2 (2.0)	1.3	0.47	6.8
	30 – 60	51	19	na	na	30	na	0.15	26	51	16	15	9	1.1	7			38.4 (2.6)	26.0 (3.3)	1.2	0.28	7.8
	60 – 90	49	19	na	na	32	na	0.22	24	49	25	11	10	2.3	13			39.5 (3.8)	27.2 (2.8)	1.2	0.24	7.9
	90 - 120	53	19	na	na	28	na	0.29	25	47	25	10	10	2.5	18			39.7 (3.8)	27.5 (2.4)	1.2	0.19	7.9

* data missing – insufficient dispersion during analysis

Table 11 Continued

Horizon	Depth	Clay	Silt	Fine sand	Coarse Sand	Total sand	Gravel & stones	EC 1:5	CEC	CEC/ Clay	Ca	Mg	Na	Ca/ Mg	ESP	Lab measured FC	Lab measured PWP	Predicted unconstrained FC	Predicted unconstrained PWP	Predicted unconstrained AWC	SOC	pH 1:5
	cm	%	%	%	%	%		dS/cm	cmol+/kg						%	mm/mm		mm/mm		mm/cm	%	water
Profile 35 – Carrabear West																						
A0	0 – 3	39	14	35	12	47	0	0.10	21	54	13	7	0	1.9	1	47	15.7	33.4 (1.1)	20.4 (1.1)	1.3	2.76	6
A1	3 – 12	46	14	29	11	40	0	0.06	24	52	15	8	1	2.0	2	42.5	15.7	37.4 (2.6)	24.2 (2.0)	1.3	0.77	7.1
B21	12 - 45	49	13	25	13	38	0	0.13	28	57	19	9	2	2.2	7	43.9	15.8	38.4 (2.6)	26.0 (3.3)	1.2	0.39	8.9
B22	45 - 90	46	14	21	12	33	0	0.23	30	65	16	10	5	1.6	16	49.9	18	39.5 (3.8)	27.2 (2.8)	1.2	0.37	9.3
B23	90 - 130	56	14	20	10	30	0	1.56	32	57	22	11	7	2.0	22	47.5	18.8	39.7 (3.8)	27.5 (2.4)	1.2	0.41	8.3
Profile 115 - Type profile Carrabear West																						
A0	0 - 2	48	13	31	8	39	0	0.12	20	42	13	5	0	2.5	0	43.9	13.8				1.39	6.7
A1	2 - 10	53	13	25	9	34	0	0.11	22	41	16	6	0	2.6	0	42.1	15.2				0.73	7.2
B21	10 - 35	51	12	26	11	37	0	0.12	22	42	15	7	0	2.2	0	39.7	15.7				0.41	8.1
B21	35 - 55	51	14	25	10	35	0	0.15	22	43	16	7	1	2.2	5	39.7	15.9				0.38	8.9
B22	55 - 85	52	14	25	9	34	0	0.16	22	42	15	8	2	1.9	11	42.2	16.7				0.27	9.1
B3	85 - 130	53	13	26	8	34	0	0.26	21	40	11	8	4	1.4	20	45.7	17.3				0.34	9.3
Profile 64 – Carrabear East																						
A1	0 – 5	23	13	22	42	64	0	0.17	15	65	7	3	0	2.1	2	28.8	7.8				1.11	7.1
B21	5 - 30	47	12	14	27	41	0	0.19	32	68	24	8	2	2.9	7	42.1	17				0.71	9.1
B22	30 - 60	48	11	15	26	41	0	0.34	32	67	22	10	4	2.3	13	44.7	17.4				0.59	9.4
B3	60 – 100	43	11	17	29	46	0	0.59	30	70	17	10	6	1.7	21	43.8	16.6				0.28	9.4
B3	100 - 150	43	11	18	28	46	0	0.82	29	67	14	10	6	1.5	22	43.5	16.6				0.08	9.2
Profile 29 – Type profile Carrabear East																						
A1	0 - 5	40	14	13	33	46	0	0.07	22	55	14	6	0	2.4	2	39.8	13.1				0.71	7.7
B21	5 - 25	44	14	12	30	42	0	0.09	25	56	17	7	1	2.5	3	41.8	15.3				0.7	8.2
B22	25 - 35	48	16	9	27	36	0	0.17	29	60	20	9	2	2.2	8	43.8	16.6				0.55	9.2
B3	35 - 75	48	16	9	27	36	0	0.33	29	61	18	10	4	1.8	13	47.9	17.2				0.34	9.2
B3	75 - 100	51	13	8	28	36	0	0.85	32	62	19	10	6	1.9	19	47.7	17.8				0.42	8.7
Properties Nyngan Profile 124 - Type profile Carrabear Macquarie																						
A1	0 - 8	29	23	38	10	48	0	0.08	12	43	6	4	0	1.6	2	29.5	8.8				0.81	6.3
B21	8 - 30	56	19	20	5	25	0	0.31	28	50	20	11	3	1.8	12	44.4	18.1				0.93	9
B22	30 - 65	54	22	20	4	24	0	0.48	28	51	20	11	5	1.8	17	44.1	18				0.59	9.3
B3	65 - 130	54	17	25	4	29	0	1.33	24	44	17	9	5	1.9	19	39.6	16.9				0.19	8.4

Mulla Cowal alluvial plain (MUalp)

This soil-landscape is highly variable with a range of soil materials ranging from clays to coarser materials. Soil types include Red Chromosols and Red Kandosols on higher areas and Brown Vertosols in the valley flats and backplains (Duncan et al., 2012). These backplain and meander plain soils are not separately mapped, although Duncan et al. (2012) indicate that radiometrics data could provide spatial mapping.

The Vertosol of APSoil No1155 in the Mulla Cowal backplain has ESP properties close to the type profile for the Merri Carrabear backplains (cf. Table 12 with Table 13). Comparing with the descriptions of profiles in the soil survey APSoil No1155 seems a good representative profile for the Mulla Cowal backplains, although laboratory data in the survey were limited to one profile which was in the same paddock (Table 12).

Comparison of the field measured PAWC of APSoil No1155 with those of other APSoil characterisations in the Eastern, Western and Macquarie Carrabear backplain units also confirms the similarity in hydraulic properties (Figure 28). However, given the very high levels of chloride, EC and ESP observed in APSoil No1155 (see Table 8), it is surprising that the CLL is intermediate between that of CWb and CMb. Stronger tapering of the CLL would have been expected. It is not clear what could explain the ability of the crop to extract soil moisture despite the high levels of constraints. High spatial soil variability in the paddock could have played a role, given that the meander plain soil (APSoil No1163) was in the same paddock. This meander plain soil is discussed in section alongside the meander plain soils of the Eastern, Western and Macquarie Carrabear soil landscapes.

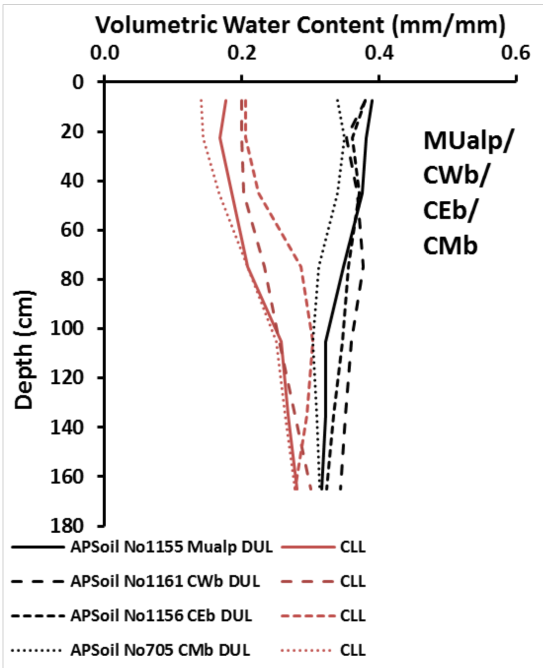


Figure 28: Comparison field measured CLL and DUL for APSoil characterisations in backplain positions across MUalp, CWb, CEb, and CMb.

