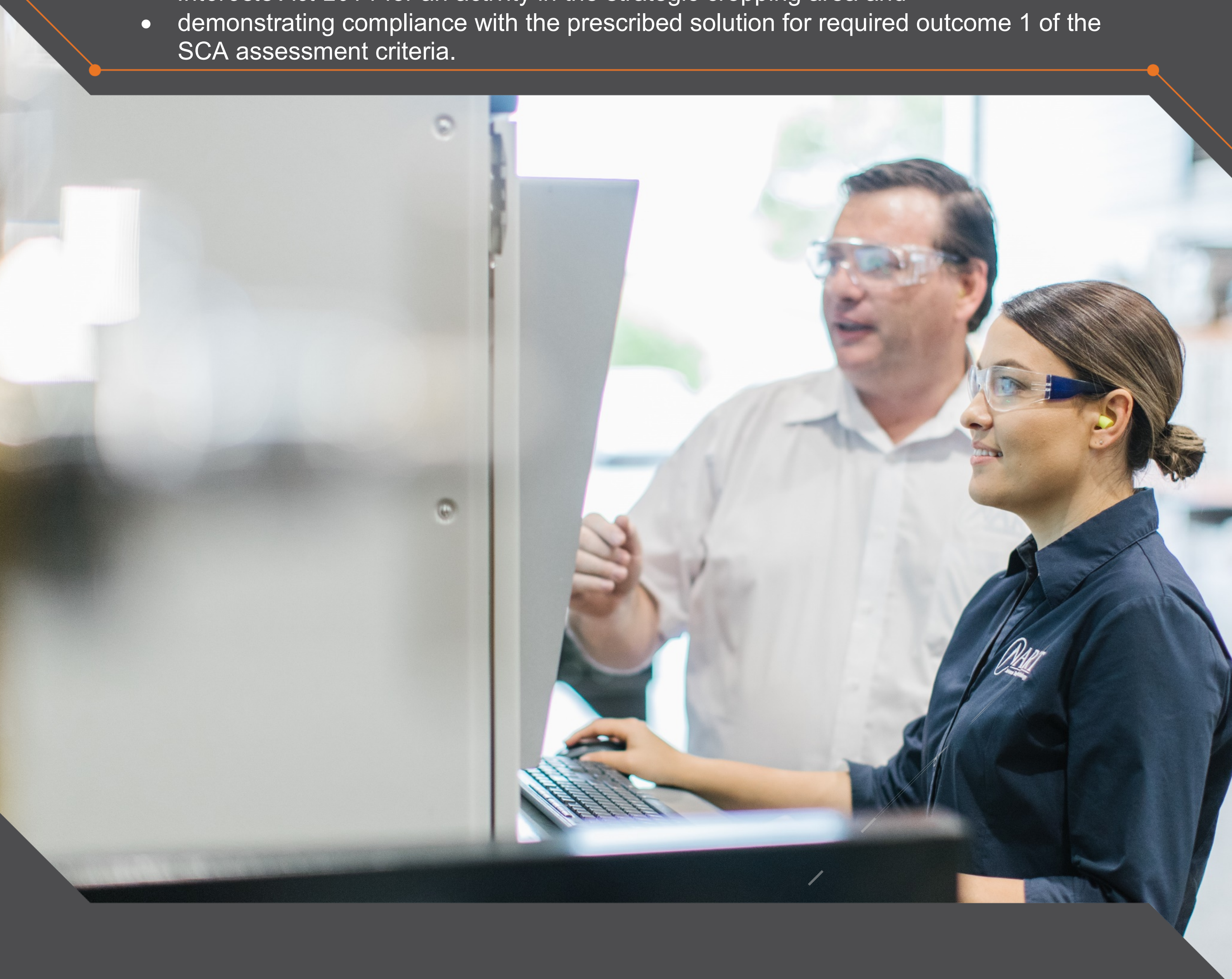
RPI Act

Statutory Guideline 08/14

How to demonstrate that land in the strategic cropping area does not meet the criteria for strategic cropping land

For use by applicants:

- seeking a Regional Interests Development Approval under the *Regional Planning Interests Act 2014* for an activity in the strategic cropping area and
- demonstrating compliance with the prescribed solution for required outcome 1 of the SCA assessment criteria.



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Introduction

The *Regional Planning Interests Act 2014* (RPI Act) identifies and protects areas of regional interest from inappropriate resource or regulated activities. The strategic cropping area (SCA) is an area of regional interest under the RPI Act and consists of the areas shown on the SCL Trigger Map as strategic cropping land (SCL). SCL is defined in the RPI Act as:

“land that is highly suitable for cropping, or likely to be highly suitable for cropping, based on a particular combination of soil, climate and landscape features”

Through the RPI Act, the government is seeking to:

- manage the impact of resource activities and regulated activities on SCL in the SCA and
- manage the coexistence of competing activities in the SCA.

A resource activity or regulated activity located within the SCA will be required to obtain a regional interests development approval (RIDA) under the RPI Act, unless exempt under section 22, 23, 24 or 25. The Regional Planning Interests Regulation 2014 (RPI Regulation) provides criteria for assessment or decision to be addressed by applicants in their application for a RIDA for an activity on land in the SCA (the ‘SCA assessment criteria’). This guideline relates to the prescribed solution for required outcome 1 included in the SCA assessment criteria which states:

“The application demonstrates the activity will not be carried out on SCL that meets the criteria stated in schedule 3, part 2.”

The criteria listed in Schedule 3, Part 2 of the RPI Regulation (the ‘SCL criteria’) relate to the following matters:

(i) slope
(ii) rockiness
(iii) gilgai
(iv) soil depth
(v) soil wetness
(vi) soil pH
(vii) salinity
(viii) soil water storage.

The criteria have a hierarchical structure which is designed to simplify the requirements of determining whether land is SCL for the purposes of meeting prescribed solution 1 of the SCA assessment criteria. They start with three relatively simple ‘above ground’ measures that allow plainly non-compliant land to be readily identified. The next four criteria (4 – 7) consider attributes that pose very serious limitations on the capacity of soil to store water. The limitations include very shallow or waterlog-prone soils and extremes of soil pH and salinity. Soils not complying with these intermediate criteria can therefore be eliminated in advance of the more comprehensive determination of soil water storage. As a result, the hierarchical structure not only maintains the technical integrity of the system but ensures it can be applied as easily and efficiently as possible.

Criteria for determining strategic cropping land

Zones

For the purposes of determining whether land mapped as SCL on the SCL Trigger Map meets the SCL criteria in Schedule 3 of the RPI Regulation, land in the SCA has been divided into five zones including:

- Western Cropping
- Eastern Darling Downs
- Coastal Queensland
- Wet Tropics
- Granite Belt.

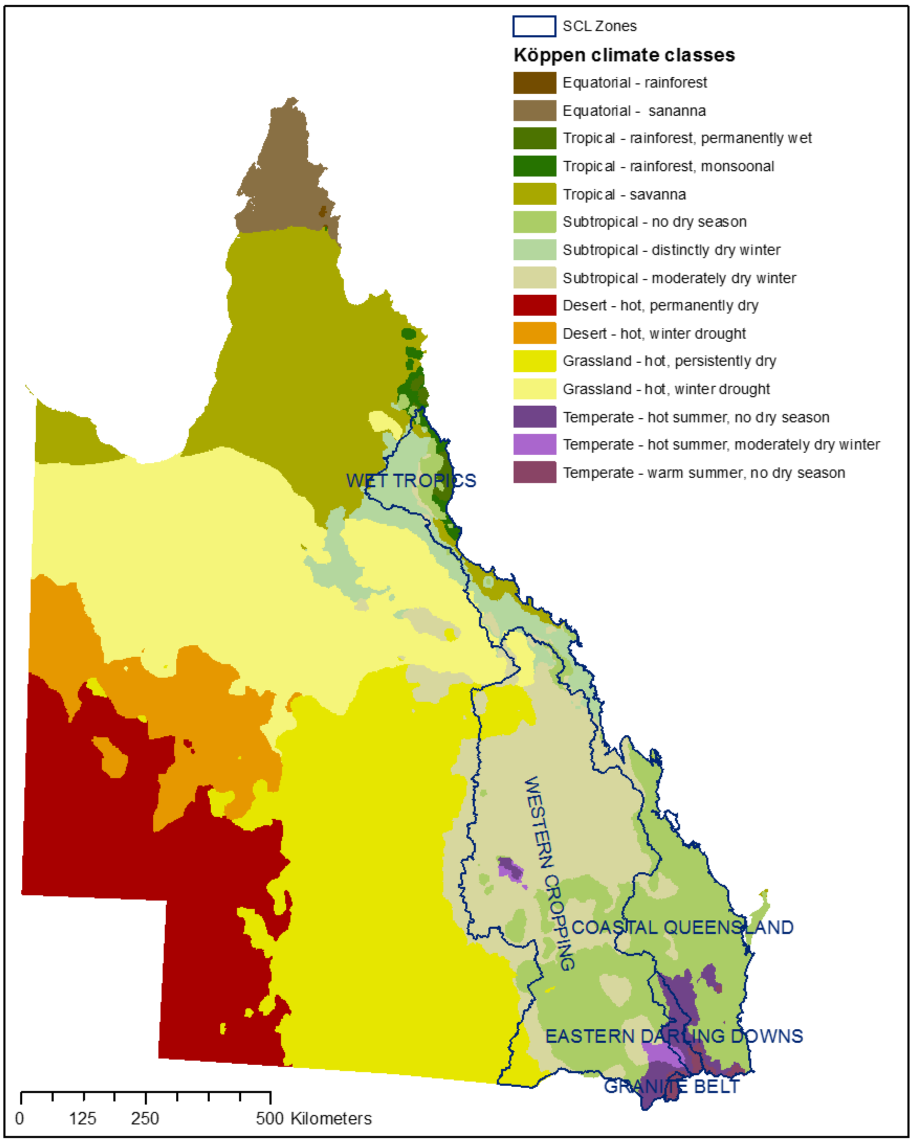
The five zones are depicted on **Figure 1** and encompass the wide range of climatic regimes capable of supporting dryland or raingrown crop production[1] in Queensland.

The five zones lie within a broad band that adjoins the eastern coastline of Queensland, running from the New South Wales border in the south, to near Mossman in the north. This band varies in width, being around 500 kilometres (km) wide in southern Queensland, where rainfall seasonality is less pronounced, to less than 50 km wide in some parts of the dry tropics, where a distinct dry season is experienced during winter.

A very diverse range of agricultural and horticultural crops is capable of being grown in Queensland. This diversity is evident in that in some areas it is possible to cultivate both summer and winter-growing species of grain, legume, oilseed and fodder crops, as well as a distinctly subtropical crop like cotton. Likewise, other areas support crops like sugarcane and tropical fruit and vegetable crops, while elsewhere it is possible to grow temperate pome, stone, vine, berry and vegetable crops, some of which have a very significant winter-chilling requirement.

Collectively the five zones accommodate this diversity of crops. Individually the zones reflect the combination of climatic and soil conditions required to produce certain types of these crops.

Figure 1: Zone boundaries overlaid on Koppen climate classification of Queensland



1 While most irrigable land has the attributes that allow it to be mapped as SCL, a small proportion of the irrigable land does not and it would be unlikely this land could be reliably cropped if it did not have access to irrigation. As such, it has not been identified on the SCL Trigger Map

Thresholds for SCL criteria

While the same SCL criteria are used in all five zones, different threshold values apply as shown in **Table 1**. This allows each zone to accommodate important regional differences in climate, land forms and cropping systems.

