



A PROTOCOL FOR THE DEVELOPMENT OF APSOIL PARAMETER VALUES FOR USE IN APSIM

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Introduction

These guidelines have been developed to assist with the creation of APSOil files from field and lab based data and to successfully use the file to run a crop simulation using APSIM. A description of each parameter is provided along with protocols for the development of the required input information.

APSoil

The APSOil database is the repository of soils information developed for use in the APSIM cropping systems model (Keating *et al.* 2003; Holzworth *et al.* 2014). It has a focus on the physical and chemical soil characteristics that drive crop production, particularly soil water and crop nutrition. While the development of the database has been driven by the need for such information in cropping systems modelling, these data are also invaluable to agricultural researchers, consultants and farmers who require soils information for business management. As a result, APSOil data is available through the APSIM *Soils* toolbox and a number of standalone delivery products.

For non-modellers the most convenient means of accessing APSOil data is to download the database or the Google Earth .kmz file at <http://www.apsim.info/Products/APSoil.aspx>. Google Earth is a particularly convenient way of viewing the data as it allows spatial comparison of soils for a particular requirement. Updated APSOil data files are also able to be downloaded at this site. A more recent innovation has been the development of SoilMapp which enables soils information from the APSOil and other national databases to be viewed and modified (APSoil only) whilst in the field using an iPad tablet (Thomas *et al.* 2012). Amongst other options, SoilMapp provides the opportunity to identify a soil of interest and to match it to locally characterised sites within the database. This product is available for download at <https://itunes.apple.com/au/app/soilmapp/id578173447?mt=8>.

Information for 1200+ soils is now contained in the APSOil database and while the majority of these are from the agricultural areas of Australia, a small number have also been characterised in Africa and Asia as part of international research projects.



Resources for undertaking field-based soil characterisation

Publications are available to assist in the field characterisation of soils and in the general understanding of soil physical properties. These include *Soil matters* (Dalgliesh and Foale, 1998) and *Estimating Plant Available Water Capacity* (Burk and Dalgliesh, 2013) both of which are available for download (.pdf) at <http://www.apsim.info/Products/APSoil.aspx>.

Developing a soil from scratch

While it will be common for APSIM users to directly modify soil parameters within the APSOil database, there will also be times when it is necessary to develop a soil from scratch using field and laboratory based information. It is also likely that some information will be unavailable and require 'best bet' estimations to be made by the user based on their own experience and knowledge.

Often, the development of a soil may only require some relatively small adjustments to an existing soil that already resides in APSOil. In this case the modifications can be made directly within the database by changing the values in individual data boxes (by double clicking on the box) and saving the modified soil under a new name. Whilst a totally new soil can also be developed in this way, it is often more expedient to create the soil in Excel and then export it to the database. It should be noted that soils modified and saved in this way do not enter the public domain as part of the official APSOil database.

Using Excel to develop a new soil-creating the soil file format:

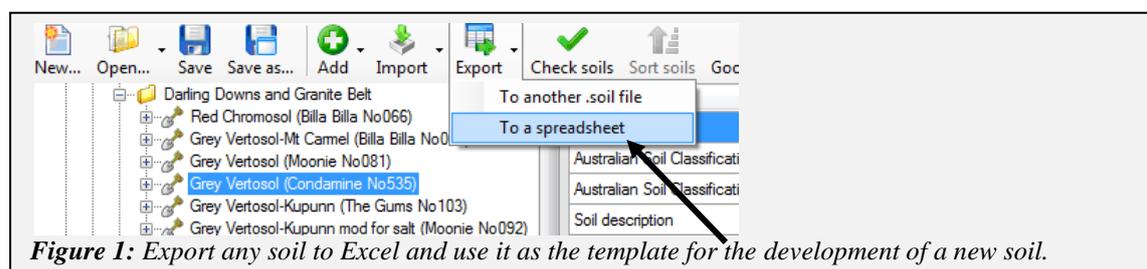


Figure 1: Export any soil to Excel and use it as the template for the development of a new soil.

The simplest way to create an accurate APSOil format is to select any existing soil within the APSOil database (Figure 1), export it to Excel and use it as an example of the required format whilst developing the new soil (Figure 2). While the headings are the most important component of the downloaded file, leaving the existing data in place while developing the new soil provides examples of the required data formats.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Name	RecordNo	Country	State	Region	NearestTcSite	ApsoilNur	SoilType	ASC_Orde	ASC_Sub-	Latitude	Longitude	LocationA	DataSourc	Comment	NaturalVe	MunselIC	MunselC	MunselS
2	Black Vert	31	Australia	Queensl	Darling Dc	Jimbour, (Jimbour	14	Black Vert	Vertosol	Black	-26.943	151.153	+/- 20m	CSIRO Sustainable Ec	Grassland, mainly Qld	Blue			
3	Black Vert	31	Australia	Queensl	Darling Dc	Jimbour, (Jimbour	14	Black Vert	Vertosol	Black	-26.943	151.153	+/- 20m	CSIRO Sustainable Ec	Grassland, mainly Qld	Blue			
4	Black Vert	31	Australia	Queensl	Darling Dc	Jimbour, (Jimbour	14	Black Vert	Vertosol	Black	-26.943	151.153	+/- 20m	CSIRO Sustainable Ec	Grassland, mainly Qld	Blue			
5	Black Vert	31	Australia	Queensl	Darling Dc	Jimbour, (Jimbour	14	Black Vert	Vertosol	Black	-26.943	151.153	+/- 20m	CSIRO Sustainable Ec	Grassland, mainly Qld	Blue			
6	Black Vert	31	Australia	Queensl	Darling Dc	Jimbour, (Jimbour	14	Black Vert	Vertosol	Black	-26.943	151.153	+/- 20m	CSIRO Sustainable Ec	Grassland, mainly Qld	Blue			
7	Black Vert	31	Australia	Queensl	Darling Dc	Jimbour, (Jimbour	14	Black Vert	Vertosol	Black	-26.943	151.153	+/- 20m	CSIRO Sustainable Ec	Grassland, mainly Qld	Blue			
8	Black Vert	31	Australia	Queensl	Darling Dc	Jimbour, (Jimbour	14	Black Vert	Vertosol	Black	-26.943	151.153	+/- 20m	CSIRO Sustainable Ec	Grassland, mainly Qld	Blue			
9																			
10																			
11																			

Figure 2: Use the headings and data formats as a template to develop the new soil.

Importing the new soil file to APSOil:

Once the soil has been developed within Excel it can be imported back to APSOil (Figure 3 and 4). After upload, the file may be selected and copied to another directory if required.

Note: The Excel work sheet must be named SoilData for the upload to be successful.