Table 12: Soil properties relevant to PAWC for backplains of Mulla Cowal (MUalp) comparing APSoil No1155 with select profiles underpinning the soil survey (data with permission from Duncan et al. 2012 and from eSpade).

Horizon	Depth	Clay	Silt	Fine sand	Coarse Sand	Total sand	Gravel & stones	EC 1:5	CEC	CEC/ Clay	Ca	Mg	Na	Ca/ Mg	ESP	Lab measured FC	Lab measured PWP	Predicted unconstrained FC	Predicted unconstrained PWP	Predicted unconstrained AWC	SOC	pH 1:5
	cm	%	%	%	%	%		dS/cm	cmol+/kg						%	mm/mm		mm/mm		mm/cm	%	water
Properties of APSoil No 1155 – Mulla Cowal																						
	0 – 15	37	19	37	7	44	na	0.1	19	51	10	6	1	1.7	7						0.63	7.1
	15 – 30	45	18	32	5	37	na	0.3	27	60	15	8	3	1.9	12						0.48	8.9
	30 – 60	43	18	31	8	39	na	0.7	26	60	12	7	5	1.7	21						0.28	9.3
	60 – 90	41	19	34	6	40	na	2.5	27	66	11	8	8	1.4	29						0.15	9.1
	90 - 120	38	22	33	7	40	na	1.1	31	82	14	7	8	2.0	27						0.16	8.0
Properties Nyngan Profile 1403 - Type profile Mulla Cowal (data from eSpade)																						
A11	0 - 20	48	12	30	10	40	0	0.16	33	68	16	6	1	2.5	2	38.3	16.1					8.6
B21	20 - 60	50	14	26	9	35	1	0.27	34	67	16	12	3	1.4	9	40.9	18.9					9.3
B22	60 -130	54	15	24	6	30	1	0.65	36	66	13	14	7	0.9	20	52.6	20.9					9.4
B23	130 - 150	52	17	25	6	31	0	1.03	36	68	12	13	9	0.9	26	49.9	20.6					9.2
Properties Nyngan Profile 124 - Type profile Carrabear Macquarie																						
A1	0 - 8	29	23	38	10	48	0	0.08	12	43	6	4	0	1.6	2	29.5	8.8				0.81	6.3
B21	8 - 30	56	19	20	5	25	0	0.31	28	50	20	11	3	1.8	12	44.4	18.1				0.93	9
B22	30 - 65	54	22	20	4	24	0	0.48	28	51	20	11	5	1.8	17	44.1	18				0.59	9.3
B3	65 - 130	54	17	25	4	29	0	1.33	24	44	17	9	5	1.9	19	39.6	16.9				0.19	8.4

Merri Carrabear backplains (CRb)

The backplains on the Merri Carrabear Formation are strongly influenced by more sodic soil materials. They may have been derived from a source of materials high in sodium. The main soils are Brown Vertosols usually with weakly sodic surface soil and occasional strongly sodic surface soils (Duncan et al. 2012). It represents some of the most structurally and chemically constrained soils in region.

APSoil No1160 has properties close to the type profile for the Merri Carrabear backplains. Generally APSoil No1160 seems a good representative profile for the Merri Carrabear backplains, although with the clay content lower than that of the single Merri Carrabear backplain survey profile that had particle size data, its predicted PWP and FC are lower (Table 13, Figure 29a).

The predicted FC/PWP and field measured DUL/CLL of APSoil No1160 match reasonably well (Figure 29b). The CLL of APSoil No1160 was similar to that of the Trangie backplain soil (APSoil No684) in the top 120 cm. At the depth where subsoil constraints would have been expected to increase in CLL (Cl > 600 mg/kg below 120 cm; Table 6), this effect appears to be off-set by the reduction in clay content (35-36%) and increase in sand content (52-55%) (Table 6). The low PAWC of APSoil No1160 appears related to its lower DUL, which could be driven by its high percentage of coarse sand.

Combara Carrabear backplains (CCb)

The Combara Carrabear soil landscape group was identified largely on the evidence of the radiometric signal late in the soil survey. Limited information is available and only few shallow profiles were obtained. The materials of this landscape are associated with alluvium derived from the nearby Tertiary volcanics.

Because there is limited data it is difficult to say how the properties of APSoil No1158 relate to the expected soil properties. The high ESP in the surface of APSoil No1158 (Table 13) could be an anomaly caused by the low CEC and perhaps a consequence of sampling localised microsite. The high silt in APSoil No1158 suggests a possible different source of parent material and is consistent with the volcanic source but the very high ESP values are not. As this leaves unanswered questions for this profile, it is difficult to confidently extrapolate this result with any confidence. The predicted FC is remarkably similar to the field measured DUL (Figure 29b). The deviation in PWP at 75 cm (60-90 cm layer) is due to the low clay content, which appears to be an anomaly (Table 13). The CLL and DUL in top 120 cm are not too different from that of the Trangie backplain soil (APSoil No684). Very high clay content (54-55% vs 43-48% for APSoil No684) could explain differences in DUL in surface and below 120 cm.

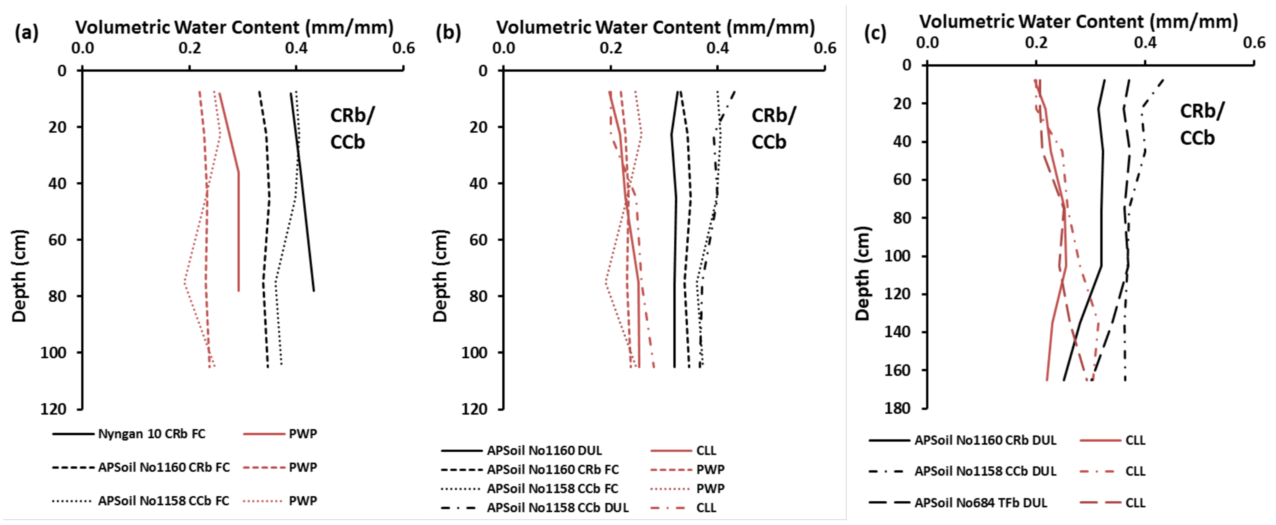


Figure 29: (a) predicted volumetric FC and PWP based on particle size data for Nyngan 10 (Merri Carrabear backplain (CRb) soil, APSoil No1160 (CRb) and No1158 (Combara Carrabear backplain, CCb), (b) comparison predicted FC/PWP with field measured DUL/CLL for APSoil No1158 and 1160, (c) comparison of field measured DUL/CLL for across CRb, CCb and Trangie backplain soil (TFb) APSoil No684 (note different y-axis scale).