The SCL criteria use definitive threshold levels to determine compliance, which limits the scope for subjectivity or opinion in evaluating land and demonstrating whether land meets the SCL criteria.

Table 1: Thresholds for SCL criteria

Criteria	Thresholds for each zone				
	Western Cropping	Eastern Darling Downs	Coastal Queensland	Wet Tropics	Granite Belt
Slope	Equal to or less than 3%	Equal to or less than 5%			
Rockiness	Equal to or less than 20% for rocks greater than 60mm in diameter				
Gilgai	Less than 50% of land surface being gilgai of greater than 500mm in depth				
Soil depth	Equal to or greater than 600mm				
Soil wetness	Has favourable drainage				Has satisfactory drainage
Soil pH	For rigid soils, the soil at 300mm and 600mm soil depth must be within the range of $pH_{1:5}$ 5.1 to $pH_{1:5}$ 8.9 inclusive For non-rigid soils, the soil at 300mm and 600mm soil depth must be greater than $pH_{1:5}$ 5.0.				
Salinity	Chloride content is less than 800mg/kg at 600mm soil depth		$EC_{1:5}$ is less than 0.56dS/m at 600mm soil depth		
Soil water storage	Equal to or greater than 100mm to a soil depth or soil physico-chemical limitation of equal to or less than 1000mm		Equal to or greater than 75mm to a soil depth or soil physico-chemical limitation of equal to or less than 1000mm	Equal to or greater than 50mm to a soil depth or soil physico-chemical limitation of equal to or less than 1000mm	Equal to or greater than 25mm to a soil depth or soil physico-chemical limitation of equal to or less than 1000mm

Breakdown of SCL criteria

Slope

Slope is the upward or downward incline of the land surface, measured in per cent.

In Queensland it is not uncommon to find slopes with gradients of up to 15 per cent being cropped. However, as the SCL concept entails the enduring capacity of land to be used for cropping, the threshold gradients applicable to the slope criterion - 3 per cent in the Western Cropping zone and 5 per cent elsewhere - have been selected so that the long-term rate of erosive soil loss is of a similar magnitude to the rate of soil formation.

The selection of these slope thresholds is not to say that steeper land cannot or should not be cropped. Rather, they merely reflect that land with gradients less than the threshold values will not require the same quality and intensity of management or level of expenditure on soil conservation measures, and in some cases suffer the constraints on cropping versatility, that can be associated with more steeply sloping land in a particular zone.

Details of the acceptable measurement methods and the reporting requirements for this criterion are provided in **Appendix 1**.

Rockiness

Rockiness refers to the presence of unattached coarse rock fragments and rock outcrops at the soil surface.

Severe levels of rockiness represent a significant impediment to tillage, as well as more general farming operations.

While it might be possible in some instances to successfully grow particular crops, such as perennial horticultural tree and vine crops, in extremely rocky soils, the restricted range of suitable crops means that affected soils lack the cropping versatility necessary to be considered SCL.

Although rockiness can be associated with shallow soils or soils in steeper terrain, this is not always the case and therefore rockiness needs to be assessed in its own right.

Importantly, the rockiness criterion does not apply to coarse fragments found within the soil profile (i.e. under the soil surface), although the presence of coarse fragments in the soil profile needs to be considered in assessing compliance with the soil depth and soil water storage criteria.

Details of the acceptable measurement methods and the reporting requirements for this criterion are provided in **Appendix 1**.

Gilgai

Gilgai are a form of microrelief that is a natural feature in certain non-rigid soils in Queensland. These non-rigid soils are commonly called cracking clays, and under the Australian Soil Classification (Isbell, 2002), are classified as Vertosols. Importantly though, not all Vertosol soils will have gilgai present.

Gilgai consist of mounds and depressions, sometimes separated by an almost planar ground surface (NCST 2009). There is often significant variation in soil properties between the mound and depression.

Gilgai can take various forms, with melon-hole, linear and 'normal' forms being the more common types found in Queensland. While the precise mechanism by which gilgai form is still debatable, it almost certainly involves some form of moisture-induced soil heaving.

Gilgai depressions capture and retain surface runoff. In the more severe forms of gilgai the resultant ponding and soil wetness in these depressions frequently impede cultivation, crop growth and harvesting operations, and so reduce the productivity of the affected cropland. The overall effect on productivity is generally in direct proportional to the areal extent and depth of the gilgai depressions. Consequently, these are the two factors used as the basis for the criteria thresholds.

Aside from the wetness and physical impediments, since the soil in gilgai mounds tends to have attributes similar to the subsoil, the salinity and sodicity levels are often elevated in mounds. This can further affect crop yields. Attempts to land-plane areas having very severe gilgai can exacerbate these undesirable soil characteristics and further compromise crop yields, rather than increase them. Consequently, the effects of gilgai that are more severe than the threshold levels normally represent a major limitation on successful cropping, and one which is not readily ameliorated.

With cultivation and the resultant steady movement of soil, the milder forms of gilgai generally become less pronounced, and typically represent a minor problem in most seasons. Nonetheless, the underlying soil characteristics that cause gilgai may still remain and they can reform if regular cultivation ceases.

The non-rigid soils associated with gilgai represent a significant proportion of the better quality cropping lands in the Western Cropping zone, and a smaller, but still sizeable proportion in the Eastern Darling Downs zone. Gilgai can be found in certain locations in Coastal Queensland zone, but are far less common in the Wet Tropics zone. Owing to a near complete absence of non-rigid soils, gilgai are extremely rare in the Granite Belt zone.

Details of the acceptable measurement methods and the reporting requirements for this criterion are provided in **Appendix 1**.

Soil depth

In the context of the SCL criteria, soil depth is the depth of soil material from the surface of the soil to an underlying physical barrier. That barrier can include bedrock, weathered rock, hard pans and continuous gravel layers. These physical barriers will restrict the penetration of plant roots and so effectively limit the amount of soil water able to be exploited by most crop species. This places a critical limitation on the yield potential of the crops growing in shallow soils. In addition, since there is less soil to lose, shallower soils are inherently more susceptible to degradation through soil erosion. For that reason alone, very shallow soils tend not to be well suited to permanent cultivation.

Due to the hierarchical structure of the criteria, soil depth is effectively a preliminary evaluation of effective rooting depth in the soil water storage criterion. An evaluation of soil depth therefore allows the early elimination of non-compliant soils, without undertaking a more complex and costly evaluation of soil water storage. On the other hand, shallow soils tend to be more common in steeper terrain, and again owing to the hierarchical structure of the SCL criteria, the slope criterion will eliminate many shallow soils without having to physically determine soil depth.

Details of the acceptable measurement methods and the reporting requirements for this criterion are provided in **Appendix 1**.

Soil wetness

Soil wetness caused by poor internal drainage can severely affect crop productivity.

Waterlogged conditions will occur from time to time in most agricultural soils. However if waterlogged conditions occur either frequently or for lengthy periods, the persistently anoxic soil conditions result in reduced forms of elements such as iron and manganese predominating, and soil matrix colours being characteristically dull, pale greys (i.e. soil colour value equal to or greater than 4, chroma equal to or less than 2), or dull blue-greys and green-greys (i.e. gley colours). Where these particular colours are observed in a soil, the soil conditions are sufficiently hostile to inhibit root development and pose a serious limitation to productivity in most crops.

In Queensland the seasonal waterlogging of soils over summer is not uncommon. These seasonally waterlogged soils are generally subject to some drying and aeration during periods of drier weather, over winter. When oxygen re-enters a drying, seasonally waterlogged soil, the resultant oxidisation of the reduced forms of iron present in that soil cause lepidocrocite and/or ferrihydrite crystals to form.

Lepidocrocite and ferrihydrite are characteristically orangey and rusty-red in colour (i.e. their typical colours being 5YR 6/8 and 2.5YR 3/6 respectively). They are responsible for the orange or the rusty mottles that form within a dull grey coloured soil matrix in seasonally waterlogged soils or, less frequently, the converse with an orangey or rusty coloured soil matrix that contains gley coloured mottles.

Importantly, mottling simply indicates that a soil is subject to significant wetting and drying cycles. Mottling by itself does not necessarily show that the soil is saturated frequently or for a period of time sufficient to automatically disqualify that soil from being SCL on the basis of soil wetness. It is the characteristic orange, rusty, dull, pale grey and gley soil matrix or mottle colours that indicate the frequency and duration of saturated conditions are sufficient for soil wetness to be considered a significant constraint on crop growth, and that the affected soil is unlikely to qualify as SCL.

Figure 2 provides an example of a soil where the soil matrix and mottle colours would disqualify a soil from being meeting the soil wetness criterion.

Figure 2: Example of soil showing the combination of soil matrix and mottle colours that are indicative of poor drainage

In texture contrast or duplex soils, water can pond seasonally in the coarser-textured A horizon above a less-permeable, clayey, B horizon. This ponding can result in anaerobic conditions immediately above the interface between the two soil horizons. Under these conditions the more soluble, reduced forms of iron and manganese can be leached from the saturated layer, and so leave behind a light coloured or 'bleached' soil matrix. A bleached A2e soil horizon is a common result of this leaching process. In some cases these bleached horizons overlie a contrastingly darker horizon, where the leached iron and manganese have subsequently re-oxidised, and formed less soluble compounds that have precipitated from the soil solution.

A relatively thick (greater than 100mm), conspicuously bleached layer in texture contrast soils is therefore indicative of the associated ponding being a significant and either a frequent or a lengthy occurrence. In such circumstances, soil wetness would again be a serious constraint on crop production.

Landscape and vegetation indicators of waterlogged soils, such as sedges and rushes in low-lying landscape positions or at breaks of slope, can be useful indicators of areas where land might fail the soil wetness criterion. However, by themselves these particular indicators do not disqualify land from meeting this criterion of the SCL criteria.

Likewise, while waterlogged soils are often associated with some limitation on the hydraulic conductivity of an underlying stratum, the converse is not necessarily true. Under the climatic conditions in Queensland, soils with low hydraulic conductivities may not necessarily be waterlogged often or for long enough to fail the soil wetness criterion – in fact slow internal drainage in a soil may provide some advantages in the drier Western Cropping zone.

Normally in Queensland the combinations of soil and climatic conditions likely to result in soils being non-compliant with the soil wetness criterion will generally only occur in areas relatively close to the coast.

Details of the acceptable measurement methods and the reporting requirements for this criterion are provided in **Appendix 1**.

Soil pH

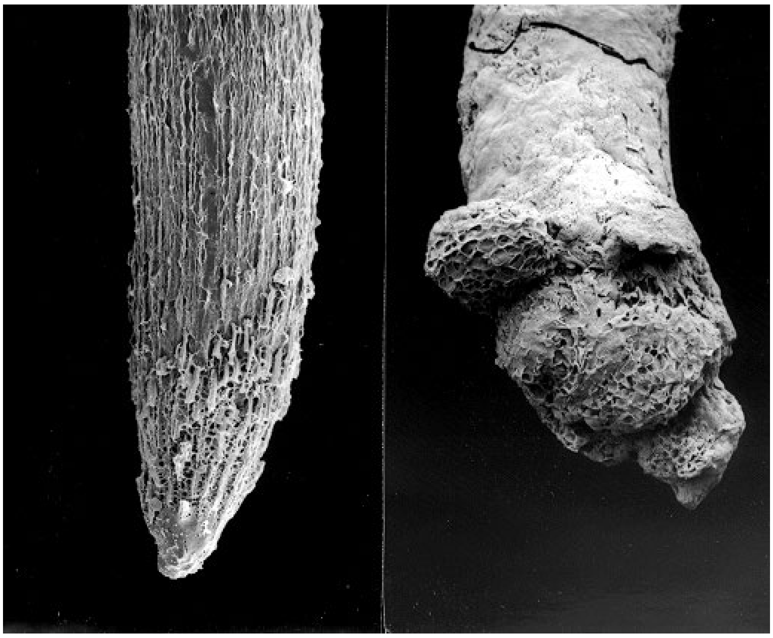
Soil pH refers to the alkalinity or acidity of a soil.