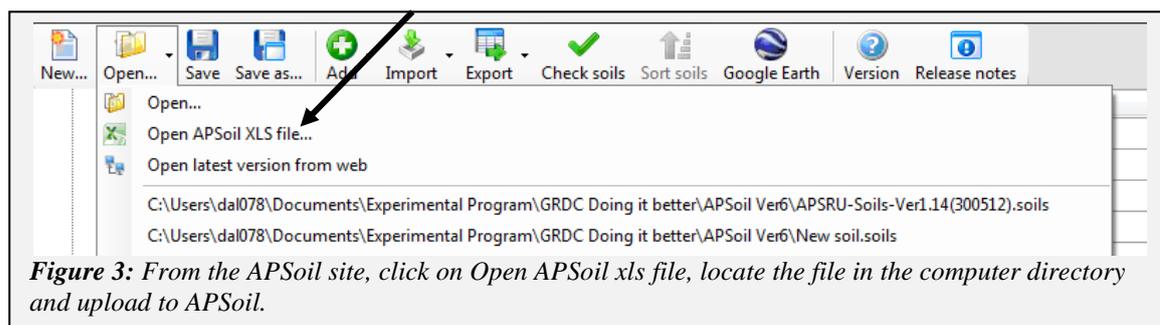


Figure 3: From the APSOil site, click on Open APSOil xls file, locate the file in the computer directory and upload to APSOil.

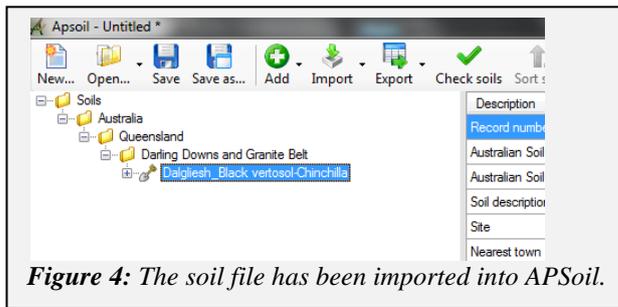


Figure 4: The soil file has been imported into APSOIL.

Error checking:

Prior to using the file in APSIM it should be checked and any errors corrected. This is commonly done within the Excel file (Figure 5, 6 and 7).



Figure 5: Select Check soils to error check the file.

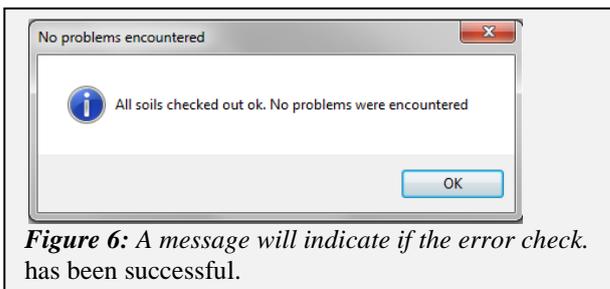


Figure 6: A message will indicate if the error check has been successful.

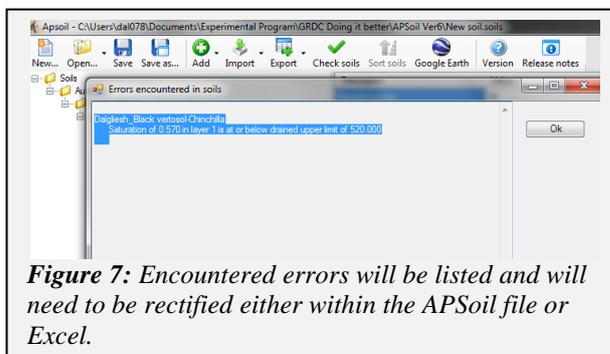


Figure 7: Encountered errors will be listed and will need to be rectified either within the APSOIL file or Excel.

Meta data

The following data (Table 1) are required to locate soil characterisation sites in the landscape. Whilst private information relating to the owner of the property (their name, property name, address) may be collected to facilitate collaborator communication it should not be divulged publicly. Sites should only be identified publicly using GPS co-ordinates (with permission of land owner). Personal information displayed in files residing in APSoil will be removed. In the APSoil Excel file these meta-data are repeated for each soil layer.

Table 1: APSoil meta data attributes

Attribute	Description information
Name	Usually a combination of soil type, texture or other descriptor field, nearest town field and APSoil number (if being included in the official database). See naming of existing APSoil records.
Record Number:	Allocated by database manager and included if and when the soil is submitted and approved for inclusion in APSoil
Country:	
State:	
Region:	Use the Bureau of Meteorology regional boundaries for each state
Nearest town:	Local town which will assist in locating the site
Site:	Local district or road or some other locally recognisable identifier
APSoil number:	Allocated by database manager and included if and when the soil is submitted and accepted for APSoil publication
Soil type, texture or other descriptor	Brief soil type or texture description for the whole profile (e.g. sandy loam over clay)
Local name:	May be a colloquial soil name used by local farmers or one provided during earlier soil surveys e.g. Waco or Mywybilla or Cecilvale. In Western Australia this field is used to indicate the MySoil classification.
ASC (Australian Soil Classification) Order:	Found at http://www.clw.csiro.au/aclep/asc_re_on_line_V2/soilhome.htm
ASC (Australian Soil Classification) Sub Order:	Found at http://www.clw.csiro.au/aclep/asc_re_on_line_V2/soilhome.htm
Longitude and Latitude	In decimal degrees using WGS84 datum.
GPS location accuracy:	If the site has been located using GPS, insert the accuracy level as indicated on the GPS unit. If the site is 'regional' i.e. a general soil developed for a particular reason and region, note that the soil is 'regional, based on a particular town'. If the soil is generic, i.e. typical of a particular soil classification, note that the soil is 'generic'.
Year of sampling:	Particularly important when considering soil values that change over time e.g. soil carbon
Data source:	Attribution to the person/organisation that collected the data, the project (if applicable) and the funding organisation under which the work was done
Comments:	Record any information which may assist in the identification of the soil including: <ul style="list-style-type: none"> • Whether the soil was self-mulching, cracking, hard setting, duplex etc. • Description and position of the soil in the landscape • Slope on which the soil was located • Depth of A-B horizon boundary • Provide any external references that provide additional information/maps on the soil • Any issues/problems with characterisation (e.g. tent blown off, hard layer preventing deeper sampling, etc.) • Identify estimated values, missing data • Year of additional characterisation e.g. specify when an additional CLL was provided for inclusion with the particular soil
<i>Note: Do not use comma's to separate the information.</i>	
Natural Vegetation:	Useful when attempting to select an appropriate soil

Provenance data for individual parameters

When developing a soil that will be included in the APSoil database and used in the public domain, it is important that data provenance be provided to allow future users to understand the origins of the data and something about their collection. The following list provides the recommended codes for important soil water parameters. These codes should be included in the appropriate columns adjacent to the data (in the exported APSoil Excel spreadsheet) when developing a soil for use in APSIM.