Table 13: Soil properties relevant to PAWC for Merri Carrabear and Combara Carrabear backplain soils (data with permission from Forbes et al. 2012b). Predicted values for unconstrained profiles from Neuroman program with mean and standard error given.

Horizon	Depth	Clay	Silt	Fine sand	Coarse Sand	Total sand	Gravel & stones	EC 1:5	CEC	CEC/ Clay	Ca	Mg	Na	Ca/ Mg	ESP	Lab measured FC	PWP	Predicted (unconstrained) FC	PWP	AWC	SOC	pH 1:5
	cm	%	%	%	%	%		dS/cm	cmol+/kg						%	mm/mm		mm/mm		mm/cm	%	water
Mean soil properties CRb (4 profiles), 1 profile for particle size analysis, hydraulic poroperties and organic carbon																						
A	0 – 16	49	14	9	28	37	0	0.21	24.4	50	14.0	7.9	2.2	1.8	9.0	32.1	19.9	38.9 (2.5)	25.7 (2.6)	1.3	0.65	7.6
	SD							*0.1*	*6.1*		*5*	*1.2*	*0.7*		*1.1*							*0.34*
B21	16 – 56	51	14	10	25	35	0	0.42	27.4	54	15.0	8.7	4.3	1.7	15.5	42.2	18	40.8 (2.7)	29.2 (2.8)	1.3	0.41	8.95
	SD							*0.15*	*4.5*		*4.3*	*1.0*	*1.5*		*4.3*							*0.39*
B22	56 – 100	56	18	9	17	26	0	0.66	28.7	51	12.9	9.8	5.7	1.3	19.9	45.5	19.3	43.3 (2.9)	29.2 (2.6)	1.2	0.22	8.93
	SD							*0.30*	*3.4*		*2.1*	*1.0*	*1.1*		*3.5*							*0.13*
Properties of APSoil No1160 - Carrabear Merri backplain																						
	0 – 15	39	14	15	32	47	na	0.3	24	62	17	5	1	3.4	4			33.1 (2.0)	21.9 (2.5)	1.1	0.60	8.2
	15 – 30	42	14	15	29	44	na	0.3	26	62	19	6	3	3.2	12			34.4 (2.3)	22.7 (2.2)	1.2	0.39	8.9
	30 – 60	44	13	3	31	43	na	0.3	26	59	15	6	4	2.5	15			34.9 (2.5)	23.3 (2.3)	1.2	0.39	9.2
	60 – 90	43	11	14	32	46	na	0.6	25	58	13	6	6	2.2	24			33.8 (2.4)	23.1 (3.2)	1.1	0.27	9.2
	90 - 120	45	11	15	29	44	na	0.9	28	62	14	6	8	2.3	29			34.7 (2.8)	23.7 (3.2)	1.1	0.19	9.0
Properties of APSoil No1158 - Carrabear Combara backplain																						
	0 – 15	49	25	13	14	27	na	0.5	32	65	19	7	5	2.7	16			40.0 (3.5)	24.6 (3.0)	1.5	0.60	8.5
	15 – 30	55	23	10	13	23	na	0.3	34	62	21	8	3	2.6	9			40.5 (4.5)	25.8 (4.1)	1.5	0.59	8.6
	30 – 60	46	30	13	11	24	na	0.2	33	72	19	8	5	2.4	15			39.8 (3.8)	23.1 (3.2)	1.7	0.43	9.0
	60 – 90	*	*	13	7	20	na	1.0	33	*	18	7	6	2.6	18			36.1 (4.9)	19.1 (4.5)	1.7	0.42	7.4
	90 - 120	50	36	9	5	14	na	0.9	33	66	14	9	9	1.6	27			37.2 (6.8)	24.8 (7.9)	1.2	0.39	7.9

* data missing – insufficient dispersion during analysis

Trangie Meander Plains (TFm)

Duncan et al. (2012) describes the main soils of the meander plains of the Trangie soil-landscape group (TFm) as "Red Chromosols and some Red Dermosols with fine sandy loam to fine sandy clay loam topsoils." Adding further that "surface soils and subsoils are usually strongly red in colour which is a diagnostic feature of the landscape."

APSoil No683 has properties close to the modal profile for the Trangie meander plain. However, it is slightly less sodic in the deeper subsoil (> 75 cm) than the modal profile (Table 14) and this may affect PAWC. At the extremes there are profiles with differing properties such as profile Nyngan 12, which has less clay and so likely a lower PAWC, and profile Nyngan 42, which has more clay but also higher salinity (as judged from EC 1:5) and sodicity and so likely a more restricted PAWC. The laboratory PWP and FC as well as the predicted unconstrained AWC profiles suggest more variability within the meander plain soils than the backplain soils (cf. Figure 25 and Figure 30). This indicates that extrapolation from APSoil No683 may be more difficult.

In an earlier detailed study of the soils and landscapes around Trangie by McKenzie (1992), the Trangie meander plain soils were associated with a local soil profile class 'Mitchel', which was divided into three phases (well drained, moderately drained and poorly drained). APSoil No683 appears to correspond well with the well-drained phase, which is characterised by its strong red colour, lack of mottles and low EC. The moderately and poorly drained phases are situated lower in the landscape and have increasing EC, ESP and pH in the B horizons, which is related to the degree of impeded drainage. Visually they can be recognised by the browner colour and increased mottling. Further APSoil characterisations may be required to allow prediction of PAWC in these less well drained meander plain soils.

It would also be worth exploring whether digital soil attribute mapping of PSA (for prediction of AWC) and terrain analysis based on fine resolution DEM (for prediction of subsoil constraints) can identify the variation in PAWC within the meander plain soils. However, even though APSoil No683 was not affected by subsoil constraints, the predicted AWC did not match the field measured PAWC as well as it did for the backplain soil. The predicted FC and PWP showed the same depth patterns as the field measured DUL and CLL, but the latter were both considerably lower than the predicted values (Figure 30c).

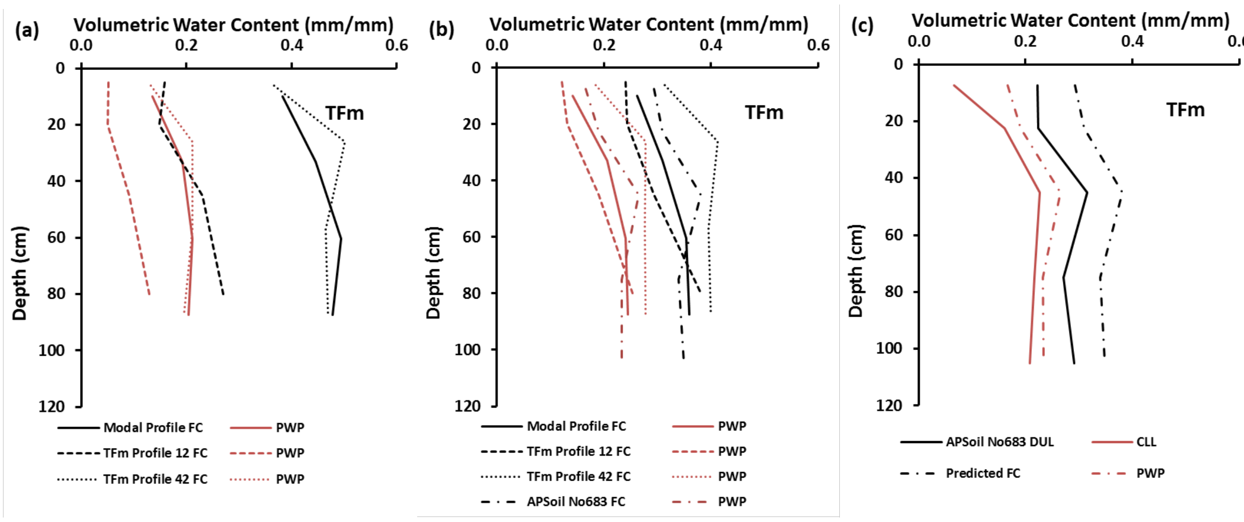


Figure 30: (a) Lab measured volumetric FC and PWP for modal and select TFm soil survey profiles; (b) predicted volumetric FC and PWP based on particle size data for APSoil No683, modal and select TFm survey profiles; (c) comparison predicted volumetric FC and PWP with field measured CLL and DUL for APSoil No683.