Extremes in soil pH (i.e. less than 5 and greater than 9) have a major effect on the availability of nutrient and other elements for plant uptake. While in surface and near-surface soils the resultant deficiencies and toxicities are usually readily ameliorated, extremes in pH deeper in the soil profile (e.g. equal to or greater than 300mm) are symptomatic of more serious problems, which are not readily ameliorated.

A very low soil pH favours the soluble forms of aluminium. While aluminium is a significant component of all soils, it occurs in forms that have only very low solubilities in the pH range of 5 to 9. Plant roots are extremely sensitive to even mildly elevated concentrations of aluminium ions in the soil solution. As such, strongly acidic soil conditions at depth (i.e. $pH_{1:5}$ equal to or less than 5 at equal to or greater than 300mm depth), which favour the soluble forms of aluminium, represent a serious constraint on root development, and therefore crop yields, in most major crop species in most soils.

Figure 3 illustrates the effect of a modest concentration of aluminium ions[2] on the root tips of a tolerant and an ordinary (i.e. sensitive) wheat cultivar. The root tips of the tolerant and the sensitive cultivars are shown in the left-hand and right-hand electron microscope images, respectively.

Figure 2: Effect of aluminium toxicity on root apices – healthy root apex on left



Very low soil pH in the subsoil can similarly increase the availability of manganese to phytotoxic levels.

Strongly alkaline soil conditions at depth (i.e. $pH_{1:5}$ equal to or greater than 9 at equal to or greater than 300mm depth) are also indicative of soil conditions that are very hostile to root growth. This is primarily due the elevated concentrations of sodium carbonate (Na_2CO_3) present when $pH_{1:5}$ values exceed 9. Sodium carbonate is phytotoxic at concentrations as low as 0.05 per cent (Scholz & Moore, 2001). These strongly alkaline soils are almost invariably extremely sodic (for example, ESP greater than 30 per cent), and suffer the structural problems associated with soil sodicity.

Certain soluble forms of aluminium, such as sodium aluminate ($Na_2O.Al_2O_3$), will also occur in some soils at pH values above 9 (Brautigan, 2010), and have the same effect on root development as those forms of aluminium found in strongly acidic soils.

A consequence of the phytotoxic effects of sodium carbonate and aluminium ions, and the effects of soil sodicity on soil structure, is that strongly alkaline subsoils also represent a serious constraint on effective rooting depth and crop yields.

In the generally calcareous, smectite-dominated Vertosol or non-rigid soils common in the Western cropping zone, calcium carbonate (rather than sodium carbonate) is the dominant carbonate salt present[3]. Calcium carbonate is not particularly phytotoxic. Consequently, when trying to determine whether land meets the SCL criteria, the upper (alkaline) soil pH threshold applies only to rigid soils and not non-rigid soils.

Soils with strongly acid subsoils tend to be more common in the zones closer to the coast, where the climate is wetter. In the Western Cropping zone, strongly acid conditions are sometimes observed towards the base of the soil profile in the otherwise alkaline, and frequently gilgai-affected, Vertosol soils that originally carried brigalow/belah vegetation communities. However, this ‘pH inversion’ effect usually occurs at depths below the 600mm sampling depth specified for this criterion[4].

[2] A solution of 5 μM Al^{3+} at a pH of 4.3

[3] Theoretically the pH in these soils should be a maximum of around 8.3, and thus not exceed 9.0

[4] This does not stop these ‘pH inversions’ being a limitation on effective rooting depth when assessing criterion 8 of the SCL criteria.

Since the non-rigid Vertosol soils common in the Western Cropping zone are not disqualified as SCL on the basis of strongly alkaline subsoils, agricultural soils with pH values exceeding the upper soil pH threshold tend not to be particularly common in any of the zones.

As with other lower order criteria, disqualifying a soil on the basis of soil pH at depth can avoid the need for a more complex and costly determination of soil water storage.

Details of the acceptable measurement methods and the reporting requirements for this criterion are provided in **Appendix 1**.

Soil water storage

Soil water storage refers to the amount of water able to be stored in a soil that is potentially available for plant use i.e. plants being unable to extract all of the water present in any soil, no matter how dry the conditions are.

If a plant is unable to extract sufficient water from a soil to support essential physiological process, crop death and a total loss of yield is inevitable. Since the amount of water a crop transpires during its growing period and the yield of that crop are inextricably linked, even moderate degrees of water stress will affect crop yield. More severe forms of water stress, even for short periods, can have very serious effects on crop yield – particularly if those events coincide with critical developmental stages in the crop, such as flowering or anthesis. Hence the capacity of a soil to satisfy a crop's water needs is a fundamental factor in assessing the value of a soil for cropping.

The threshold soil water storage values of 100mm in the Western Cropping and Eastern Darling Downs zones, 75mm in the Coastal Queensland zone, 50mm in the West tropics zone and 25mm in the Granite Belt zone, are based on a combination of practical experience, empirical evidence and crop water use modelling. These variations in the threshold values reflect considerations like the nature of the crops grown and the characteristics of dominant soils, as well as climatic factors such as the amount, variability and reliability of the rainfall received in the different zones.

Soil water storage is expressed as millimetres of water over a specified depth of soil. For the purposes of determining whether mapped SCL meets this criterion, soil water storage is calculated for whichever is the lesser of the following soil depths:

- the upper 1000mm of the soil profile
- the actual or physical soil depth if it is less than 1000mm
- a depth less than 1000mm at which a soil physico-chemical limitation is encountered.

The recognised physico-chemical limitations on the effective rooting depths in crops are:

- elevated soil salinity levels (as with criterion 7, the applicable analytical tests being for $EC_{1:5}$ and chloride in the respective zone)
- extremes of soil pH (i.e. $pH_{1:5}$ equal to or less than 5 and, except in non-rigid soils, $pH_{1:5}$ equal to or greater than 9)
- strongly sodic conditions (i.e. ESP[5] greater than 15 per cent) and gross imbalances between exchangeable calcium and magnesium (i.e. Ca:Mg equal to or less than 0.1) in rigid soils other than those having:
    a) Sandy loam or lighter textures or
    b) Caution exchange capacities less than 3 $cmol_+$/kg.

While soil depth, salinity and soil pH at depths equal to or less than 600mm have been considered in the preceding criteria, consideration here extends to soil depths up to 1000mm, as well as extending to imbalances between the dominant soil cautions; calcium, magnesium and sodium.

Prior to undertaking any assessment of the soil water storage criterion, non-compliance all other criteria should have at least been considered, if not evaluated. It should be only necessary then for soil water storage to be assessed if that soil has not failed any of other, less complex, criteria.

Details of the acceptable measurement methods and the reporting requirements for this criterion are provided in **Appendix 1**.

[5] Exchangeable sodium percentage – see definition in Section 15(2), Schedule 3 of the Regional Planning Interests Regulation 2014.

Meeting the criteria

To demonstrate that the land does not meet the SCL criteria an applicant must demonstrate that it fails at least one of the eight criteria. The following steps (and **Figure 4**) provide guidance on how an applicant may achieve this:

(1) check the land the subject of the application for the regional interests development approval is identified as SCL on the SCL Trigger Map

(2) identify in which zone the land that is the subject of the application is located in

(3) ascertain the likelihood of land not meeting all the SCL criteria

(4) undertake a desktop assessment

(5) undertake a reconnaissance survey (if necessary)

(6) prepare for and undertake field survey(s) (if necessary)

(7) send field data to laboratory for analysis

(8) collate all required data and information and prepare report and maps and / or necessary documentation for submission.

The steps required to be undertaken may vary depending on the size and the nature of the activity and / or the area of land which the applicant is seeking to demonstrate does not meet the criteria.

It is recommended the applicant engages technical expertise where required. Technical expertise will usually be required to undertake evaluations where:

(1) determining whether land meets the SCL criteria relating to soil depth, soil wetness, soil pH and soil water storage

(2) the results for slope, rockiness and gilgai are close to SCL criteria threshold values

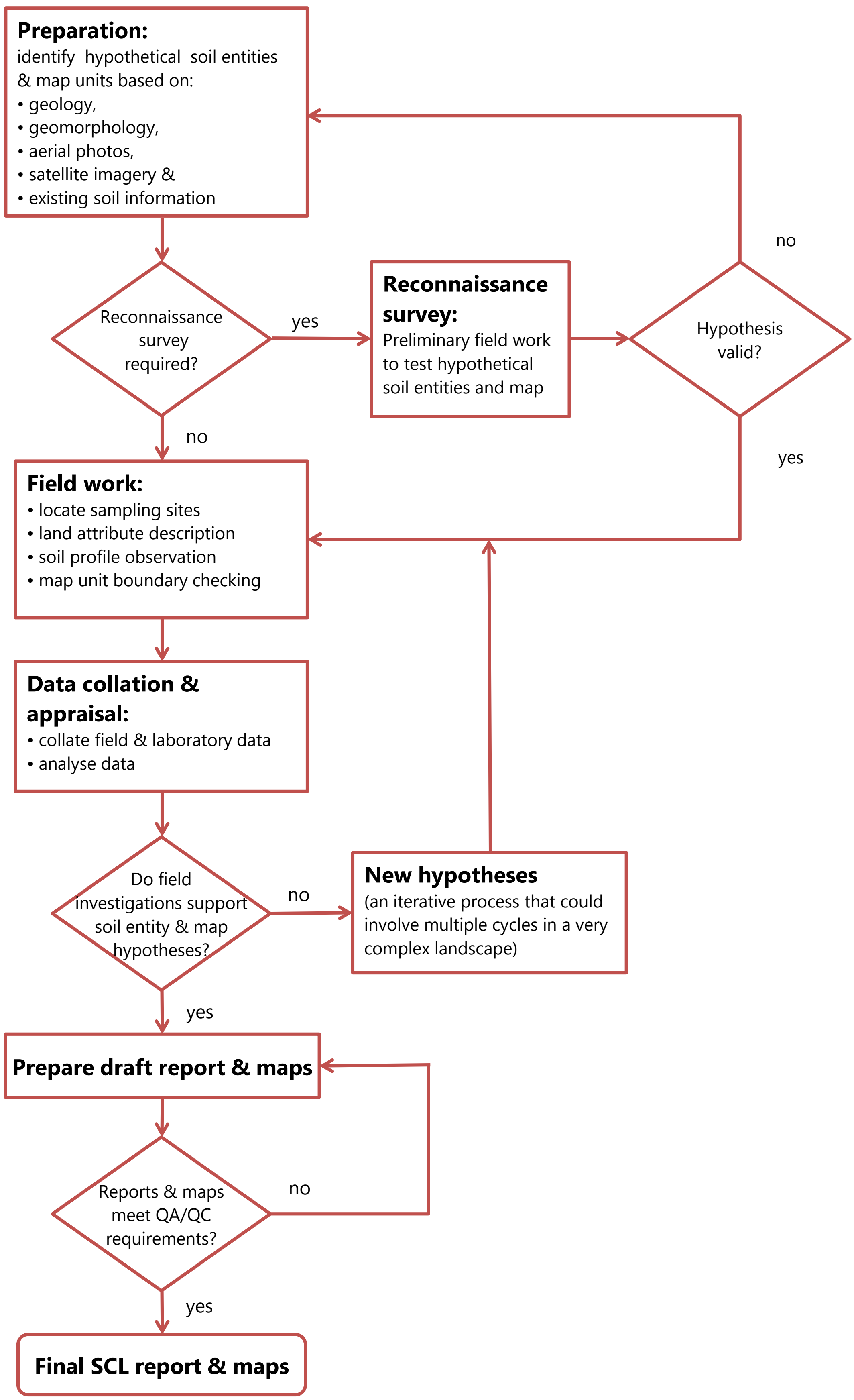
(3) detailed topographic surveys, such as total station or real time kinematic (RTK) survey or remote sensing methods (e.g. LiDAR and SRTM) are being used to evaluate compliance with slope.