*Note: While not all of the listed parameters are directly used by the APSIM model, they do provide a more comprehensive physical and chemical picture of the soil which is valuable in interpreting the particular soil situation and for setting appropriate parameter values related to water holding capacity (these data are designated by * in Table 2).*

Table 2: Parameter list for the development of soils within the APSoil database

Parameter	Code	Explanation
Bulk density (BD)	FM	Field measured and checked for sensibility i.e. PO-SAT and SAT-DUL, BD data are logical, if not then BD is modified to comply with set rules
	C_grav	Calculated from gravimetric moisture when the soil profile is wet but drained (Vertosols only) using PO-SAT=3% and SAT-DUL=5%
	E	Estimated – best estimate based on local knowledge, soil texture etc
	U	Unknown source or quality of data
Saturation (SAT)	C_bd	Calculated from measured or estimated data, or calculated from PO where PO (% volumetric water)=(1-BD/2.65)*100 and PO-SAT = 3% for heavy clay soils, to 7% for sandy soils
	C_pt	Developed using a pedo-transfer function
	Lab	Laboratory based measurement of the soil water characteristic
	E	Estimated – best estimate based on local knowledge and soil type
	U	Unknown source of data or quality of data
Drained upper limit (DUL)	FM	Field measured
	Lab	Laboratory based measurement of the soil water characteristic
	E	Estimated – best estimate based on local knowledge and soil type
	U	Unknown source of data or quality of data
LL15 and air dry (AD)	Lab	Laboratory based measurement of the soil water characteristic
	E	Estimated – best estimate based on local knowledge and soil type
	U	Unknown source of data or quality of data
Crop lower limit (CLL)	FM	Field measured
	E	Estimated
	U	Unknown source or quality of data
Organic Carbon OC)	M (Walkley Black %)	Measured using the Walkley Black methodology. (APSIM will convert Walkley Black % to Total % by multiplying by 1.3.)
	M (Total %)	Measured Total % (e.g. using the Leco technique)
	E (Walkley Black %) or E (Total %)	Estimated – best estimated based on local knowledge, soil type and land use history. Quoted as either Walkley Black % or Total %. (APSIM will convert Walkley Black % to Total % by multiplying by 1.3.)
	U (Walkley Black %) or U (Total %)	Unknown source or quality of data. Quoted as either Walkley Black % or Total %. (APSIM will convert Walkley Black % to Total % by multiplying by 1.3.)
		<i>Please note that APSIM will determine whether data is Walkley Black % or Total % based on coding of the first layer.</i>
Electrical Conductivity (EC)	E	Estimated – best estimate based on local knowledge. Quoted as EC1:5 in dS/m

Parameter	Code	Explanation
	M	Measured as EC1:5 and quoted in dS/m
	U	Unknown source or quality of data
pH	M (1:5 water) or M (CaCl ₂)	Laboratory measured. Quoted as either pH 1:5 water or pH CaCl ₂ depending on method of measurement. (APSIM will convert pH CaCl ₂ to pH 1:5 water using the equation: $\text{pH 1:5 water} = \text{pH CaCl}_2 \times 1.1045 - 0.1375$)
	E (1:5 water) or E (CaCl ₂)	Estimated – best estimate based on local knowledge. Quoted as either pH 1:5 water or pH CaCl ₂ depending on the method of measurement. (APSIM will convert pH CaCl ₂ to pH 1:5 water using the equation: $\text{pH 1:5 water} = \text{pH CaCl}_2 \times 1.1045 - 0.1375$)
	U (1:5 water) or U (CaCl ₂)	Unknown source or quality of data. Quoted as either pH 1:5 water or pH CaCl ₂ . (APSIM will convert pH CaCl ₂ to pH 1:5 water using the equation: $\text{pH 1:5 water} = \text{pH CaCl}_2 \times 1.1045 - 0.1375$)
<i>Please note that APSIM will determine whether data is pH 1:5 water or pH CaCl₂ based on coding of the first layer.</i>		
Chloride (Cl)	E	Estimated – best estimate based on local knowledge. Quoted in mg/kg
	M	Laboratory measured in mg/kg
	U	Unknown source or quality of data
*Boron (B)	E	Estimated – best estimate based on local knowledge. Quoted in mg/kg
	M	Laboratory measured using Hot CaCl ₂ methodology. If methodology is unknown indicate ‘U’. Quoted in mg/kg.
	U	Unknown source or quality of data
*Cation Exchange Capacity (CEC)	E	Estimated – best estimate based on local knowledge. Quoted in meq/100g
	M	Laboratory measured in meq/100g
	U	Unknown source or quality of data
*Cations (Ca, Mg, Na, K)	E	Estimated – best estimate based on local knowledge. Quoted in meq/100g
	M	Laboratory measured in meq/100g
	U	Unknown source or quality of data
Exchangeable Sodium (ESP%)	E	Estimated – best estimate based on local knowledge. Quoted as %
	C	Calculated from laboratory analysis. $ESP = (Na [meq/100g] / \text{Sum of Cations}[meq/100g]) * 100$
	CEC	Calculated from laboratory analysis. $ESP = (Na [meq/100g] / CEC[meq/100g]) * 100$
*Manganese (Mn)	E	Estimated – best estimate based on local knowledge. Quoted as mg/kg
	M	Laboratory measured in mg/kg
*Aluminium (Al)	E	Estimated – best estimate based on local knowledge. Quoted as cmol(+)/kg
	M	Laboratory measured in cmol(+)/kg
*Rock (Rocks %)	E	Estimated – best estimate based on local knowledge. Quoted as E (wt%) or E (vol%)
	M	Laboratory measured % rock (of bulk soil). Quote as M (wt%) or M (vol%)
*Particle Size (PSA)	E	Estimated – best estimate of % sand, silt and clay (fine earth fractions, adding to 100%)
	M	Laboratory measured % of sand, silt and clay (fine earth fractions, adding to 100%)

Note: APSoil records can handle a separate layer structure for the soil chemistry data (OC, EC, pH, Cl, B, CEC, cations, ESP, Mn, Al and PSA). This layer structure is specified in mm in

the 'ThicknessChem (mm)' column of the APSoil Excel spreadsheet. The layer structure for the other parameters (PAWC and APSIM parameters) is specified in the 'LayerNo' and 'Thickness (mm)' columns of the APSoil Excel spreadsheet.

Development of individual parameters

Soil water parameters in APSoil are based on in-field measurement. This is in contrast to laboratory practice which relies on the measurement of water potential at field capacity (FC) (-0.1 or -0.3 bar) and wilting point (LL15) (-15 bar) respectively.

Calculations are outlined in Dalgliesh and Foale, 1998 (Module 4) and Burk and Dalgliesh, 2013. An Excel spreadsheet with calculation sheets and graphs to assist with data processing is available <http://www.apsim.info/Products/APSoil.aspx>. It has separate calculation procedures for non-shrink swell (rigid) soils and shrink swell soils.

Bulk density (BD)

Using field measured BD is the preferred option for non-shrink swell (rigid) soils with the profile accessed using either a surface based approach, such as that described in Burk and Dalgliesh, 2013, or through the digging of a pit. The graphs in the Excel spreadsheet from the APSoil webpage can be used to check for outliers among the replicate measurements that may be due to measurement error.