Table 14: Soil properties relevant to PAWC for Trangie meander plain (TFm) comparing APSoil No683 with modal and select profiles underpinning the soil survey (data with permission from Duncan et al. 2012) . Predicted values for unconstrained profiles from Neuroman program with mean and standard error given.

Horizon	Depth	Clay	Silt	Fine sand	Coarse Sand	Total sand	Gravel & stones	EC 1:5	CEC	CEC/ Clay	Ca	Mg	Na	Ca/ Mg	ESP	Lab measured FC	Lab measured PWP	Predicted unconstrained FC	Predicted unconstrained PWP	Predicted unconstrained AWC	SOC	pH 1:5
	cm	%	%	%	%	%		dS/cm	cmol+/kg						%	mm/mm		mm/mm		mm/cm	%	water
Modal profile, TFm, mean soil properties (9 profiles)																						
A	0 – 20	22.3	11.7	36.2	29.9	66.1	0	0.114	13.2	59	8.7	2.1	0.1	4.1	1.0	24.9	8.1	26.2 (1.2)	14.1 (1.3)	1.2	1.56	6.9
	SD	*7.8*	*2.7*	*9.0*	*15.0*	*10.0*	*0*	*0.084*	*6.6*		*7.6*	*1.5*	*0.1*		*0.6*	*9.4*	*4*				*1.39*	*0.94*
B21	20 – 46	37.3	10.2	24.1	28.3	52.4	0	0.09	15.2	41	9.7	3.7	0.4	2.6	2.1	29.1	10.9	30.9 (2.0)	20.6 (2.8)	1.0	0.45	7.61
	SD	*11.5*	*3.0*	*6.7*	*17.2*	*13.2*	*0*	*0.06*	*7.6*		*7.2*	*3.1*	*0.6*		*1.9*	*11.3*	*5*				*0.4*	*0.93*
B22	46 – 75	47.0	9.9	19.2	23.7	42.9	0.2	0.11	16.9	36	11.0	5.5	0.8	2.0	3.7	32.1	13.7	35.4 (2.8)	24.1 (3.3)	1.1	0.29	8.09
	SD	*10.3*	*2.3*	*5.6*	*13.6*	*11.5*	*0.7*	*0.11*	*7.6*		*6.9*	*3.2*	*1.1*		*3.6*	*9.9*	*4.4*				*0.23*	*0.84*
B23	75 - 100	47.4	10.6	20.6	21.2	41.8	0.2	0.20	18.0	38	11.3	6.2	1.5	1.8	6.4	34.4	14.6	35.9 (3.2)	24.5 (3.2)	1.1	0.23	8.44
	SD	*12.7*	*2.0*	*3.1*	*15.7*	*14.0*	*0.4*	*0.21*	*7.6*		*5.3*	*3.8*	*1.9*		*6.5*	*10.6*	*4.8*				*0.14*	*0.86*
Properties of APSoil No 683																						
	0 – 15	24	21	na	na	56	na	0.04	9	38	7	1	0	7.0	1			29.3 (1.9)	16.6 (2.7)	1.3	0.82	5.1
	15 – 30	30	17	na	na	53	na	0.03	10	33	8	2	0	4.0	0			31.0 (1.9)	19.0 (2.8)	1.2	0.32	5.8
	30 – 60	51	10	na	na	39	na	0.03	16	31	12	4	0	3.0	1			38.1 (3.9)	26.5 (5.0)	1.2	0.17	6.1
	60 – 90	44	9	na	na	47	na	0.03	15	34	11	4	0	2.8	1			34.0 (2.7)	23.3 (4.1)	1.1	0.09	6.7
	90 - 120	48	7	na	na	45	na	0.05	15	31	11	4	0	2.8	1			34.9 (3.6)	23.4 (3.8)	1.2	0.11	6.7
Profile 41, TFm Type profile																						
A1	0 - 10	20	11	45	24	69	0	0.31	14	68	7	2	0	3.5	0	27.0	7.7				1.84	7.0
A1	10 - 20	24	12	41	23	64	0	0.17	12	49	5	2	0	2.9	0	26.4	7.6				0.97	7.0
B21	20 - 40	38	11	32	19	51	0	0.17	15	40	8	4	0	2.2	0	33.2	12.1				0.36	7.6
B21	40 - 60	43	11	27	19	46	0	0.22	18	41	11	6	1	1.8	0	36.4	13.7				0.23	8.1
B22	60 - 100	49	10	24	16	40	1	0.22	21	43	14	7	2	1.9	0	38.5	15.6				0.16	8.9
Profile 12, TFm, estimated about 20th percentile																						
A1	0 -10	15	9	31	45	76	0	0.11	10	69	6	1	0	6.6	0	15.8	5.2	24.1 (1.8)	12.2 (2.1)	1.2	1.50	6.3
A3	10 – 30	17	8	26	49	75	0	0.06	8	46	3	1	0	3.3	1	14.8	5.0	24.3 (2.2)	13.1 (4.0)	1.1	0.42	6.2
B21	30 - 60	36	8	17	39	56	0	0.04	11	30	5	2	0	2.4	2	23.1	9.2	29.3 (1.8)	19.1 (3.1)	1	0.17	7.6
B22	60 - 100	52	9	14	25	39	0	0.05	13	26	8	4	0	1.9	2	27.0	13.0	38.1 (3.7)	25.3 (3.3)	1.3	0.14	7.8
Profile 42, TFm, estimated about 80th percentile																						
A1	0 – 12	33	16	37	14	51	0	0.16	19	57	12	5	0	2.5	2	36.6	13.3	31.3 (1.2)	18.5 (1.4)	1.3	1.55	7.1
B21	12 – 40	58	11	20	11	31	0	0.20	29	50	18	11	2	1.6	6	50.2	21.2	41.3 (4.2)	27.8 (3.7)	1.4	0.46	8.9
B22	40 – 75	51	13	23	13	36	0	0.35	31	61	21	12	4	1.7	12	46.5	21.1	39.5 (3.0)	27.6 (4.8)	1.2	0.55	9.5
B23	75 -100	52	13	23	12	35	0	0.55	29	55	19	11	5	1.7	16	46.9	19.6	39.9 (3.0)	27.8 (4.2)	1.2	0.47	9.5

Western Carrabear and Macquarie Carrabear meander plains and Mulla Cowal meander plain

The main soils on the Western Carrabear and Macquarie Carrabear meander plains (CWm and CMm, respectively) are Red and Brown Kandosols, Red and Brown Chromosols, and less commonly Dermosols and Sodosol (Duncan et al. 2012). The soils are often high in silt and fine sand.

APSoil No 248 on the Macquarie Carrabear meander plain and APSoil No1163 on the Mulla Cowal meander plain appear similar soils based on their soil physical and chemical data (Table 15). There are many similarities to the modal soil of the Western Carrabear meander plains (Table 15) and this is reflected in the similar predicted AWCs (Figure 31a). However, the deeper subsoils of the two APSoil characterisations are less saline and sodic than the modal profile (Table 15). The two APSoil characterisations, therefore, probably represent the better, less constrained proportion of the soils of the Western Carrabear and Macquarie meander plains. In locations of these meander plains where salinity is present, the PAWC is likely less than those of APSoil No248 and No1163.

Despite the lack of subsoil constraints, the predicted FC and PWP differ from the field derived DUL and CLL, especially at depth (Figure 31b). The two APSoil profiles are also quite different, despite the similarity in soil physical and chemical properties.