Engaging persons with proven competencies specifically in land and soil resource studies will help to ensure that the mapping and reporting required for the assessment against the SCL criteria provide the necessary information to allow the application to be assessed in a timely and cost-effective manner.

A pre-application meeting is strongly recommended to discuss a proposed activity that is located in an area of regional interest.

Please email **RPIAct@dsdmip.qld.gov.au** or visit **www.dsdmip.qld.gov.au**/RPI Act for further information and to arrange a pre-application meeting with the Department of State Development, Manufacturing, Infrastructure and Planning.

Figure 3: Suggested process for confirming whether mapped SCL meets the SCL criteria



Desktop assessment

In most instances a desktop assessment of all available sources of relevant information should be undertaken prior to undertaking further work such as a reconnaissance survey or an intensive field survey. The aims of the desktop assessment should be to:

- identify map units and provide an indication on the soil type/s present in the area where each activity is proposed to be located
- identify land that is a likely candidate for not meeting the more simple ‘above ground’ criterion (i.e. soil, rockiness, gilgai)
- identify the survey area and the number and location of observation sites for further field investigation based on the likely number of soil types represented, the nature of those soils and their likely distribution across the area of interest. This may be larger than the land the subject of the application and the immediate activity footprint
- pinpoint any obvious or critical data gaps.

Suitable sources of information for the desktop assessment might include:

- geology mapping and reports
- topographic mapping
- remote sensing data (e.g. land use mapping, digital elevation models, etc.)
- aerial photographs and satellite imagery
- existing soils and land resource reports, maps and associated information.

There is a substantial body of published soil and land resource reports and mapping that have been produced by various federal and state government agencies that are likely to be relevant to RIDA assessment applications relating to the SCL criteria. This material comes in a range of scales and is generally freely available or available at minimal cost.

In many coastal areas, as well as some inland areas of Queensland, detailed mapping at a scale of 1:25 000 to 1:100 000 is available and may include soil attribute data. In the majority of inland areas only broadscale ‘land system’ or ‘land resource area’ mapping is available at scales of 1:250 000 or 1:500 000. Soil, land system and land resource mapping at all the above scales are often complemented by detailed reports.

The scales applicable to published maps are generally similar to those applied in preparing the SCL Trigger Map, and like the trigger map, will normally need to be refined by a field survey covering the area of interest to an applicant. However, there are certain areas which have been subject to very intensive soil surveys by government agencies and those surveys could potentially yield information and data suitable for forming the sole or principal basis of an application

Existing soils data, whether taken from the SALI database, directly from government agency publications, or other privately collected data may not fully satisfy the requirements for demonstrating that land does not meet the SCL criteria. This is frequently due to the data being originally collected for a purpose other than for assessing outcome 1 of the SCA assessment criteria.

Some common examples of where existing data would not be suitable to use in assessing outcome 1 of the SCA assessment include:

- mottle colours not being reported using the required colour chip notation
- $EC_{1:5}$ values, but not chloride values being provided for sites in the Western Cropping and Eastern Darling Downs zones
- gilgai presence or the gilgai element sampled my not be reported
- analytical methods applied in older studies being the currently preferred or acceptable method, or the specific method required for assessing SCL criteria.

Electronic copies of existing government soil reports and maps, and GIS spatial data for the associated mapping, can be accessed through the following websites:

- the Department of Environment and Science library (PDF versions of reports and maps) **https://qldgov.softlinkhosting.com.au/liberty/libraryHome.do?SAMLResponse=&clientAlias=&time=&digest=&corporationAlias=DERM**
- the Queensland Government (GIS spatial data) – **https://data.qld.gov.au/dataset/land-resource-areas-series**

Reconnaissance survey

In some cases a desktop assessment of available soil mapping and data might be sufficient to demonstrate compliance with the prescribed solution for required outcome 1 of the SCA assessment criteria. Where more detail is required, a pilot or reconnaissance survey, while not obligatory, can be a very cost-effective step that complements the desktop assessment—more so where the only available land resource mapping is at scales of 1:100 000 or a broader scale.

A competent soil scientist, armed with some basic equipment (e.g. a hand auger, corer or similar, GPS), and the knowledge gained from the desktop assessment, should be able to quickly survey a parcel of mapped SCL and, if necessary, review or refine the survey area for a subsequent, more detailed field survey.

Information gained in the reconnaissance survey can provide significant benefits in planning any subsequent, detailed field survey, including:

- providing guidance on the validity of the concepts developed (in the desktop assessment) on the likely distribution and nature of the in the survey area
- focussing resources to be used in the field survey on areas that are most likely not to meet the SCL criteria, and avoiding areas that are almost certainly mapped correctly
- limiting the data collection and soil analyses to just the prospective disqualifying criteria
- allowing more accurate costing and budgeting for the field survey.

If done correctly, the information and data gained in the reconnaissance survey should be suitable to demonstrate what land does or doesn't meet the SCL criteria and potentially reduce the amount of information and data that needs to be collected in the subsequent, more detailed field survey.

Detailed field survey

Preparation

The critical aspect of a field survey is the identification and characterisation of sufficient 'observation sites' to be examined, documented and evaluated.

There are four types of observation sites that can be used to determine whether land meets the SCL criteria, including:

(4) exclusion sites

(5) detailed sites

(6) analysed sites

(7) check sites.

A brief overview of the four types of observation sites is provided in **Table 2**. More specific details and the reporting requirements for each type of observation site are provided in **Appendix 2**.

Table 2: Summary information on the types of observation sites used in a detailed field survey

Site	What is it?	When is it required?
Exclusion site	An observation site from which land can quickly and easily be determined as meeting or not meeting criteria relating to slope, rockiness or gilgai	Used to evaluate SCL criteria 1, 2 and 3 (slope, rockiness or gilgai)
Detailed site	An observation site that allows for: • Identification of any physiographic factors or vegetation associations that characterise the site and associated map unit • The pedological characterisation of the soil • Identification of soil features of relevance to the SCL criteria	Used to identify the different soil types, characterise the dominant soil in a map unit, and evaluate SCL criteria 4 and 5 (soil depth and soil wetness)
Analysed site	A detailed site from which soil samples are collected and subsequently analysed in a laboratory.	Used to evaluate observation sites within a map unit against SCL criteria 6, 7 and 8 (soil pH, salinity and soil water storage)
Check site	An observation site that is examined in sufficient detail to allocate the site to a specific soil type and map unit.	Used to accurately delineate the location of the boundaries of map units or to ascertain the degree of variability within a map unit

Identifying suitable observation sites and deciding on an appropriate number of each of the various type of observation sites used in a detailed field survey will be dependent upon information and data from the desktop assessment and:

- the complexity of the landscape
- the dominant morphological processes at the site
- the associated geology
- prior land use and disturbance
- existing levels of land degradation (e.g. soil erosion)
- the specific criteria under consideration
- the specific data required to evaluate compliance with the candidate criteria
- the particular criterion or criteria being considered (i.e. 1, 2 or 3 versus 4, 5, 6, 7 or 8)
- the size of the associated map unit
- the degree of detail required in the evidence being used to support the application.

The following factors should also be considered in selecting observation sites:

- ordinarily sites should be located in cleared areas and preferably within active cropping or pasture land
- sites should not be selected in areas disturbed by physical infrastructure (contour and diversion banks, road verges, table/spoon drains, grassed waterways, terraces, fences, stockyards, gateways, pipelines, etc.)
- sites must not be selected in small atypical areas, such as those affected by seepages, salt scalds, erosion gullies, stock camps and pads, or post-clearing fire heaps
- in any areas having gilgai or other microrelief, including areas where the depth of the gilgai is less than the zonal criteria threshold of 500mm, site and soil descriptions and soil sampling should be undertaken on both the mounds and the depressions, so providing a complementary pair of datasets for each detailed or analysed site
- in areas cropped using permanent mounds, permanent or semi-permanent beds or other seasonally enduring mounding methods, samples should be taken, wherever possible, from the bed or mound where the crop is planted.

Undertake field survey

The location coordinates for each observation site should be logged using a GPS, with the coordinate units specified in either Map Grid of Australia 1994 (MGA94) units (Easting, Northing and Zone) or geographic coordinates (Latitude and Longitude), both using the Geocentric Datum of Australia 1994 (GDA 94) datum.

At the scale applicable to mapping SCL, MGA94 coordinates using the GDA94 datum, are effectively equivalent to the UTM coordinates based on the WGS 84 datum, which is the default system used in most handheld GPS.

The reported accuracy, or if that is not available the manufacturer’s specified precision of the GPS equipment, should be quoted in the verification application.

Description of an observation site, particularly a detailed site, can include any information that might relate that site to any existing soil information in the area, but the basis for that relationship needs to be stated. It is certainly not necessary, and in many cases not useful, to align soils found at survey sites with ‘named’ concept or archetypal soils described in published land resource publications.

Suitable soil profile and landscape descriptions need to be provided for observation sites in all the mappable units identified in the field survey. **Appendix 2** provides further information on the level of detail required to be provided on the site and soil profile descriptions for each observation site. Full details about soil profile and landscape description are available in the Australian soil and land survey field handbook (NCST 2009), commonly referred to as the ‘yellow book’.

Laboratories for soil analysis

Under normal circumstances the laboratories performing the analysis of soil samples required to determine whether land meets the SCL criteria will need to:

1. comply with the Australian Standard (AS) *AS ISO/IEC 17025-2005: General requirements for the competence of testing and calibration laboratories*
2. have the technical expertise for the specific analytical methods.

Accreditation provided by the National Association of Testing Authorities (NATA) can provide evidence of compliance to this standard.

Preferably, analytical laboratories should also participate in Australasian Soil and Plant Analysis Council (ASPAC) proficiency trials and maintain certification for the relevant methods. The ASPAC website (www.aspac-australasia.com.au) lists participating laboratories.

In the cases of both NATA and ASPAC, the respective accreditation or certification is for specific analytical tests or methodologies (e.g. method 15C1 in Rayment & Lyons, 2011), and is not a generic accreditation for all analyses undertaken at a laboratory. Therefore, before submitting soil samples for analysis, it is important to check that the laboratory is accredited and/or holds certification for all of the required tests.

While the use of sample handling and preservation focused quality assurance measures, such as chain-of-custody documentation, analysis of field and trip blanks, spiked and duplicate samples, is not to be discouraged, if site selection and sample collection are not of a suitable quality, post sampling quality assurance measures are of no value and will not overcome sampling or procedural deficiencies.