It is also not uncommon to need to rely on an estimate of BD. While this may lead to some reduction in the accuracy of calculation of nitrogen and water availability, this can be minimised by using data from similar regional soils, or through a literature search to identify soils of similar texture. Variation in the depth of textural horizon should be considered when allocating layer depth and appropriate BD. This is particularly an issue in texture contrast soils. BD also tends to increase with depth, a result of the weight of the soil over-burden (assuming texture remains the same).

In shrink-swell clays like vertosols, the BD of the soil component (excluding cracks) increases as water is extracted by the plants. As this change is difficult to measure and to account for in simulation, the BD of shrink/swell soils is estimated or measured at what is considered to be field capacity or drained upper limit (DUL-see below). Consequently, care needs to be taken when calculating BD from gravimetrically measured DUL to ensure that the profile has been fully re-charged prior to sampling. This is a particular issue where soils have been re-charged through rainfall but may not be fully wet throughout the whole profile. BD calculated from samples that are at a gravimetric moisture content of <DUL will result in higher BD values than those calculated when the soil is at a moisture content that equates to DUL. This will result in a less accurate estimation of soil parameters such as DUL, CLL, PAWC, PAW and available N. A procedure designed to reduce these errors is described and calculation sheets supplied in Dalgliesh and Foale, 1998 (Module 4) and Burk and Dalgliesh, 2013.

Drained upper limit (DUL)

DUL is field-measured after either the planned wetting-up of an area of the soil of interest or after sufficient rainfall has been received to fill the soil profile to the depth of crop rooting. It is generally measured in conjunction with BD (see above). Procedures for the wetting-up of a site, its subsequent field measurement and the calculation of DUL are covered in detail in Burk and Dalgliesh, 2013. Again, separate procedures are used for rigid and shrink-swell soils.

Interpreting DUL field data

- a) The biggest challenge with the field measurement of DUL is ensuring that the site is fully wet to potential crop rooting depth prior to sampling. In unconstrained soils, annual summer crops e.g. cotton, sorghum, have the capacity to root to a depth of 1.8 to 2 m. This is the depth to which data should be collected. Of course, if it is known that sub-soil constraints exist at a particular depth it may not be necessary to sample as deep, although care should be taken when making this assumption as many crops are able to extract at least some water from constrained soils. A clear indicator that a soil has not been wet to depth is when the DUL graph line at depth does not meet the crop lower limit line (that is the bucket does not join at depth). In freely draining soils, such as sands or loams, it is sufficient to assume that a soil will be wet to depth after a few days or weeks of water application, however on soils that exhibit slow infiltration rates, such as the vertosols, it may be a number of months. As the measurement of DUL is a significant investment in time and resources it is suggested that wetting up be monitored using an NMM or similar device or through regular gravimetric sampling.
- b) The calculation sheet for rigid soils (measured BD) will automatically check whether there is at least a 0.05 gap between DUL and Saturation (SAT) calculated from BD (see below). If not, it will recalculate BD, DUL and SAT based on the equations for swelling soils (calculated BD; see Burk and Dalgliesh, 2013). Prior to finalising the PAWC profile, consider whether this automatic recalculation is warranted or whether a gap smaller than 0.05 may be related to insufficient drainage or due to compaction during sampling of heavy clay layers.
- c) Ponds for the measurement of DUL are generally covered with black plastic sheeting to reduce evaporation during the wetting up phase and to reduce water extraction by weeds. The high temperatures generated under the plastic can result in evaporation of water from the soil surface under the plastic layer with the water condensing on the underside of the sheet. This water then recycles through the surface layer of the profile, increasing gravimetric water content. This shows up on the PAWC graph as a kick to the right in the DUL graph line. Of course this kick may be legitimate, indicating a significant change in surface texture between layer 1 and 2. Use the texture information to confirm. If there is no texture change the DUL soil water value should be set to a value similar to the value for layer 2.

Crop Lower Limit (CLL)

There are three options for obtaining a CLL:

1. Measured field data generally obtained using a rain exclusion shelter (Burk and Dalgliesh 2013)
2. Predicted data (for Vertosols only; Hochman *et al.* 2001)
3. Estimated (synthesised) data

Whilst measured data is the preferred option, it is often unavailable. This results in the need to estimate CLL based on known information, particularly DUL and soil texture. While the following rules of thumb provide some pointers to developing a sensible CLL such values may need to be modified iteratively to ensure credible yield simulation results are obtained.

Field measured data

CLL in the 0-15 and 15-30 cm layers should be set equal to the value in the 30-60 cm (or the first layer below which air drying is assumed to occur) (Figure 8 and 9). This rule assumes similar textures and applies whether CLL is measured or estimated. It takes into consideration the surface and near-surface air drying of the soil prior to sampling. See below if there is a texture change between these depths.

Rules/judgements on which to base the estimation of CLL

Uniform soils (Non-texture contrast)

- For all texture classes where DUL is known, but CLL data is unavailable (and no sub-soil constraints present), setting CLL at 50% of DUL in the surface depth layer and the subsequent 2 layers, is a good starting point (assuming similar textures and considering the above suggestions on using measured data).
- In high clay soils, CLL in the layers below the third should be set as tapering towards, and meeting DUL at 180 cm for summer crops and 150 cm for wheat and other cereals (Figure 8). Shallow rooted legumes such as Mungbean should taper to 120 cm. This rule of thumb requires modification where the profile is <150-180 cm deep or where there are sub-soil constraints (see sub-soil constraints section). Observed plant rooting depth is a good indicator of the depth to which plants are accessing resources although it should be remembered that it is likely that there are roots to greater depths than can be observed by the naked eye.
- In lighter textured soils, and in particular sands, it is common for the measures of CLL and DUL to run in parallel (Figure 9) for the depth of the profile. The non-meeting of the DUL and CLL lines may indicate that the depth of sampling was insufficient although it is unlikely to have significant impact on overall PAWC when it occurs at depth (such as in Figure 9). In sandy soils DUL is commonly around 10-12% volumetric for the full depth and CLL around 5-6% . It is also common for the maximum rooting depth of sandy soils to be deeper than for clay soils although this is dependent on rainfall, soil depth and sub-soil constraints (Figure 9).

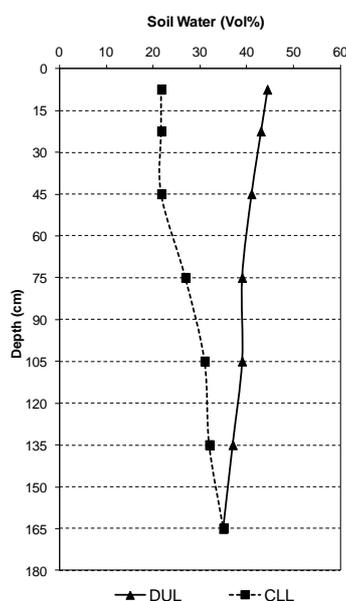


Figure 8: A typical Vertosol PAWC profile for a wheat crop. Showing the high volumetric water contents at DUL and CLL. CLL in the 2 top soil layers is set to the layer 3 value to account for surface air drying prior to soil sampling.