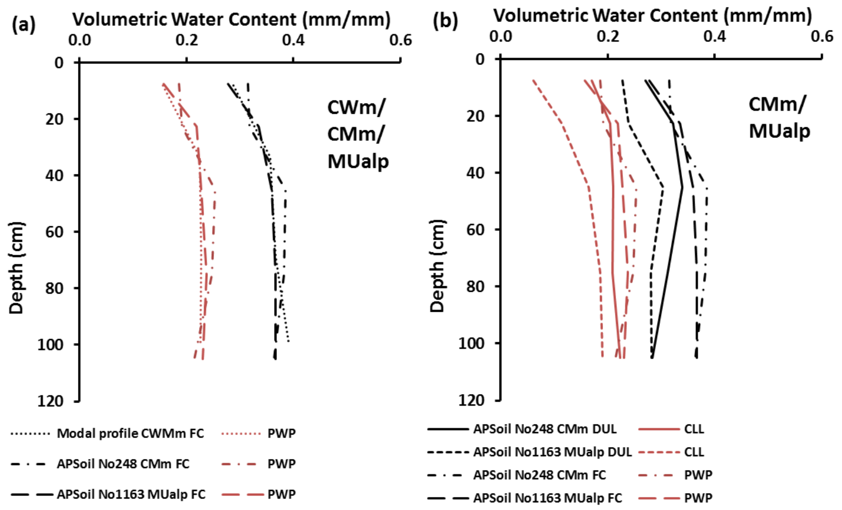


Figure 31: (a) predicted volumetric FC and PWP based on particle size data for APSoil No1161 and 1156, modal CWMm profile; (c) comparison of the predicted FC and PWP profiles with field measured CLL and DUL for APSoil No1161 and 1156.

Eastern Carrabear meander plains

The soils of the Eastern Carrabear meander plains are significantly sandier than the meander plains of the Western Carrabear and Macquarie Carrabear meander plains. They are especially higher in coarse sand. Therefore, they have lower water holding capacity and lower PAWC (cf. Figure 31 and Figure 32). A proportion of the soils are on levees that are quite sandy and form sandy Tenosols and Kandosols that have especially low water holding capacity and PAWC (see Nyngan profiles 25 in Table 15). These need to be considered separately in the assessment of water holding capacity for soils to the other meander plain soils.

No APSoil characterisations were located in the Eastern Carrabear meander plains.

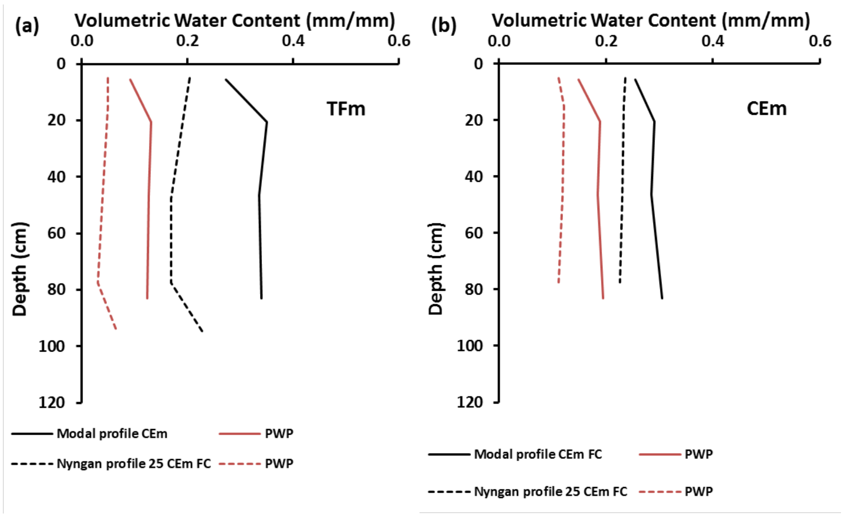


Figure 32: (a) Lab measured volmetric FC and PWP for modal and select CEm soil survey profiles; (b) predicted volumetric FC and PWP based on particle size data for CEm modal and survey profiles.

Table 15: Soil properties relevant to PAWC for meander plans of Western Carrabear, Macquarie Carrabear, Eastern Carrabear and Mulla Cowal comparing APSoil No248 and No1163 with modal and select profiles underpinning the soil survey. (data with permission from Duncan et al. 2012). Predicted values for unconstrained profiles from Neuroman program with mean and standard error given.