Where analytical testing of soil samples is undertaken outside of an accredited facility, the agency assessing a verification application might require evidence that:

- the equipment used has been calibrated or recalibrated by the equipment supplier, or another entity with suitable expertise, and that the calibration is current
- the calibration of the equipment is routinely checked when the equipment is operating
- a recognised analytical methodology has been followed
- a documented set of suitable quality assurance procedures is in place to cover all aspects of the testing, from sample receipt to the provision of the results
- the persons undertaking the tests have the competencies necessary to prepare the samples, operate the testing equipment, record the results, and identify quality assurance non-conformities and any anomalous results.

Irrespective of the accreditation or certification held by a laboratory, copies of all analysis certificates provided by the analytical laboratories or other providers must be submitted to for assessment by the government.

Mapping strategic cropping land

Key to addressing outcome 1 of the SCA assessment criteria will be the capacity to accurately delineate the spatial extents of any map unit not meeting the SCL criteria.

Map units

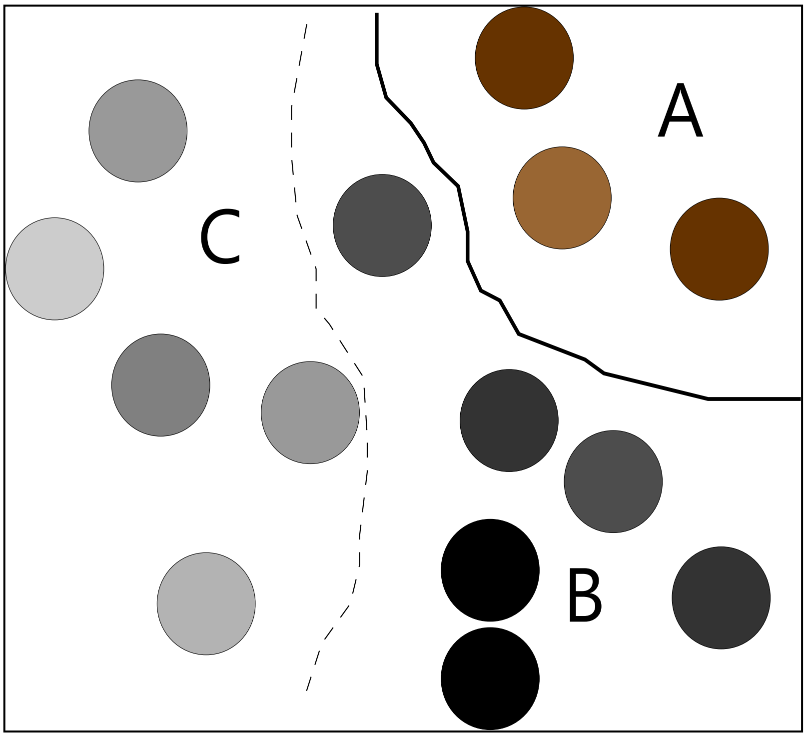
Despite what soil maps would appear to suggest, soils vary on a continuum and do not occur in sizeable, discrete, entirely homogeneous units within a landscape. However, to manage soil and land resources it still is useful to categorise soils into discrete spatial units mapped at some suitable scale.

Speight & McDonald (2009) explain the concept of an observation site as a small area of land considered representative of the landform, vegetation, land surface and other features associated with a soil observation. Due to the landform features of interest built into the SCL criteria (such as slope), a site for a survey may include the area within a 20m radius around the location where the soil sample is actually taken.

Map unit polygons are constructed by drawing boundaries around those areas containing observation sites that for the purposes of the survey, display similar soil and landscape attributes. The size of the map unit polygons and the reliability with which they can be delineated depends on the scale or intensity of the survey. This is illustrated using **Figure 5**.

By choosing any three sites in **Figure 5** at random, it is possible, but not necessarily certain, that soil unit **A** could be separated from the remainder. However, with appropriate preparations, it should be possible using a 'free survey' technique to purposely locate one inspection site in area **A**, and even at this early stage reliably differentiate soil unit **A** from the remainder of the survey area (i.e. to draw in the heavy dark line). However, the number of attributes of the three sites used in that differentiation would be limited (e.g. just colour in **Figure 5**).

Figure 4: Map units as per desktop assessment and observation sites



Increasing the refinement of the scale applied in investigating the area depicted in **Figure 5** requires a commensurate increase in the number of observation sites. At some point in this refinement process it should become possible to differentiate between soil units **B** and **C**, and thereby draw in the dotted line in **Figure 5**. If still more sites were to be inspected, sub-units within **A**, **B** and **C** might be identifiable.

In delineating the soil units in **Figure 5** (or any soil mapping exercise) some fundamental factors should be considered including:

- that there will ordinarily be a strong correlation between the distribution of soils and physiographic aspects of the survey area (e.g. substrate geology, landform element, slope, etc.), as well as specific vegetation associations
- for the inclusion of a site in a soil unit, the soil at the site should have more in common with other sites in that unit than it has with sites outside the unit. (i.e. intra-unit variance should be substantially less than inter-unit variance).

If in the example in **Figure 5** the soil in unit **A** is a moderately deep, hard-setting, Brown Sodosol that occurs on fine-grained Jurassic sediments exposed in the northern part of the study area, and the soil in unit **B** is a deep, coarse textured, dark grey cracking clay (Vertosol), found on clayey Quaternary alluvium in the balance of the investigation area.   Importantly differentiating characteristics such as these need to be both evident and suitably described in any report providing evidence of land not meeting the SCL criteria.

Should map unit **A** in **Figure 5** be less than the minimum size for a SCL map unit (i.e. the polygon is less than the minimum area or minimum width), unit **A** could be aggregated with a larger unit **B** to produce a composite map unit larger than the minimum size, in which the soil in unit **A** is the sub-dominant soil in the combined unit.

Likewise, if the soil in unit **C** is a moderately deep, Grey Vertosol, but is too small to comply with the minimum size requirements, it could be treated as a variant of the soil in unit **B**, and two units aggregated and subsequently described as perhaps a deep to moderately deep, grey to black Vertosol. In all cases it is the attributes of the dominant soil in an aggregated unit that determine compliance with the SCL criteria.

Map scales and site density

The number of observation sites inspected during a field survey determines the accuracy of mapping and the scale at which it can be reliably interpreted. As landscape complexity or the variability of the soil environment increases, the number of observation sites will also need to increase proportionately.

While keeping the number of observation sites to the absolute minimum might appear to be a means of saving costs, if the number of sites does not provide the necessary level of accuracy and reliability for the assessment agency to decide the application, the resultant delays and any supplementary fieldwork could be more costly than the initial saving. One of the major advantages of undertaking an initial reconnaissance survey is that the requirements in terms of the final number of observation sites and their distribution can be better understood, and properly costed before undertaking the fieldwork for the main survey.

Table 3 provides guidance for applicants on the number of observation sites that should be inspected during a detailed field survey that covers areas equal to or greater than the minimum map unit area shown in that table. Where it is intended to confine the field survey to areas smaller than those listed, specific advice should be sought from the DSDMIP or DNRME. The capacity to assess these small areas will depend on the nature of the area of interest and the SCL criteria being considered.

Table 3: Map unit size and the density of the four types of observation sites applicable in the five zones

	Western Cropping zone	Eastern Downs zone	All other zones
Minimum map unit area	10ha	10ha	2ha
Minimum map unit width	80m	50m	30m
Minimum density of sites in a map unit	1 site per 50ha	1 site per 25ha	1 site per 12ha
Exclusion sites (criteria 2 and 3)	3	3	3
Check sites per map unit (criteria 4 to 8)	Equal to or greater than 2	Equal to or greater than 2	Equal to or greater than 2
Detailed sites per map unit (criteria 4 and 5)	3	3	3
Analysed sites per map unit (criteria 6, 7 and 8)	3	3	3

Table 4 provides one example of the presentation of information confirming the number of observation sites and the density of those sites and how they comply with the requirements set out in **Table 3**.

Table 4: Example of documentation demonstrating number of observation sites

Map unit	ASC class	Area	Site type	Site ID	Sites	Required sites
C	Vertosol	40.65 ha	Analysed	A03, A04, A05	3	Equal to or greater than 3
			Detailed	D01	1	Not applicable*
			Check	C01, C02, C03, C04, C05, C06, C07, C08, C09, C10, C14, C17	12	Equal to or greater than 2
Total					**16**	**Greater than or equal to 5**
Site density					**2.5 ha/site**	**Less than 12 ha/site**

* This map unit is to be assessed against criteria 6, 7 and 8. The three analysed sites in this map unit substitute directly for detailed sites and obviate the need for any detailed sites at all. Despite this, in this instance the applicant still had one detailed site despite there being no specific requirement for detailed sites in this particular map unit.

Example: minimum number of check sites per map unit

While the recommended minimum number of check sites is two per map unit (refer **Table 3**), the actual number will depend on how readily the boundary between the subject map unit and its adjoining units can be delineated, and how uniform the soils are in the unit being mapped. Accordingly, two sites might be sufficient where the extent of the map unit is apparent in aerial photography or satellite imagery, and it is necessary to just confirm that the photo-interpretation is correct. In some other instances though, it may be necessary to visit a large number of check sites to reliably confirm the 'on ground' extents of the map unit.

Where the soil characteristics that might allow the differentiation of two map units occur within the soil profile itself, check sites can effectively become detailed sites. In such cases there might be no need for check sites as such, but the total number of detailed sites should increase proportionately (e.g. 3 detailed sites + 2 soil profile observation sites = 5 detailed sites).

Surface attributes that might allow the differentiation of map units can include the following:

- surface soil colour
- surface soil texture
- surface coarse fragments
- microrelief – including gilgai shallower or less extensive than required for non-compliance with criterion 3
- surface soil conditions (e.g. cracking, hard-setting or self-mulching) – although recent cultivation and antecedent rainfall can limit the usefulness of this attribute
- soil erodibility (e.g. erosion rills and similar artefacts)
- vegetation characteristics (e.g. crop vigour and native vegetation or weed associations)

Care should be taken in relying on surface attributes in areas that have been land-planed, subject to siltation, have a long history of unidirectional ploughing or being subject to other forms or disturbance or modification.

An example of the potential for the use of vegetation characteristics can be seen in the site photograph in **Figure 6**. In this case a heavy infestation of the weed button grass (Dactyloctenium radulans) was associated exclusively with the sandy clay loam surface soil of the Brown Dermosol in this unit. The clay textured surface soils in the adjoining soil units were largely weed-free, with only a very few, isolated clumps of another weed, awnless barnyard grass (Echinochloa colona), being present.

Irrespective of what method is used at check sites to differentiate between soil units, the applied method should be stated, and where appropriate, suitable confirmatory evidence provided (e.g. a photograph of the site or soil surface).

Soil map units and strategic cropping land

Whether a soil map unit remains identified as SCL on the SCL Trigger Map will depend upon whether the individual observation sites located within that map unit meet the SCL criteria.

Table 5 and **Table 6** provide examples of an evaluation of the compliance with criteria 6, 7 and 8 of two hypothetical analysed sites – 6, 7 and 8 being the criteria specifically addressed by data collected at analysed sites. The site in **Table 7** represents a non-rigid soil (a Vertosol), while the site in **Table 8** represents a rigid soil (Sodosol). The two sites are intended to be located in two separate soil map units. The land in this hypothetical evaluation is located in the Coastal Queensland zone.

Both tables also provide examples of suitable, but not obligatory methods of presenting the analytical data supporting an SCL evaluation.