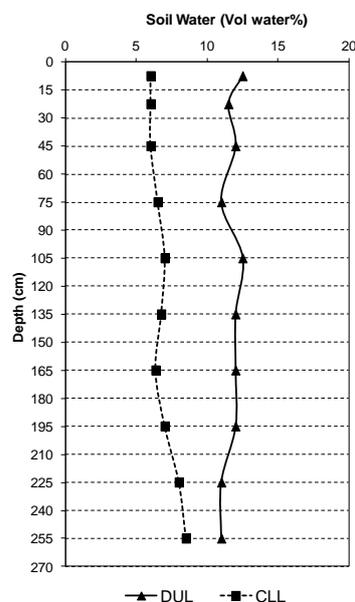


Figure 9: A common sandy textured soil profile for a wheat crop. Showing the volumetric water contents at DUL and CLL. CLL in the 2 top soil layers is set to the layer 3 value to account for surface air drying before soil sampling. It is not uncommon for rooting depth to be deeper on sandy soils.

Prediction of CLL

Predicted CLL values for Black and Grey Vertosols may be done in APSOIL using the relationship between DUL and CLL for heavy clay soils developed by Hochman *et al.* (2001). It is based on field measured data from the northern Australian cropping region with prediction only used when measured CLL is not available for the following crops: wheat, cotton, chickpea, sorghum, barley, fababean and mungbean. An Excel tool is available to undertake these calculations outside of the APSOIL database (<http://www.apsim.info/Products/APSOIL.aspx> see CLL tool).

Gradational soils (Texture contrast)

- a) CLL values in the top two layers are likely to be lower than the third layer (or at the depth where textural change occurs). These values should form the basis for development of sensible CLL values although care should be taken to adequately account for air drying.
- b) Where CLL data is not available and estimation required, a similar process to that described above for non-texture contrast soils is suggested. CLL should be taken as 50% of each individual layer for the top 3 layers. Some tapering towards DUL should be done in deeper layers with observed rooting depth and density taken as an indicator of maximum rooting depth.

Prediction of CLL for crops other than wheat

Where the soil described does not have CLL values for the crop of interest rules of thumb may be used to estimate the CLL of that crop.

- 1) For other winter cereals and canola use wheat LL values
- 2) For winter legumes (e.g. chickpeas) assume a shallower rooting system than the cereals and that the roots spend less time extracting water at depths > 60cm. Therefore, we take the following steps:
 - a) Nominate the reduced maximum rooting depth (e.g. wheat max depth is 150 cm, chickpea maximum depth is 120 cm)
 - b) Assume the same CLL as wheat to 60 cm depth
 - c) This gives us 60-90 cm 90-120 cm and 120-150 CLL values to modify (i.e. 3 depth)
 - d) For depth 1 (60-90 cm), using CLL and DUL values of that layer:
Chickpea LL = Wheat LL + 1/3 * (DUL-Wheat LL)
 - e) For depth 2 (90-120 cm), using CLL and DUL values of that layer:
Chickpea LL = Wheat LL + 2/3 * (DUL-Wheat LL)
 - f) For depth 3 (120-150 cm), using CLL and DUL values of that layer:
Chickpea LL = Wheat LL + 3/3 * (DUL-Wheat LL), i.e Chickpea LL = DUL
- 3) For deeper rooting crops (e.g perennials, lucerne)
 - a) Nominate the increased maximum rooting depth
 - b) Depending on the number of added layers taper the lower limit of the Perennial crop as per Chickpea example so that Peren_LL is increased from wheat LL at 120-150 cm to Peren_LL=DUL at the layer below the maximum rooting zone.

Where CLL is estimated, in addition to noting the estimation approach in the CLL code field, it should also be noted in the Comments field.

LL15 (-15 bar)

If measures of LL15 are available these data should be used in APSoil, if measured data is not available then estimates will be required.

Rules of thumb

Non-texture contrast soils (heavy clay and lighter textured soils)

- a) LL15 is to be set equal to CLL in the top 3 soil layers (assuming 0-15, 15-30 or similar) using the assumption that the CLL in the top 2 layers has already been set to equal CLL in the 3rd layer (30-60 cm or similar) (Figure 10).
- b) LL15 in layers deeper than 30-60 cm should be set equal to the value for CLL found in the 30-60 cm layer, unless a subsequent CLL value is lower than that found in the 30-60 cm layer, in which case all subsequent layers should be set equal to that value (Figure 11).

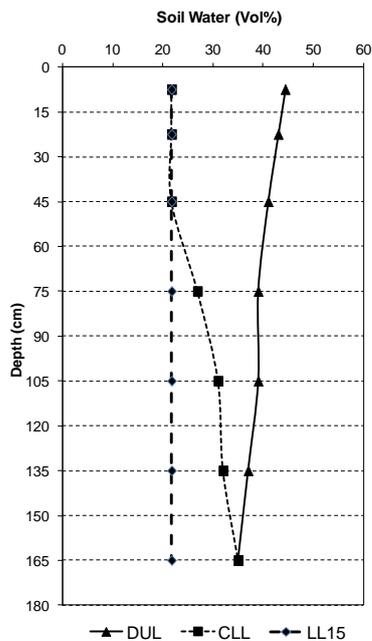


Figure 10: Estimated LL15 values for a Vertosol soil where %CLL deeper in the profile is always higher than in the surface 3 layers.

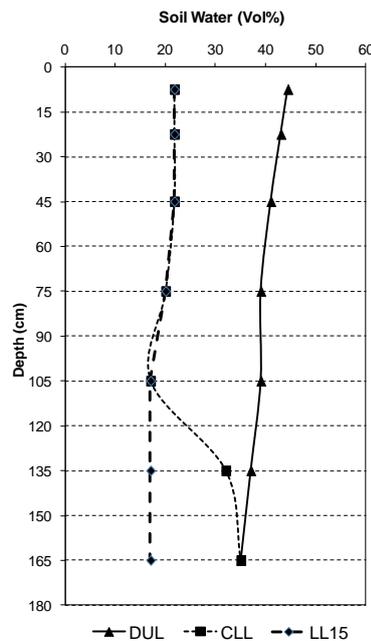


Figure 11: Estimated LL15 values for Vertosol soil where %CLL in the deeper profile is actually lower than in the surface layers and showing how LL15 is treated under these circumstances.

Texture contrast soils

- LL15 should equal measured/estimated values for CLL in the 0-15, 15-30, 30-60cm layers
- LL15 to equal the value for LL15 30-60cm layer in all deeper layers
- Care should be taken in duplex soils where the texture change is deeper than the 30-60 cm layer. In these cases LL15 in the deeper layers may equal the 60-90 cm layer or wherever the horizon changes from sand or loam to clay.

Local knowledge can be used to make exceptions to these rules but the reasoning should be noted in the comments section of APSoil.