Horizon	Depth	Clay	Silt	Fine sand	Coarse Sand	Total sand	Gravel & stones	EC 1:5	CEC	CEC/ Clay	Ca	Mg	Na	Ca/ Mg	ESP	Lab measured FC	PWP	Predicted (unconstrained) FC	PWP	AWC	SOC	pH 1:5
	cm	%	%	%	%	%		dS/cm	cmol+/kg						%	mm/mm		mm/mm		mm/cm	%	water
Mean soil properties (10 profiles Western and Macquarie Carrabear), Red chromosol, Dermosol, Kandosol soil group																						
A	0 - 16	22.0	21.4	34.3	22.3	56.6	0	0.14	11.2	51	6.3	2.5	0.2	2.5	1.4	23.7	7.8	28.8 (1.8)	15.6 (1.5)	1.5	1.13	6.6
		7.3	*9.0*	*7.0*	*15.9*	*12.8*	*0*	*0.08*	*3.1*		*3.2*	*1.7*	*0.3*		*2.3*	*6.9*	*3.0*				*0.39*	*0.61*
B21	16 - 51	40.0	20.6	23.8	15.4	39.2	0	0.24	20.3	51	15.1	6.9	2	2.2	9	36.4	13.1	35.7 (3.0)	22.5 (2.1)	1.3	0.49	8.58
		12.6	*9.0*	*9.6*	*15.4*	*16.7*	*0*	*0.18*	*6.0*		*5.8*	*2.5*	*2.1*		*9*	*8.0*	*4.2*				*0.27*	*0.7*
B22	51 - 86	40.7	23.5	21.4	13.6	35.0	0	0.56	22.5	55	17.8	8.6	3.2	2.1	13.3	36.9	13.3	36.7 (3/0)	22.8 (2.6)	1.4	0.46	8.09
		10.1	*10.7*	*9.6*	*13.6*	*15.4*	*0*	*0.53*	*4.8*		*5.1*	*3.3*	*2.3*		*9.4*	*5.7*	*3.8*				*0.27*	*0.76*
	86 - 112	43.9	28.6	16.3	10.8	27.0	0	0.92	25.1	57	18.6	10.4	5.2	1.8	20.6	38.9	15.1	39.1 (3.2)	22.6 (2.7)	1.7	0.30	9.04
		6.6	*10.5*	*2.3*	*7.3*	*8.8*	*0*	*0.58*	*2.2*		*3.4*	*3.3*	*1.6*		*6.2*	*2.3*	*1.1*				*0.14*	*0.37*
Properties of APSoil No248 - Carrabear Macquarie meander plain																						
	0 - 15	29	22	na	na	49		0.1	11	38	7	3	0	2.3	1			31.5 (1.8)	18.6 (2.9)	1.3	1.03	4.9
	15 - 30	31	21	na	na	48		0	12	39	7	4	0	1.8	2			31.8 (2.0)	19.2 (3.1)	1.3	0.53	4.8
	30 - 60	47	17	na	na	36		0.1	24	51	13	9	1	1.4	5			38.6 (2.8)	25.3 (2.1)	1.3	0.38	6.5
	60 - 90	45	18	na	na	36		0.2	23	51	11	10	2	1.1	7			38.3 (2.7)	24.7 (2.1)	1.4	0.19	7.7
	90 - 120	44	21	na	na	35		0.2	22	50	10	9	2	1.1	8			36.4 (2.4)	21.5 (1.7	1.5	0.09	8.0
Properties of APSoil No1163 - Mulla Cowal alluvial plain (meander plain position)																						
	0 - 15	24	14	47	15	61		0.1	11	46	7	2	0	3.5	0			27.8 (1.6)	15.8 (1.8)	1.2	0.87	6.5
	15 - 30	39	15	35	11	46		0.1	21	54	15	4	0	3.8	1			33.5 (2.1)	21.9 (2.4)	1.2	0.58	7.8
	30 - 60	41	20	30	9	39		0.1	22	54	15	6	0	2.5	2			36.0 (2.6)	22.7 (2.1)	1.3	0.33	8.3
	60 - 90	44	17	28	11	39		0.1	22	50	13	6	1	2.2	4			36.6 (2.6)	23.8 (2.0)	1.3	0.17	8.9
	90 - 120	42	20	29	9	38		0.2	22	52	11	7	1	1.6	7			36.6 (2.8)	23.1 (2.1)	1.4	0.16	9.1
Mean soil properties (6 profiles Eastern Carrabear), Red chromosol, Dermosol soil group																						
A	0 - 11	24.2	8.0	26.6	41.2	67.8	0	0.11	14	58	9.6	2.8	0.1	3.4	0.1	27.3	9.2	25.5 (1.5)	14.9 (2.1)	1.1	1.05	6.8
		11.8	*3.9*	*5.1*	*15.6*	*15.5*	*0*	*0.07*	*7.7*		*8.2*	*2.1*	*0.1*		*0.1*	*11.5*	*4.5*				*0.30*	*1.09*
B21	11 - 30	32.2	8.8	26.5	32.5	59.0	0	0.16	19.3	60	14.3	5.2	0.7	2.8	2.7	35.0	13.1	29.0 (3.5)	18.9 (6.2)	1.0	0.74	7.92
		11.0	*3.8*	*7.3*	*8.5*	*14.2*	*0*	*0.13*	*10*		*8.9*	*3.7*	*1.0*		*63.6*	*8.3*	*4.9*				*0.36*	*0.97*
B22	30 - 61	33.8	8.3	23.2	34.7	57.8	0	0.22	20.8	62	15.4	5.9	2	2.6	7.1	33.6	12.7	28.5 (2.1)	18.5 (2.3)	1.0	0.48	7.67
		9.7	*4.5*	*4.2*	*10.5*	*13.9*	*0*	*0.21*	*10.3*		*8.5*	*3.7*	*2.2*		*7.3*	*9.8*	*5.5*				*0.31*	*0.76*
	61 - 105	36.2	10.7	20.5	32.7	53.2	0	0.66	22.5	62	17.8	7	3.5	2.5	12.4	34.0	12.4	30.5 (1.9)	19.5 (2.5)	1.1	0.55	8.55
		8.3	*6.8*	*6.7*	*7.7*	*14.1*	*0*	*0.68*	*9.7*		*8.4*	*3.2*	*3.0*		*10.0*	*10.3*	*5.9*				*0.47*	*1.09*
Properties of Nyngan profile 25 - Levee (similar to 10% of Carrabear Eastern meander plains?)																						
	0 - 10	10	7	17	66	83	0	0.04	9.1	91	4.8	1.4	0.1	3.4	1.1	20.4	4.9	23.6 (3.2)	11.1 (2.8)	1.3	0.85	7.1
	10 - 20	11	8	22	59	81	0	0.03	9.8	89	5.3	1.4	0.1	3.8	1.0	19.6	4.9	23.4 (2.3)	12.1 (3.8)	1.1	0.72	7.6
	20 - 75	11	7	23	59	82	0	0.07	10	91	5.3	1	0.1	5.3	1.0	16.9	3.9	23.1 (2.4)	11.8 (3.8)	1.1	0.35	8.1
	75 - 80	10	6	22	62	84	0	0.07	8.4	84	6.0	0.7	0.1	8.6	1.2	16.9	3.1	22.6 (2.3)	11.1 (2.6)	1.2	0.10	8.9
	80 - 110	20	4	19	57	73	0	0.07	11	55	7.1	2.3	0.2	3.1	1.8	22.9	6.7	23.9 (1.8	12.9 (2.3)	1.1	0.09	8.8

Combara Carrabear meander plain (CCm)

The Combara Carrabear meander plain main soils are Red and Brown Chromosols and Dermosols (Duncan et al. 2012). The surface soils are loam to clay loam. The soils do not have a clear affiliation with any of the other meander plains based on the available data. The particle size distribution of the APSoil profile (No1159; very high coarse sand and relatively low silt content) in combination with low salinity levels is different from that of the other APSoil characterisations in the meander plains (cf. Table 15 and Table 16). Consequently, its PAWC profile is shifted to lower water contents compared with the others (Figure 33a). There is limited data available in the soil landscape survey to confirm whether that is typical for the Combara Carrabear meander plain or represents a profile on the coarse texture end like profile 12 of the Trangie meander plain and profile 25 of the Eastern Carrabear meander plains (cf. Figure 33b with Figure 30b and Figure 32b).

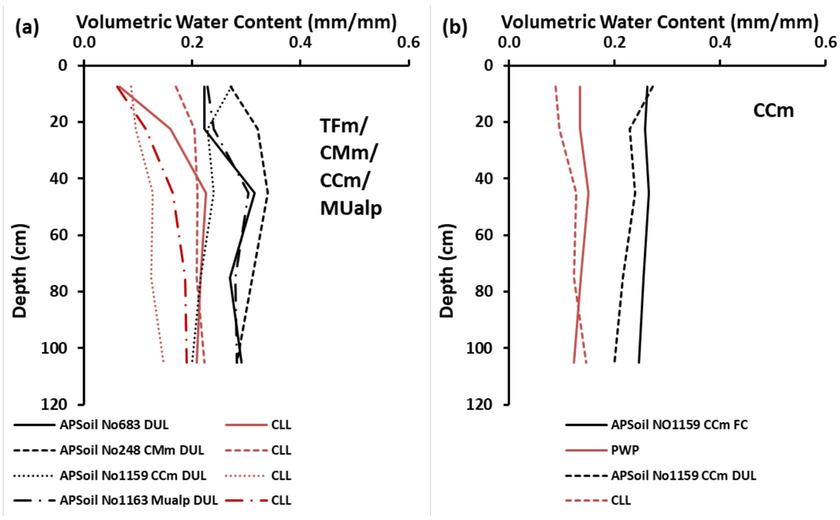


Figure 33: (a) comparison of APSoil No1159 (CCm) with the other meander plain APSoil characterisations, (b) predicted volumetric FC and PWP based on particle size data for APSoil No1159

Table 16: Soil properties relevant to PAWC for Combara Carrabear meander plain soils (data with permission from Forbes et al. 2012b). Predicted values for unconstrained profiles from Neuroman program with mean and standard error given.

Depth	Clay	Silt	Fine sand	Coarse Sand	Total sand	EC 1:5	CEC	CEC/ Clay	Ca	Mg	Na	Ca/ Mg	ESP	Predicted (unconstrained) FC	PWP	AWC	SOC	pH 1:5
cm	%	%	%	%	%	dS/cm	cmol+/kg						%	mm/mm		mm/cm	%	water
Properties of APSoil No1159 - Combara Carrabear meander plain																		
0 – 15	17	16	39	28	67	0.1	10	1	6	2	1	3.8	13	26.3 (1.8)	13.5 (1.7)	1.3	0.52	7.2
15 – 30	18	13	40	29	69	0.1	12	1	8	2	1	4.1	9	25.8 (1.3)	13.5 (2.4)	1.2	0.48	7.4
30 – 60	22	12	33	33	66	0.1	13	1	10	2	1	5.0	7	26.6 (1.5)	15.1 (3.3)	1.1	0.37	7.7
60 – 90	18	12	34	36	70	0.1	14	1	12	2	0	7.3	3	25.6 (1.4)	13.6 (3.2)	1.2	0.21	8.6
90 - 120	17	10	31	42	73	0.1	12	1	10	2	0	5.1	3	24.6 (1.2)	12.3 (1.5)	1.2	0.17	8.5

Pangee old alluvial plain (PFsta) and Summervale soil landscape group

As its name suggests, the Pangee old alluvial plain is no longer active and the materials were deposited during earlier fluvial activity (Duncan et al. 2012). It has Red Chromosols and Red Kandosols, with surface soils fine sandy loams to loams (Duncan et al. 2012). The Kandosol on the Pangee old alluvial plain has properties close to the type profile for the Pangee old alluvial plain in Duncan et al. (2012). Generally, APSoil profile No246 seems a good representative profile for the Pangee old alluvial plain (Table 17).