Table 5: Example of analysed site that meets criteria 6, 7 and 8

Parameter	Units	Threshold	Map unit C (Vertosol)				
Site ID			A03				
Soil	rigid/non-rigid		non-rigid				
Upper layer interval	mm		0	200	500	800	900
Lower layer interval	mm		100	300	600	900	1000
$pH_{1:5}$		>5.0	7.4	7.8	8.2	8.2	8.3
$EC_{1:5}$	dS/m	0.56	0.10	0.08	0.26	0.32	0.35
Sand	%		30	29	20	19	21
Silt	%		18	18	14	19	12
Clay	%		56	58	68	69	67
Soil texture			MHC	MHC	HC	HC	HC
Look-up table SWS	mm/100 mm		12	12	12	12	12
Effective rooting depth	mm		1000				
Total SWS	mm	>100	120				
Criterion 6 compliance			OK				
Criterion 7 compliance			OK				
Criterion 8 compliance			OK				

Table 6: Example of analysed site that does not meet the criteria 6 and 8

Parameter	**Units**	**Threshold**	**Map unit B (Sodosol)**				
Site ID			**A07**				
Soil	**rigid/non-rigid**		**rigid**				
Upper layer interval	**mm**		**0**	**200**	**500**	**800**	**900**
Lower layer interval	**mm**		**100**	**300**	**600**	**900**	**1000**
$pH_{1:5}$		**>5.0, <9.0**	**8.1**	**8.6**	**9.1**	**9.3**	**9.4**
$EC_{1:5}$	**dS/m**	**<0.56**	**0.05**	**0.08**	**0.14**	**0.23**	**0.32**
CEC	**cmol+/kg**		**18**	**27**	**29**	**25**	**28**
Exchangeable Ca	**cmol+/kg**		**12.3**	**18.3**	**16.6**	**11.8**	**11.6**
Exchangeable Mg	**cmol+/kg**		**4.4**	**7.2**	**10.1**	**10.1**	**12.0**
Exchangeable Na	**cmol+/kg**		**0.13**	**0.49**	**1.72**	**3.32**	**4.47**
ESP	**%**		**0.1**	**1.8**	**5.9**	**13.3**	**16.0**
Ca:Mg			**2.8**	**2.5**	**1.6**	**1.2**	**0.9**

Sand	**%**		**53**	**49**	**53**	**48**	**46**
Silt	**%**		**22**	**7**	**11**	**6**	**6**
Clay	**%**		**35**	**47**	**40**	**47**	**49**
Soil texture			**CL**	**LC**	**LC**	**LC**	**LC**
Look-up table SWS	**mm/100 mm**		**8**	**10**	**10**	**10**	**10**
Effective rooting depth	**mm**		**500**				
Total SWS	**mm**	**>100**	**48**				
Criterion 6 compliance			**non-compliant**				
Criterion 7 compliance			**OK**				
Criterion 8 compliance			**non-compliant**				

Table 7 shows a hypothetical example of the summarised compliance (or non-compliance) of nine analysed sites and one detailed site in three different soil map units (**A**, **B** and **C**). In this example the compliance of the analysed sites is assessed against criteria 4 to 8, while that of the single detailed site is assessed against criteria 4 and 5. Again the presentation format is not an obligatory one.

Table 7: Example of assessment of three soil map units against SCL criteria

Unit	Site	4. Depth	5. Wetness	6. Soil pH	7. Salinity	8. SWS	SCL status
A	A01	non-compliant	OK	OK	OK	non-compliant	**Not SCL**
	A02	OK	OK	OK	OK	non-compliant	
	A08	OK	OK	non-compliant	OK	non-compliant	
B	A06	OK	non-compliant	OK	OK	non-compliant	**Not SCL**
	A07	OK	OK	non-compliant	OK	non-compliant	
	A09	OK	OK	OK	OK	non-compliant	
C	A03	OK	OK	OK	OK	OK	likely SCL
	A04	OK	OK	OK	OK	OK	
	A05	OK	OK	OK	OK	OK	
	D01	OK	OK	—	—	—	

An important aspect of the example in **Table 7** is that it is the consistent non-compliance with the criterion 8 seen in the three analysed sites in soil unit **A** and in soil unit **B** that allows these two units to be judged as not meeting the SCL criteria, and not the haphazard non-compliance with criteria 4, 5 or 6 of some individual sites in those soil units.

Reporting on findings

Information gathered from the desktop assessment, field work and laboratory analysis should be appropriately collated, analysed and presented.

The following provides guidance on how this may be achieved to demonstrate compliance with prescribed solution 1 of the SCA assessment criteria.

Mapping requirements

The application should be supported by maps which show:

- all land the subject of the application
- the location of all activities the subject of the application

- the extent of mapped SCL on that land (as per the SCL Trigger Map)
- any cadastral and resource authority boundaries
- each of the map units identified over the land the subject of the application
- the location and identification of each observation site and the type of observation site (if applicable)
- the extent of mapped SCL which the applicant has determined does not meet the SCL criteria.

Considerations for preparing maps

During the fieldwork, site and soil profile descriptions are obtained, and specific soil types are identified by recognising and grouping sites that are similar. For example, soil profiles may be similar in terms of colour, texture-profile, rockiness, segregations or soil depth. The observation sites may also have similar superficial characteristics and be associated with similar physiographic elements.

The various soil types will need to be subsequently delineated on a map as soil map units. Importantly, the distinguishing features that allow the common grouping of soils at different sites and the delineation of map unit boundaries need to be stated in the verification report. An unsubstantiated polygon boundary is effectively nothing more than an arbitrary line on a map.

The SCL status of the identified map units is then determined by assessing the compliance of the detailed and/or analysed sites within each map unit with the applicable SCL criteria.

Artificial and natural lineal features (e.g. watercourses or roads), that are less than 80 m wide in the Western Cropping zone, 50 m wide in the Eastern Darling Downs zone, or 30 m wide in any of the other zones, should be ignored in the mapping process, and any soil unit on one side made continuous with a common soil unit on the other.

If a potentially non-compliant map unit abuts the boundary of the subject land, but is too small to be a mappable unit (i.e. less than 10 ha in the Western Cropping and Eastern Darling Downs zones, and less than 2 ha in the remaining zones), it is still possible to apply to have the otherwise undersized unit on the subject land recognised as not SCL provided it is clearly evident that:

- the soil unit extends beyond the boundary of the subject land
- if they were treated as a single unit, the area of the combined unit then exceeds the minimum size.

The following figures provide examples of mapping that could support an application under the RPI Act.