Air Dry (AD)

Unless AD water content has been field measured, set AD at 50% of the LL15 value in the top soil layer, 80% in the second layer and 100% for the remainder of the profile. In soil types where air drying occurs to >30 cm depth AD will require adjusting to reflect this. Whilst there are no hard and fast rules, it could be suggested that were AD occurring to a depth of 60 cm that the sequence would be 50%, 70%, 90%, and then 100% of LL15 for the remainder of the profile (Figure 12).

In using estimated AD values in APSIM modelling, there may be issues associated with the simulation of crop germination when soil surface layers of 10, 15 or 30 cm thickness are being used. With small rainfall events (particularly when the soil is at or near AD) the soil may not reach a moisture content of >CLL which will result in delayed simulated germination. This may be different from practical reality in which germination will commence when there is sufficient moisture immediately around the seed. A solution is to use shallower soil layers in the soil surface.

Note: When field measured soil water values taken prior to planting, or after harvest are below the estimated air dry values, manual modification of the estimated air dry values in APSOil is recommended to fit the measured data.

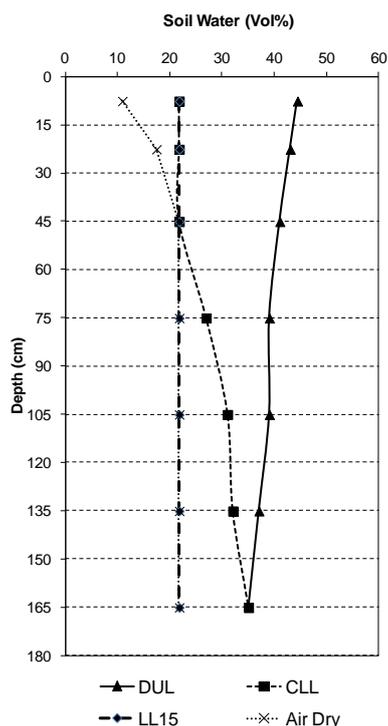


Figure 12: Estimated soil Air Dry values as a % of LL15 in each layer. This example considers that air drying occurs in the top 2 soil layers. Air drying to a greater depth will require reconfiguration of AD.

Saturation (SAT)

SAT data is rarely available, and as a consequence, is generally calculated from the Total Porosity (PO) of the soil determined from measured soil bulk density and an assumed soil particle density of 2.65. SAT is then calculated by subtracting the assumed entrapped air% for the particular textural class (e). These calculations allow SAT to be calculated across the range of soil textures (Figure 13) (Dalglish and Foale, 1998).

$$\text{Porosity (PO) (\% Volumetric)} = (1 - \text{BD}/2.65) \times 100$$

For example:

$$\begin{aligned} \text{PO} &= (1 - 1.4/2.65) \times 100 \\ &= 47\% \end{aligned}$$

$$\text{Saturation (SAT) (\% Volumetric)} = (\text{PO} * -e) \times 100$$

*Where PO is expressed as a decimal fraction

For example:

$$\begin{aligned} \text{SAT} &= 47\% - 5\% \text{ (for a loam)} \\ &= 42\% \end{aligned}$$

Where values for e are soil dependent:

- Clay soils-3%
- Loams-5%
- Sand-7%

The calculation sheets for rigid soils will calculate the difference between SAT and DUL. If this is less than 0.05 it will recalculate BD, DUL and SAT (see section on DUL). Occasionally, a DUL > PO is obtained. This is strictly speaking not possible and may indicate a sampling issue, error in wet or dry weights or core volume. A DUL > PO can also occur if the soil particle density is more than 2.65.

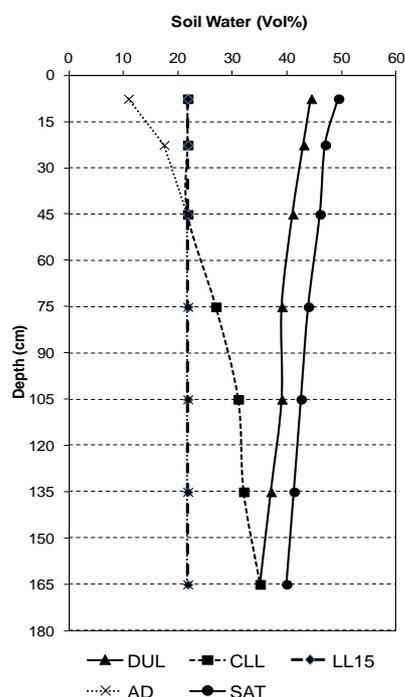


Figure 13: The calculation of total soil porosity (PO) from the soils BD and an assumed soil particle density enables SAT to be calculated using an assumed entrapped air content (PO-SAT) which varies with soil texture.

pH

pH is required for each soil layer. Whilst APSIM uses water based pH analyses as its standard, it will automatically convert CaCl₂ based measures using the following formula:

$$pH \text{ in water} = (pH \text{ in CaCl}_2 \times 1.1045) - 0.1375$$

Rock

While the presence of rock in a soil affects the overall BD of the soil and impacts on the presence and availability of water and nutrients, adjustment of these parameters in rocky soils is not automatically undertaken by APSIM. While this will be rectified in the future, APSIM currently calculates the quantities of water (including DUL and CLL) and nutrients based on the overall BD (soil and rock fractions) of the soil. If % rock is available for a sample, please include it in the APSoil record (along with coding whether this is a volumetric or weight %).

Chemical sub-soil constraints (SSC)

The presence of sub-soil constraints impacts on Plant Available Water Capacity (PAWC) through a reduction in the capacity of the plant to extract water from the soil profile. This is reflected in an increase in the CLL% which reduces PAWC. Whilst shallow soil types i.e.

those with an impenetrable rock layer at depth, or duplex layers through which roots have difficulty passing, should also be considered as being constrained, they are not part of this discussion and should be considered separately when setting profile rooting depth.

The most common sub-soil constraints impacting on agricultural production are salinity and sodicity.

- Chloride (Cl) has the most direct chemical impact on water extraction and should be measured directly.
- While excess levels of sodium (Na) (measured as Exchangeable Sodium (ESP)), cause a soil chemical imbalance, the impact on plant growth is physical. Excess sodium results in the dispersion of the clay particles which block pore space, increasing surface runoff and reducing water infiltration and root movement.
- Boron (B) is a constraint to agricultural production in some soils of southern Australia and should form part of the suite of chemical analysis undertaken on these soils. While it is not used directly by APSIM it is recommended that the data be included in APSoil for the general use of agronomists/farmers. Also, soil file developers should be aware of its presence and manually modify soil parameters, based on local recommendations, prior to their inclusion in APSoil. This is only an issue where CLL has not been field-measured (see note below).

Cl, ESP and EC data should be included in APSoil if available. If, however, a decision is required on where to invest resources in chemical analysis, it is recommended that they be put towards Cl. Chloride will be used by the model, as the preferred option to modify water extraction, followed by ESP and EC. It should be noted that APSIM does not directly alter CLL in the presence of sub-soil constraints but modifies the KI value which sets the fraction of plant available water (PAW) able to be extracted from a particular soil layer per day. This approach is based on Hochman *et al.* (2007).