The Summervale soil landscape group is a complex unit associated with the colluvial slopes and plains northwest of Nyngan and parent material derived from various sources (Duncan et al. 2012). The Summervale soil landscape group is representative of many of the soils of the Cobar peneplain. The colluvial slopes are characterised by Red Chromosols and Red Kandosols (Duncan et al. 2012).

The laboratory field capacity and permanent wilting point data (Figure 34a) show similar lower limit for the modal profiles of Summervale 'red soils' and the single Pangee profile. The upper limit of the modal profile for the Summervale 'red soils' is a bit higher than that of the Pangee profile in the top 60 cm, presumably due to the higher silt and lower coarse sand content.

APSoil 1162 at Hermidale appears representative of both the modal profile for the Summervale 'red soils' (Red Chromosols and Red Kandosols) and the single profile from the Pangee Stagnant Alluvial Plain (Table 17, Figure 34b), especially for lower limit. It can be expected to be representative of a wide range of the soils in the Pangee Soil Landscape Group and the Summervale Soil Landscape group. This would include a range of the red soils of the Cobar Peneplain. The CLL and DUL of the two APSoil profiles No246 and 1162 are in a similar 'ballpark' but do provide a feel for the uncertainties that can be expected around PAWC profiles among the 'red soils' within these SLUs.

There are however several soils in the Pangee and Summervale Group that are not represented by the red soils, these include the Grey Vertosols in gilgai and some of the severely sodic soils that occur in isolated areas in both soil landscape groups. In Pangee there is also an area of much sandier soils on the Pangee plain.

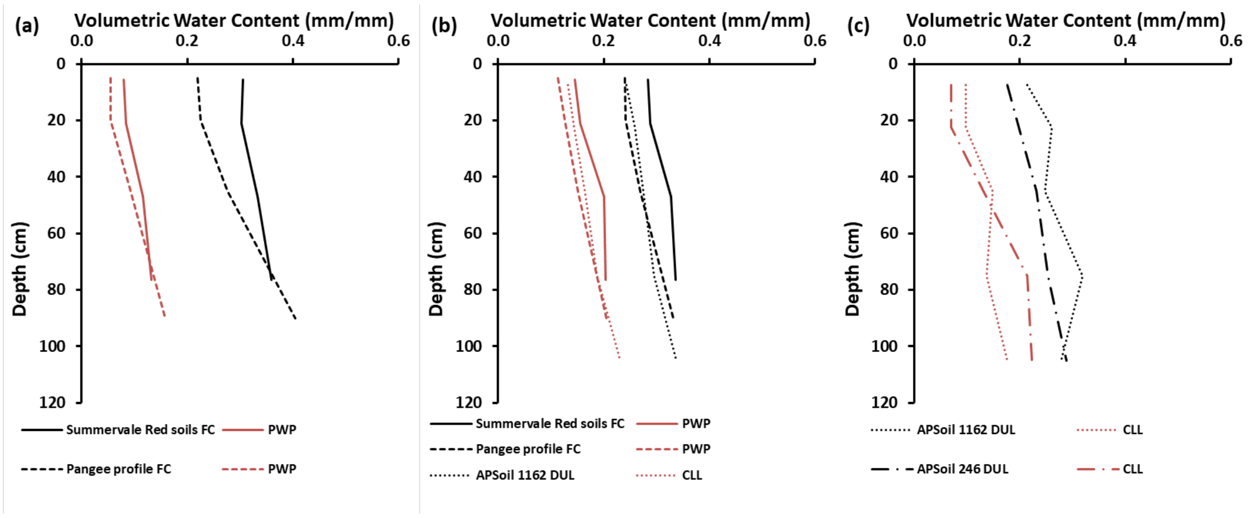


Figure 34: (a) Lab measured volumetric FC and PWP for modal Summervale 'Red soils' and the single Pangee Stagnant Alluvial Plain profile from the soil survey; (b) predicted volumetric FC and PWP based on particle size data for these profiles and APSoil No1162; (c) comparison field measured CLL and DUL for APSoil No1162 and No246.

Table 17: Soil properties relevant to PAWC for Summervale soil landscape group and Pangee stagnant alluvial plain soils (data with permission from Duncan et al. 2012). Predicted values for unconstrained profiles from Neuroman program with mean and standard error given.

Horizon	Depth	Clay	Silt	Fine sand	Coarse Sand	Total sand	Gravel & stones	EC 1:5	CEC	CEC/ Clay	Ca	Mg	Na	Ca/ Mg	ESP	Lab measured FC	PWP	Predicted unconstrained FC	PWP	AWC	SOC	pH 1:5
	cm	%	%	%	%	%		dS/cm	cmol+/kg						%	mm/mm		mm/mm		mm/cm	%	water
Summervale Red Soils (Red Chromosols and Kandosols) (4 profiles)																						
A	0 –11	21.8	15.3	54.0	8.0	62.0	1	0.08	12.1	0.6	5.4	1.7	0.1	3.2	0.8	30.5	7.9	28.3	14.5	1.4	2.32	6.33
	SD	*3.6*	*1.5*	*5.9*	*2.5*	*3.7*	*1.2*	*0.03*	*8.4*		*3.3*	*0.4*	*0.0*								*1.34*	*0.33*
B21	11 - 31	27.0	13.0	50.0	9.0	59.0	1	0.03	8.7	0.3	5.7	2.0	0.1	2.9	1.1	30.3	8.4	28.8	15.6	1.3	0.60	6.23
	SD	*3.2*	*2.1*	*5.4*	*3.1*	*3.5*	*0.7*	*0.008*	*1.7*		*2.1*	*0.6*	*0.0*								*0.10*	*0.63*
B22	31 – 63	37.0	13.5	40.8	6.8	47.5	2	0.053	13.8	0.4	8.5	3.8	0.2	2.2	1.4	33.3	11.6	32.7	20	1.3	0.31	7.30
	SD	*4.6*	*2.3*	*7.0*	*2.3*	*5.3*	*2.1*	*0.028*	*2.6*		*1.6*	*0.8*	*0.1*								*0.07*	*0.54*
B23	63 - 90	33.8	20.8	38.3	5.3	43.5	2	0.08	17.8	0.5	11.8	4.9	0.3	2.4	1.7	35.9	13.2	33.6	20.3	1.3	0.18	8.08
	SD	*8.4*	*3.6*	*6.6*	*1.8*	*5.9*	*1.9*	*0.04*	*4.0*		*3.6*	*0.8*	*0.0*								*0.05*	*0.48*
B3	90-135	31.0	21.8	37.8	5.3	43.0	4.3	0.09	19.7	0.6	12.4	6	0.5	2.1	2.5	36.7	13.9	31.8	19.4	1.2	0.13	8.55
	SD	*9.4*	*5.4*	*7.5*	*2.2*	*7.1*	*4.6*	*0.047*	*3.0*		*1.8*	*0.9*	*0.1*								*0.04*	*0.34*
Pangee Stagnant Alluvial Plain (1 profile)																						
	0 – 10	17	8	45	26	71	4	0.07	11.5	0.7	3.8	1.1	0.1	3.5	0.9	22.0	5.5	24.0	11.3	1.3	0.89	5.7
	10 – 30	21	6	38	34	72	1	0.05	7.5	0.4	3.1	1.3	0.2	2.4	2.7	22.6	5.5	24.1	12.6	1.2	0.32	5.3
	30 – 60	27	10	37	23	60	3	0.03	10.4	0.4	4.2	3.9	0.4	1.1	3.8	27.6	9.3	26.9	15.1	1.2	0.13	6.0
	60 –120	36	20	29	13	42	2	0.05	23.2	0.6	6.9	9.2	1.7	0.8	7.3	40.5	15.8	33.1	20.5	1.3	0.08	8.1
	120-160	35	17	23	11	34	13	0.20	29.4	0.8	17.3	10.7	2.2	1.6	7.5	42.3	16.1	31.0	19.7	1.1	0.08	9.0
Properties of APSoil No 1162 - Hermidale - Summervale Unit - colluvial lower slope																						
	0 – 15	22	5	35	39	74		0.11	6.4	0.3	4.3	0.8	0.1	5.1	1.1			24.3	13.2	1.1	0.67	6.4
	15 – 30	24	9	36	32	67		0.06	6.6	0.3	4.6	0.9	0.1	5.1	0.8			25.9	14.4	1.2	0.49	7.3
	30 – 60	30	8	35	27	62		0.04	8	0.3	5.4	1.4	0.1	3.9	0.9			27.5	16.4	1.1	0.26	7.5
	60 – 90	34	9	35	22	57		0.05	9.2	0.3	6.0	2.2	0.1	2.8	1.1			29.5	18.8	1.1	0.17	7.9
	90 - 120	43	11	31	15	46		0.06	11.1	0.3	6.4	3.6	0.1	1.8	1.2			33.8	23.1	1.1	0.20	7.8
Properties APSoil No 246 – Pangee																						
	0 – 15	21	8	na	na	71				0.0		3	1								0.572	7.1
	15 – 30	18	10	na	na	72		0.04	7.6	0.4	6	1	0								0.32	7.0
	30 – 60	24	9	na	na	67		0.04	7.8	0.3	5	2	0								0.152	7.1
	60 – 90	41	9	na	na	49		0.05	15.1	0.4	7	6	0								0.11	7.1
	90 - 120	51	8	na	na	42		0.08	19.7	0.4	9	8	1								0.068	7.4