Figure 5: Example showing land the subject of the application and mapped SCL

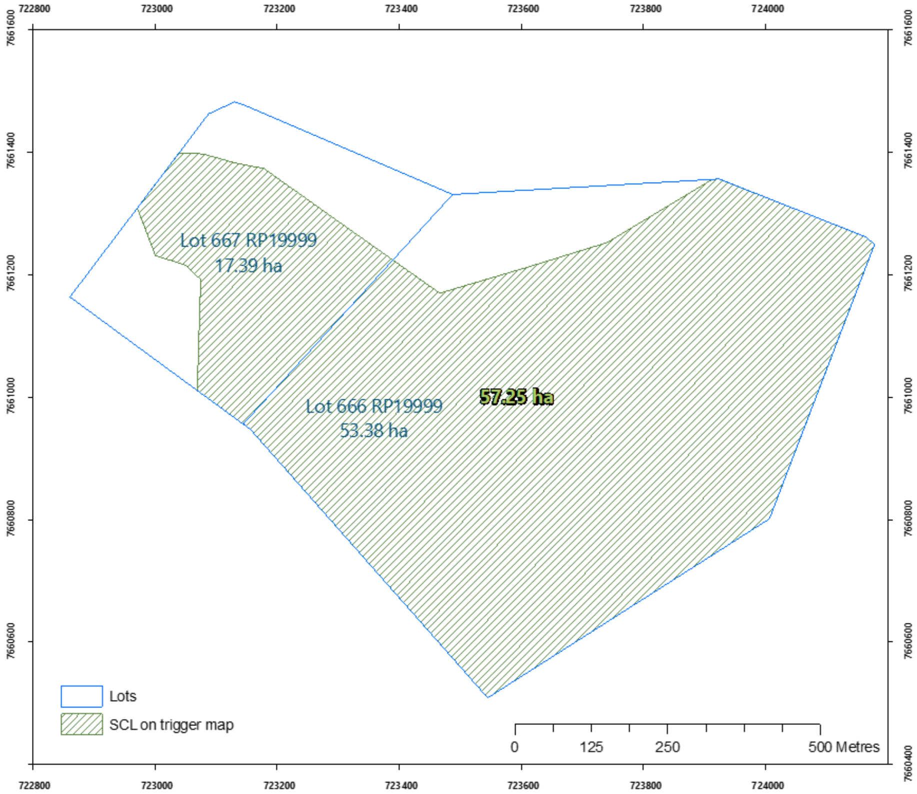


Figure 6: Example of mapping soil units and observation sites

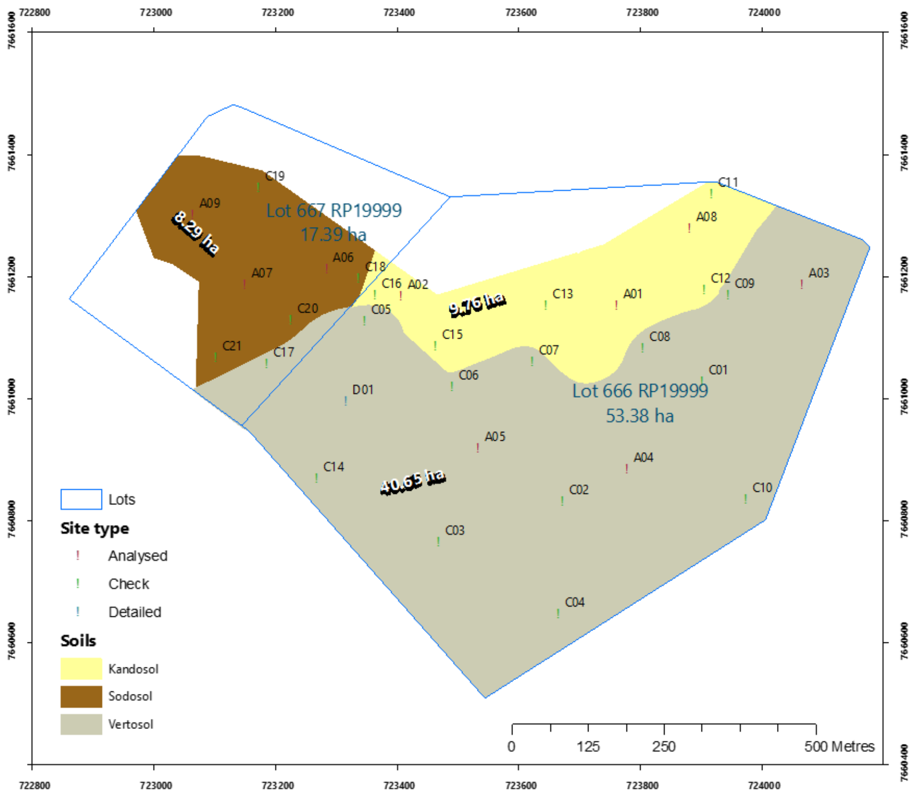
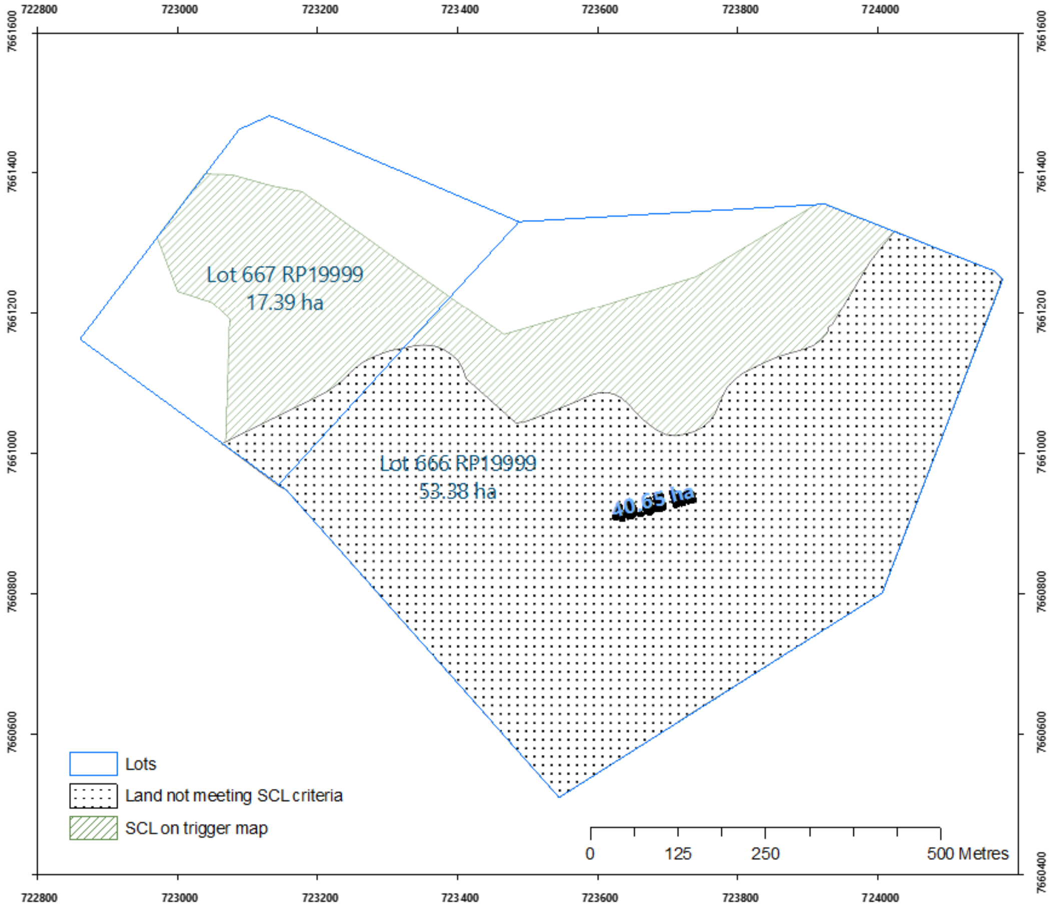


Figure 7: Example of land the applicant has determined does not meet the SCL criteria



Relatively common examples of the need to evaluate land outside of the immediate footprint of the resource activity are in infrastructure corridors or linear infrastructure.

Figure 10 shows the extents of four soil units identified in an infrastructure corridor. In this example all four map units are smaller than the minimum map unit area in **Table 3** for any of the SCL zones.

Figure 8: Soil units identified in an infrastructure corridor

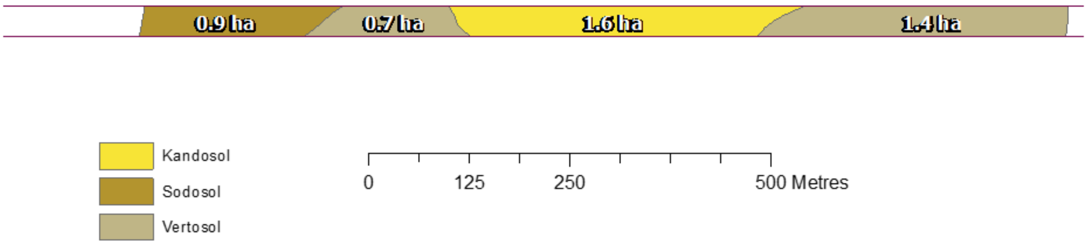
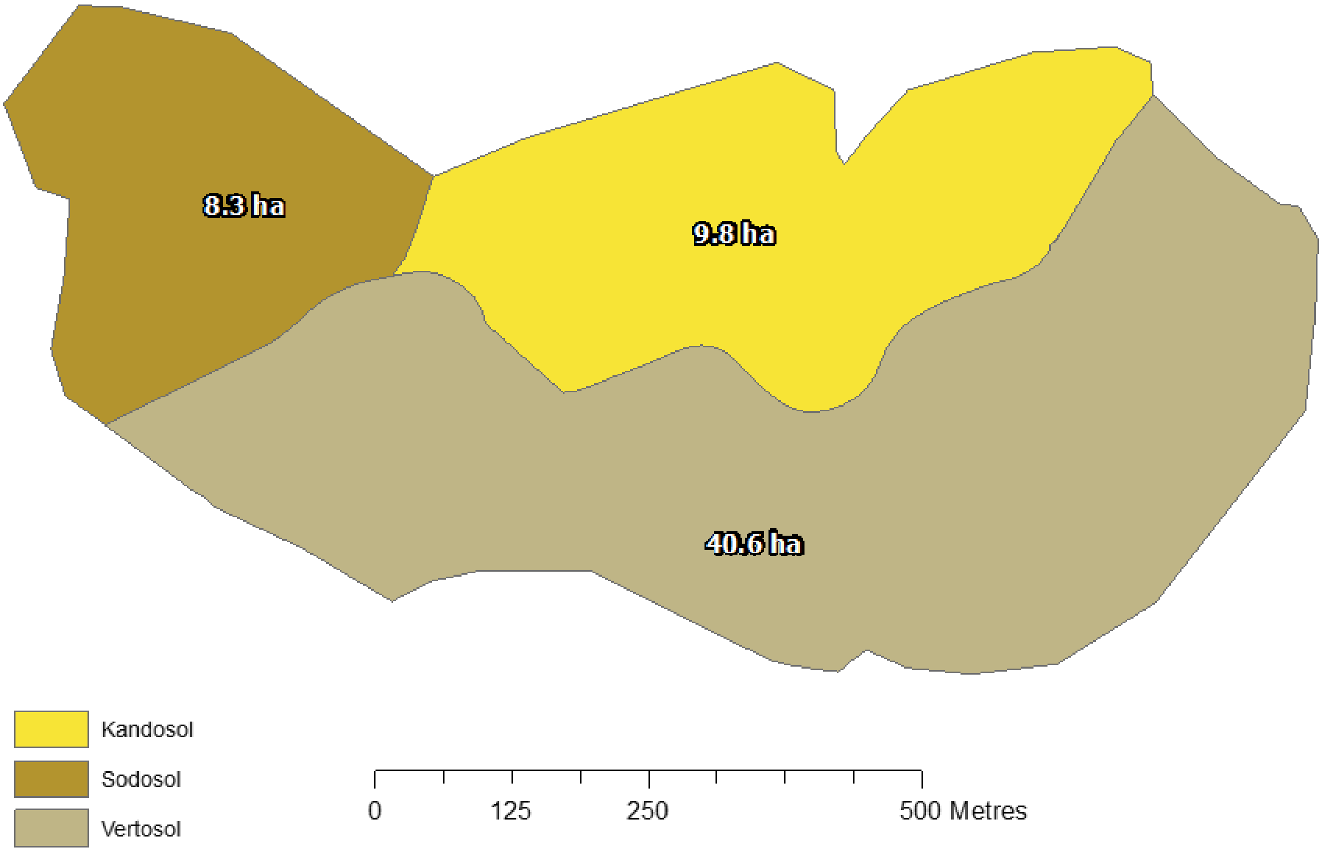


Figure 11 depicts the results when the soil survey is extended beyond the boundary of the infrastructure corridor. The benefits of extending the survey beyond the boundary of an infrastructure corridor include:

- determining that there are only three soil units represented in the area of being assessed
- those three map units would now all be larger than the minimum map unit area (assuming the verification area is in the Coastal Queensland zone)

Figure 9: The actual extents of soil units represented in the infrastructure corridor



Reporting requirements

The nature of reporting required by the applicant will depend on the size and complexity of the area of land the subject of the application and the area of mapped SCL over that land.

In the case of a very simple and straightforward application / assessment against prescribed solution 1, reporting might be very basic supported by maps.

Reporting should be simple, clear and concise to allow an affected land owner or a non-technical reader to interpret the submitted information and data. Supporting diagrams and photographs will be very useful.

The specific reporting requirements for demonstrating how mapped SCL does or does not meet the SCL criteria are provided in **Appendix 1**.

The specific reporting requirements for each observation site are detailed in **Appendix 3**.

Appendix 1: Measurement methods and reporting requirements

Slope

Measurement method

A variety of methods can be used in a land resource survey to directly or indirectly determine the gradient of terrain slopes. These methods vary not only in the type of equipment used, but also the cost and technical complexity of that equipment, the associated accuracy and precision of the measurements, as well as the form of the data output.

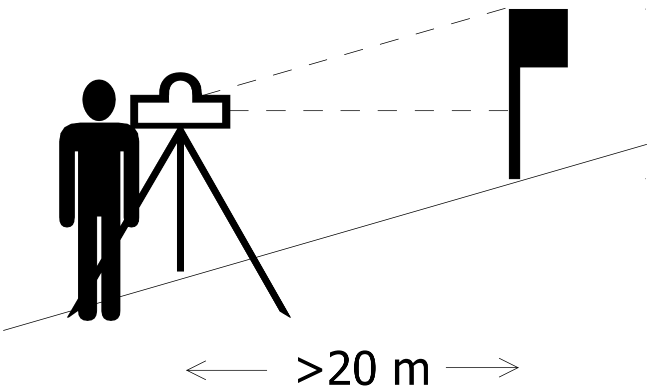
Direct in-field measurement

In land resource surveys the gradient of the slope at a specific site has traditionally been measured directly in the field, using simple, hand-held equipment such as a clinometer or Abney level.

There is a wide range of other, more precise tripod-mounted surveying equipment, which although less commonly used in land resource surveys, is well suited for direct in-field measurement of slope gradients. This tripod-mounted equipment comes in various derivative forms that have a variety of common names, including:

- dumpy levels
- automatic levels
- builder's auto levels
- digital electronic levels
- laser levels.

Figure A1-1: measuring the gradient of a slope with tripod-mounted sighting equipment



For the purpose of meeting the SCL criteria, where slope is to be measured in the field using any of these types of equipment, it must be measured:

2. at a suitable number of GPS logged sites
3. over a distance of at least 20 metres, with 50 metres being the upper limit in most terrain (refer **Figure A1-1)**.

Two measurements of the gradient should be taken at each site – one directly upslope, the other directly downslope – and the average of the two values for that site recorded.

While ordinarily persons using clinometers and Abney levels for traditional land resource surveys may not have always used some form of sighting pole or staff, to achieve the level of accuracy and precision required for SCL criteria the use of a sighting pole or staff is necessary when using either a clinometer or Abney level.

Remote and indirect measurement

Indirect methods of determining slope gradients typically involve:

- rendering elevation data into a 2D or 3D scale 'model' of the area of interest (either in a printed or a digital format)
- using the elevation data (e.g. z-coordinates or elevation contours) from the elevation model in some form of a slope analysis.