Note: If the CLL for a soil has been determined through field characterisation, any effects of SSCs can be assumed to be reflected in the data and no further modifications are required. The above recommendations only become important where, a) the CLL has been estimated and is not based on field measured characteristics, and b) when soil characteristics have been described for a soil with no SSC and the same overall characterisation is being transferred for use at another site of the same soil type but with hostile sub-soil.

Organic Carbon (OC)

Field measured OC should include the analytical methodology used in its determination when being added to APSoil (Walkley Black, Leco, MIR). Estimation of total carbon (when measured using Walkley Black) is done within APSIM.

Where only surface OC data is available, use the following method (Table 3) for estimating OC values for the deeper layers.

Table 3: Estimating organic carbon at depth based on a field measured surface layer

Depth Layer (cm)	% of surface layer
0-15	100
15-30	80
30-60	50
60-90	25
90-120	15
120-150	10
150-180	10

+SWCON*Saturated Flow-proportion of water above DUL which will drain to adjacent soil layers/day*

When water content in any soil layer is above DUL, a fraction of the water drains to the next deepest layer each day.

$$\text{Flux} = \text{SWCON} \times (\text{SW} - \text{DUL})$$

Infiltration or water movement into any layer that exceeds the saturation capacity of the layer automatically cascades to the next layer.

Set the fraction of water above DUL that moves daily to the next soil layer as follows:

Clays=0.3

Loams=0.5

Sands=0.7

Judgement should be used for other textures.

+KL*Fraction of PAW able to be extracted/day from a particular soil layer***Table 4:** *KL values for Australian crops*

Crop	0-15	15-30	30-60	60-90	90-120	120-150	150-180
Wheat	0.06	0.06	0.06	0.04	0.04	0.02	0.01
Oats	0.06	0.06	0.06	0.04	0.04	0.02	0.01
Sorghum	0.07	0.07	0.07	0.05	0.05	0.04	0.03
Barley	0.07	0.07	0.07	0.05	0.05	0.03	0.02
Chickpea	0.06	0.06	0.06	0.04	0.04	0.0	0.0
Mungbean	0.06	0.06	0.06	0.04	0.04	0.0	0.0
Cotton	0.10	0.10	0.10	0.10	0.09	0.07	0.05
Canola	0.06	0.06	0.06	0.04	0.04	0.02	0.01
Pigeon Pea	0.06	0.06	0.06	0.05	0.04	0.02	0.01
Maize	0.06	0.06	0.06	0.04	0.04	0.02	0.01
Cowpeas	0.06	0.06	0.06	0.04	0.04	0.02	0.01
Sunflower	0.1	0.1	0.08	0.06	0.04	0.02	0.01
Fababean	0.08	0.08	0.08	0.08	0.06	0.04	0.03
Lucerne	0.1	0.1	0.1	0.1	0.09	0.09	0.09
Perennials	0.1	0.1	0.1	0.1	0.09	0.07	0.05
Lupins	0.06	0.06	0.06	0.04	0.04	0.02	0.01
Lentils	0.06	0.06	0.06	0.04	0.04	0.0	0.0
Triticale	0.07	0.07	0.07	0.04	0.02	0.01	0.01
Millet	0.07	0.07	0.07	0.05	0.05	0.04	0.03
Soybeans	0.06	0.06	0.06	0.04	0.04	0.02	0.01

+XF*Root exploration factor*

XF is used in APSIM to slow down the advance of the root exploration front. This can be due to the presence of a physical constraint such as a compacted layer or to reaching a layer of parent material.

Where CLL is measured and water extraction is observed set XF=1, where no extraction XF=0.

Where 1 species is measured for CLL other estimated species will have the same XF values (the same rule applies where there are no CLL data available and data are synthesised).

+FInert

Proportion of initial organic C assumed to be inert

Soil type, age of cultivation and management impact on the proportion of organic carbon considered to be inert (FInert). However, it can be assumed that all carbon at >60 cm depth is inert and that similar amounts of inert-C are present in the near surface soil (unless local knowledge suggests otherwise) Table 5). Therefore values for inert-C can be estimated as a proportion of total carbon for each profile layer.

Table 5: Proportion of inert organic Carbon in the profile.

Depth Layer (cm)	Vertosol-Inert proportion	Other Australian soils
0-15	0.4	0.4
15-30	0.6	0.5
30-60	0.8	0.7
60-90	0.95	0.95
90-120	0.95	0.95
120-150	0.95	0.95
150-180	0.95	0.95

Note: FInert is only used at model initialisation.

+FBiom

Proportion of non-inert C in the microbial biomass pool

In a soil system without any fresh organic matter, it would be expected that the ratio of BIOM:HUM would be related to the relative rates of decomposition of the two pools. For the rates of decomposition set in the APSIM default parameter file (soil.xml), the corresponding value of FBiom is 0.01. This is the recommended value for the deeper soil layers, since it will result in stable sizes of the BIOM pools during simulation.

In the near surface layers, where the soil is affected by regular inputs of plant residues, FBiom will be higher. Values in the surface soil layer are expected to vary in the range 0.02 to 0.07. The sensibleness of the values used for FBiom can be judged from inspection of how the BIOM pool size is predicted to change through time. Table 6 provides a useful first estimate.

Table 6: Proportion of non-inert C in the microbial biomass pool across the soil profile.

	0-15	15-30	30-60	60-90	90-120	120-150	150-180
All crops/soils	0.035	0.02	0.015	0.015	0.01	0.01	0.01

+Cona

Second stage evaporation-coefficient of cumulative second stage evaporation against the square root of time

+U

First stage evaporation-amount of cumulative evaporation before soil supply falls below atmospheric demand

In APSoil, values should be set to broadly reflect the most common cropping system for the Australian region and seasonal differences (Table 7).

Table 7: Cona and U values by region

Cropping area	U	Cona	U	Cona	Changeover S to W	Changeover W to S
	Summer	Summer	Winter	Winter	JDay	JDay
North	6	3.5	4	2.5	91	305
South/West	6	3.5	2	2	91	305

+Diff Const and Slope

For water contents below DUL, water movement depends upon the water content gradient between adjacent layers and the soil's diffusivity, which is a function of the average water content of the two layers

Table 8: Diffusivity constant and slope by texture class

Texture	Diff Const	Slope
Clay	40	16
Loam	88	35
Sand	250	22

One value represents the full profile. Values for Diff Const and Slope should be based on texture of layer 2 of the soil profile. In texture contrast soils use the clay values for the whole profile.

+Root CN

Carbon to Nitrogen ratio of root material

Set at 40 for all soils

+Root Wt

Initiated at 1000 for all soils. This sets the amount of Fresh Organic Matter at the start of the simulation.