20 Summary of observations and further questions

The combined PAWC observations are summarised in Table 18. Drawing on the descriptions and findings in Part II and discussion in Section 19, we can make the following observations:

- Within the alluvial landscapes the soil-landscape mapping appeared to provide a useful guide to identifying the location of backplains, characterised by Vertosols with usually larger PAWC, and meander plains, which have texture contrast duplex soils or other more uniform lighter or gradational soils with typically lower, but more variable PAWC.
- Comparing the PAWC profiles, we see great similarities in DUL of the Vertosols at APSoil sites No684 (Trangie), No1161 (Western Carrabear), No1156 (Eastern Carrabear), No1157 (Berakee in transition to Eastern Carrabear) and No1158 (Combara Carrabear). Soil survey data (Duncan et al. 2012) support the similarities.
- The DUL of Vertosols at APSoil sites No705 (Macquarie Carrabear) and No1160 (Merri Carrabear) were slightly lower. In the case of the latter this may be due to its high sodicity. A reduction in clay content and/or increase in sodicity with depth may be responsible for the reduction in DUL with depth in APSoil profile No1155 (Mulla Cowal).
- The CLL in these Vertosols was also very similar, with differences mainly driven by subsoil constraints. Profiles without subsoil constraints had a PAWC of around 200-220 mm. Where the subsoil was strongly sodic from 60-90 cm depth, the PAWC was reduced (e.g. a reduction of around 50 mm for APSoil profile No1156).
- The PAWC of duplex and gradational soils is strongly dependent on texture profile with depth, resulting in a high variability in CLL and DUL profiles. Subsoil constraints were less of a concern at the characterised APSoil sites, but this does not preclude limitations on PAWC in meander plain soils in general. To make generalisations or develop rules of thumb for the meander plain soils will require more PAWC characterisations, ideally situated on transects and/or placed in context of other information on subsoil constraints (e.g. from digital soil mapping exercises). The meander plain soils included in this study had a PAWC 150 to 200 mm depending on texture and profile, with the duplex soils typically at the lower end of this scale.

Further questions and future work

The work presented in this reported prompted some lessons and research questions for future work, some of which are being explored in the new GRDC Project CSP00210 (marked with *). See Stockman et al. (2020) for an evaluation of spatial prediction methods.

- *The soil landscape mapping appears to capture well the contrasts between meander and backplains. The results suggest that within the backplains, differences in PAWC are mostly driven by subsoil constraints caused by salinity and/or sodicity. Can we map/predict the areas where these are most likely to happen? (terrain analysis, other?) Within the meander plains texture differences are likely the main driver – can we map/predict these? How strong is link to landscape position within the meander plain SLU?
- The meander plan positions have been sites without subsoil constraints. Soils with subsoil constraints would need to be considered in future characterisations. E.g. characterisation of a more sodic, lower meander plain position within the Trangie Meander Plain SLU could be warranted.

Table 18: Summary of soils, soil-landscape units and PAWC.

APSoil No	Soil-landscape Group	SLU	PAWC (mm)	Soil	Soil Constraints to PAWC
683	Trangie	TFm	141	Duplex	
684	Trangie	TFb	193	Vertosol	
1161	Carrabear - Western	CWb	210	Vertosol	
1156	Carrabear - Eastern	CEb	153	Vertosol	Constrained due to salinity
1157	Berakee	BAlsl	194	Vertosol	
248	Carrabear - Macquarie	CMm	148	Duplex	
705	Carrabear - Macquarie	CMb/d	184	Vertosol	
1160	Carrabear - Merri	Crb	148	Vertosol	Constrained due to salinity
1159	Carrabear - Combara	CCm	215	Gradational	
1158	Carrabear - Combara	CCb	213	Vertosol	
1155	Mulla Cowal	MUalp	209	Vertosol	
1163	Mulla Cowal	MUalp	177	Duplex	
246	Pangee	PFsta	108	Gradational	
1162	Summervale	SClsl	161	Gradational	

- *APSoil No 1155 and No1163, and APSoil No 248 and No705 indicate that unmapped variability within SLU and within paddocks is possible and can result in large differences in PAWC. This is not surprising given the scale of mapping is 1:250 000. Hence local assessment of texture, at least to 30 cm depth, would be needed to distinguish between these. It is likely these differences are already noted by the farmers. It could be explored if digital soil mapping could assist.
- Similarly, it would be of interest to explore how much variability there is within paddock/farm of subsoil salinity, as was noted in the Liverpool Plains (Verburg et al. 2017).
- *For the Trangie soil-landscape group backplains, the earlier study by McKenzie (1992) distinguished three local soil profile classes. The 'Mullah grey phase', 'Buddah' and 'Snake'. It would be useful to explore whether this earlier work can help with within SLU differentiation.
- *The younger Bugwah and Marra Creek soil-landscape groups were not represented in this study (unless APSoil 1161 was in fact Bugwah backplain rather than Western Carrabear backplain). This SLU will need additional characterisation due to its different texture (higher silt content).
- *The pedotransfer function predictions of FC and PWP matched reasonably well with the field observed DUL and CLL for the backplain profiles where subsoil constraints were not affecting CLL. The comparisons between observed and predicted FC and PWP for the meander plain soils were more variable. It would be worth exploring these differences further.

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CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

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FOR FURTHER INFORMATION

Agriculture and Food
Kirsten Verburg
t +61 2 6246 5954
e Kirsten.verburg@csiro.au

Tony Webster
t +61 7 4059 5002
e tony.webster@csiro.au

Brett Cocks
t +61 7 4571 3280
e brett.cocks@csiro.au

NSW Central West Local Land Services
Neroli Brennan
t +61 0428 692 713
e neroli.brennan@lls.nsw.gov.au

Brian Murphy
t 0412 261 230
e brian.amaroo@bigpond.com