+Soil CN

Carbon to Nitrogen ratio of soil organic matter

Refer to local experience or set to 12

+Salb

Bare soil albedo

Where possible the soil Munsell colour should be used to estimate soil colour during soil characterisation and included in the APSoil database for use by APSIM in the calculation of

albedo. Where soil colour is not available, albedo is estimated from soil texture using Tables 9 and 10. APSIM only uses the albedo value for the soil surface layer. Further information on albedo is available from Post *et al.* 2000.

Table 9: CERES Maize Model recommendations for the estimation of soil albedo

Texture	Salb (Albedo)
Sandy clay, clay, silty clay, silty clay loam	0.12
Sandy loam, loam, clay loam, sandy clay loam, sand	0.13
Silt, silty loam	0.14
Fine sandy loam	0.15
Loamy sand	0.16
Very fine sandy loam	0.17
Loamy very fine sand, loamy fine sand	0.18
Fine sand, very fine sand	0.19

Whilst the above table from Ceres Maize (Jones and Kiniry, 1986) lists all textural classes the reality is that the textural subtleties of particular soils may not be known. In this case the following simplified version may be used.

Table 10: Alternative albedo settings when information of soil texture is limited.

Texture	Salb (Albedo)
Dark clay soils	0.12
Lighter coloured clays, loams, dark coloured sands	0.13
Silt soils	0.14
Light coloured sands	0.15

+CN2-bare

Runoff curve number for BARE soil

Rainfall runoff is calculated using the USDA-Soil Conservation Service procedure known as the curve number technique (Williams *et al.* 2012). The procedure uses total precipitation from one or more storms occurring on a given day to estimate runoff. The relation excludes duration of rainfall as an explicit variable, and so rainfall intensity is ignored. When irrigation is applied it is assumed to be at low intensity and therefore no runoff is calculated.

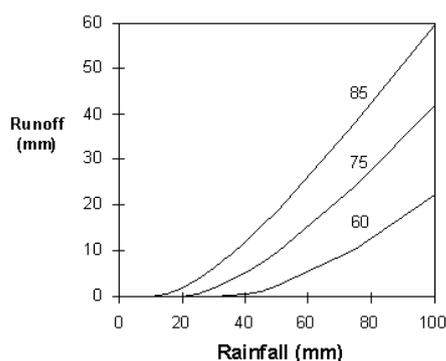


Figure 14: Runoff response curves specified by numbers from 0 (no runoff) to 100 (all runoff)

Runoff response curves i.e. runoff as a function of total daily rainfall, are specified by numbers from 0 (no runoff) to 100 (all runoff). An example of response curves for three runoff curve numbers for rainfall varying between 0 and 100 mm per day are shown in Figure 14. Table 11 provides a curve number for average antecedent rainfall conditions (CN2Bare) across a range of textural classes. Table 12 provides a curve number look-up for a range of soil types as described by the Great Soil Group (Stace *et al.* 1968) and Australian Soil Classifications (Isbell, 1996). This provides for a more nuanced determination of CN2b that takes into account the tendency of the surface soil layer to seal and of the degree of hard

setting in the tillage layer for various soil types (constructed by Zvi Hochman based on the expert knowledge of Mark Silburn).

Table 11: Suggested runoff response curve numbers for a range of soil textural classes.

Texture	CN2b
Sand	68
Heavy Clay	73
Loamy clay	84
Loam	73
Sandy loam	68
Loamy sand	73
Sandy clay	68
Clay loam	73
Sandy clay loam	73
Loamy sand	73

Table 12: Look Up chart for CN2b (Curve number for bare soil)

CN2b		68	68	68	68	73	73	73	73	73	73	73	73	84	84	84	84	84	84	84	84	84	84	94	94	94	94	96	96
Great Soil group (Aust Soil Classification Order*)	Factor																												
Krasnozem (Ferrosol)	SC*	Low		Medium		High		Very high																					
	HS#	Low		Medium		Low		Medium		Medium																			
Black Earth (Black Vertosol)	SC*	Low		Medium		High		V. High																					
	HS#	Low		Medium		Low		Medium		High		V. High																	
Red Podzolic (Chromosol, Dermosol)	SC*	Low		Medium		High		Very high		High				Very High															
	HS#	Low		Medium		Low		Medium		High				Very High															
Lateritic Podzolic (Kurosol, Dermosol and Chromosol)	SC*	Low		Medium		High		Very high		High				Very High															
	HS#	Low		Medium		Low		Medium		High				Very High															
Red Earth (Kandosol, Tenosol)	SC*	Low		Medium		High		Very high		High				Very High															
	HS#	Low		Medium		Low		Medium		High				Very High															
Grey Podzolic (Chromosol, Kurosol, Kurosol)	SC*	Low		Medium		High		Very high		High				Very High															
	HS#	Low		Medium		Low		Medium		High				Very High															
Grey Clay (Grey Vertosol)	SC*	Low		Medium		High		Very high		High				Very High															
	HS#	Low		Medium		Low		Medium		High				Very High															
Non-Calcic Brown Soil (Kurosol, Sodosol and Chromosol)	SC*	Low		Medium		High		Very high		High				Very High															
	HS#	Low		Medium		Low		Medium		High				Very High															
Gleyed Podzolic (Hydrosol)	SC*	Low		Medium		High		Very high		High				Very High															
	HS#	Low		Medium		Low		Medium		High				Very High															
Red Brown Earth (Calcarosol, Kandosol, Tenosol)	SC*	Low		Medium		High		Very high		Medium				High				V. High											
	HS#	Low		Medium		High		Very high		Low				Medium				High				V. High							
Red Clay (Vertosol)	SC*	Low		Medium		High		Very high		Medium				High				V. High											
	HS#	Low		Medium		High		Very high		Low				Medium				High				V. High							
Yellow Earth (Kandosol, Kurosol, Chromosol)	SC*	Low		Medium		High		Very high		Medium				High				V. High											
	HS#	Low		Medium		High		Very high		Low				Medium				High				V. High							
Brown Solodic (Sodosol)	SC*	Low		Medium		High		Very high		Medium				High				V. High											
	HS#	Low		Medium		High		Very high		Low				Medium				High				V. High							
Soloth (Sodosol)	SC*	Low		Medium		High		Very high		Low				Medium				High				V. High							
	HS#	Low		Medium		High		Very high		Low				Medium				High				V. High							
Yellow Podzolic (Dermosol)	SC*	Low		Medium		High		Very high		Low				Medium				High				Very High							
	HS#	Low		Medium		High		Very high		Low				Medium				High				Very High							
Solodic (Sodosol)	SC*	Low		Medium		High		Very high		Low				Medium				High				Very High							
	HS#	Low		Medium		High		Very high		Low				Medium				High				Very High							
CN2b		68	68	68	68	73	84	94	94	94	94	96	96																

SC* The soil's tendency to form a crust seal

HS# The till layer's tendency to hard set

*Note: Australian Soil Classifications are not directly comparable with Great Soil Group Classifications, consequently a range of possible ASC Orders has been provided for some GSG classifications

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