This slope analysis can be as simple as measuring the direct up and down-slope distance between elevation contours on a printed topographic map, and calculating the percentage rise or fall. However unless the map scale is very fine and the contour elevation interval is quite small, the accuracy and precision of this method will by and large limit its application in assessing whether mapped SCL meets this criterion to gradients well in excess of the threshold value for the zone the land is located in.

A slope analysis based on a 3D digital elevation model (DEM) has the potential to provide a very high level of precision. However, the level of accuracy achieved will depend on the capacity of the DEM to suitably represent the differences in elevation over the 20 to 50 m span required for assessment against of mapped SCL against the SCL criteria.

Provided the density of logged points is sufficient to meet this 20 to 50 m span requirement (i.e. ~25 logged points/ha), the use of DEMs produced in-field using GPS linked, real time kinematic (RTK), total station and similar surveying equipment is suitable for an assessment against the SCL criteria. This is particularly the case if registered permanent benchmarks have been used as reference points in the survey.

DEMs can also be produced using remote-sensing techniques, such as:

- airborne LiDAR
- Shuttle Radar Topography Mission (SRTM) data and
- stereo aerial photogrammetry.

Subject to some caveats, these DEMs can also provide an acceptable basis for slope analyses.

Potential limitations with the use of remote-sensing DEM data in the assessment of slope gradients relate primarily to the initial form of the data. These limitations typically include:

- a very high density of data points (e.g. <1 m^2/data point being common) and
- the data initially being a digital terrain model or DTM, rather than a digital elevation model of DEM.

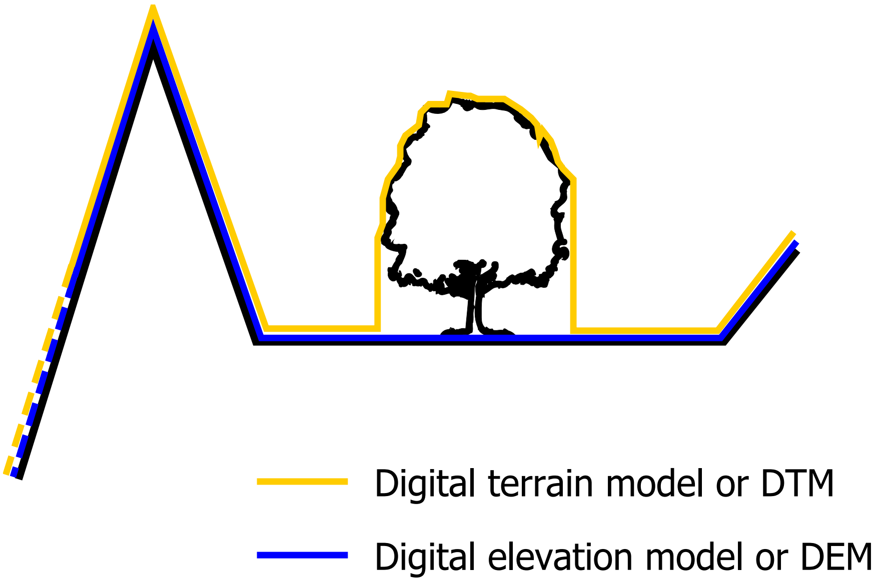
An assessment of mapped SCL against the SCL criteria requires the evaluation of slopes at an intermediate, landscape scale (i.e. at 20 to 50 m intervals). A simple analysis of high-density DEM data will be influenced by the microrelief associated with both natural features and man-made structures such as contour banks, drains, roads and tracks, and will consequently tend to overestimate landscape-scale gradients.

The limitations commonly associated with a DTM being the initial format can include the following:

- the DTM data includes signals from vegetation and built structures elevated above the land surface;
- the accuracy of the DTM can be seriously affected by high-relief terrain; and
- the DTMs are often generated by joining or 'stitching' data from consecutive flight paths or survey runs together, to provide full area coverage.

Figure A1-2 provides an illustration of the more common effects of vegetation and terrain on DTMs. It also illustrates how the final DEM is meant to have been 'cleansed' of extraneous data and 'noise' caused by vegetation, built structures and the like, and is therefore intended to provide a truer representation of the actual ground surface.

Figure A1-2: an illustration of the difference between a DTM and DEM



Despite their remarkable capabilities, the software algorithms used to derive a DEM from a DTM are not perfect, and their use can result in over and under compensation for the abovementioned effects. These imperfections are often most significant at the extremes of terrain and vegetative cover – a cleared, cultivated field in relatively flat terrain being at one extreme, and high-relief, mountainous terrain, with a near total tree cover (i.e. land unlikely to be SCL) being towards the other. Algorithms that suitably compensate at one extreme, often over or under compensate at the other extreme.

Artefacts left by DTM stitching processes, in particular SW-NE trending features sometimes seen in a SRTM DEM, are not uncommon, and need to be recognised and adequately addressed when producing or interpreting a slope analysis.

Because of the level of data manipulation involved in producing a DEM derived from remote sensing data, some basic form of validation of the DEM is recommended (e.g. some confirmatory spot in-field measurements). The results of this assessment should be presented in the assessment against the SCL criteria. Photographs taken during any in-field DEM validation can also help support the reliability of DEM data.

Triangulated Irregular Network (TIN) data, which is a particular form of DEM produced from vector data, allows the determination of the gradients from the spot height-based apexes in the triangular TIN surfaces. However, the output of slope analyses using TIN data frequently involves quite jagged outlines and disjointed shapes. This format is not highly suited to delineating logical or rational, slope-based exclusion areas for an assessment against the SCL criteria. Therefore, TIN data may need to be transformed into other formats prior to any slope analysis, or subject to post-analysis treatments to generate smooth polygons suitable for mapping land as meeting the SCL criteria or not.

Data formats

It should not matter whether a DEM is in a raster, gridded point, spot height or vector format. The critical consideration is whether the data is able to be processed to provide a suitably scaled and accurate output.

Normally the DEMs used for SCL slope analyses will initially be in a raster format and the following suggestions regarding data processing assumes that is the case. With other data formats some of the listed steps may be unnecessary or require the use of alternative methodologies. However, the general approach, in particular detailing applied methodologies, should be broadly similar.

Data preparation

If the DEM uses geographical coordinates (i.e. latitude and longitude), it may need to be transformed into projected coordinates (e.g. Easting and Northing in UTM WGS84/MGA GDA94) prior to processing so that gradients are calculated in the percentage (%) units required for determining compliance with the slope criterion.

Most GIS software includes tools that allow the necessary data transformation to take place. If not, standalone software, such as the Department of Natural Resources, Mines and Energy's GDA Datum Transformation Program: **https://www.business.qld.gov.au/industries/building-property-development/titles-property-surveying/surveying/gda** can provide a suitable means of transforming the coordinates.

Resampling of high-density DEMs

If a DEM is based on moderate to high density data (i.e. <400 m^2/data point), then prior to the analysis the elevation data needs to be resampled to obtain a suitable, lower density of data points (i.e. ~10 to 25/ha) required for SCL slope analysis. It is critical that this resampling be applied to the elevation data and not the post-analysis slope data.

Various methods are available to undertake any required resampling. Some of these methods, and in particular methods other than the default ones in the more common software products, can produce quite different and sometimes anomalous results. Therefore, the methods or algorithms used in the resampling of data, as well as the name and version of the software used, need to be stated in any reporting submitted by an applicant.

Slope analysis of DEM data

Slope analysis will typically be undertaken using some form of GIS or mapping software. The methods and algorithms, or software, version and associated tools used for the slope analysis need to be provided in any reporting submitted by an applicant. The use of any unusual or non-standard processing options should be stated and justified.

Generation of isoclines (optional)

At the a property scale, the rasterised output of the slope analysis can appear heavily pixelated and like the TIN-based output, not well suited to delineating rational exclusion areas. Consequently, it is recommended that the rasterised slope data be processed to produce slope ‘contours’ – more correctly termed isopleths or isoclines. These may look like elevation contours, but they are very different and will most cases inevitably track across elevation contours.

Generation of exclusion area polygons

If rasterised data is used the produce slope contours or isoclines, these represent polylines that can be used to produce exclusion area polygons. The threshold for the zone the land is included in isoclines (i.e. the 3% isocline in the Western Cropping zone and 5% isocline in the other zones) can be used to break apart the original potential SCL polygons, to produce exclusion areas or converted into isoclinal polygons, which can then represent the exclusion areas directly (possibly after trimming to the extents of the potential SCL polygons).

No matter how they are produced, the exclusion areas then need to be assessed against the map unit minimum area and minimum width requirements applicable to the zone the land is located in.

Polygon aggregation (optional)

By applying certain parameters which are typically the converse of the minimum width and minimum area requirements for mappable soil units, some GIS software will allow the aggregation of polygons, including undersized polygons that are a close neighbour of a larger compliant polygon. Likewise, the software may allow the removal of holes in exclusion area polygons that are less than the minimum size for a mappable unit. Such aggregation processes should be acceptable provided:

- the level of processing is stated
- the applied aggregation rules are reasonable
- the pre and post-aggregation polygons are depicted in any reporting submitted by an applicant

If in doubt as to the acceptability of any aggregation process, contact the assessment agency for advice.

Acceptable procedure for site measurement

The diversity in the methods available for measuring the gradient of slopes, and the associated differences in the accuracy and precision of the results, preclude a single, simple statement of the minimum number of sites and the minimum site density required to identify slope-based exclusion areas.

For on-ground measurements made using a clinometer or Abney level, the following procedures should be applied to demonstrate non-compliance with the slope criterion:

- observation sites within an exclusion area must be selected on an unbiased (i.e. a truly random) basis so that any above average site has the same chance as a below average site of being visited and an observation made

- slope should be measured over a distance of 20 m or greater (generally 50 m is a useful maximum distance), and two measurements made directly up and down the slope (along the maximum gradient line), straddling the observation site
- the area being assessed should not include any significant change in or break of slope
- artificial features, such as contour banks and tracks, should be ignored and not included in slope measurements
- after values have been derived for a minimum of three observation sites have been obtained, find the average (i.e. arithmetic mean) of those values to two decimal places, and compare that average value to the applicable threshold value in **Table A1-1**

If the average value exceeds the required value in **Table A1-1**, observations may stop and the results recorded; or else repeat the above steps (a to e) until either (1) the average value from all observations exceeds the applicable value in **Table A1-1**, or (2) the number of observations is greater than 100 where upon it might be assumed that the measured gradients do no differ significantly from the threshold vale and the assessment against the SCL criteria can be abandoned.

Table A1-1: average value required to demonstrate thresholds are exceeded

Observations	Zonal slope threshold	
	3%	5%
3	3.98	6.64
4	3.92	6.53
5	3.89	6.48
6	3.86	6.44
7	3.85	6.41
8	3.84	6.40
9	3.83	6.38
10	3.82	6.37
11	3.82	6.36
12	3.81	6.36
13	3.81	6.35
14	3.81	6.35
15	3.80	6.34
25	3.79	6.32
100	3.77	6.29

Where slope analyses are undertaken on DEM data in accordance with the methodology described in this guideline, the matters of the minimum number of observation sites and minimum site density are largely irrelevant, as typically there is an overabundance of elevation data. Hence no reference to the minimum number of observation sites and site density are provided in the following procedure.

For DEM data derived from remote sensing or on-ground measurements, the following procedures should be adopted:

- if necessary, resample the data to provide raster or gridded elevation data at 20 to 30 m intervals (or the local equivalent of 1 sec geographic coordinate intervals)
- apply any required coordinate transformations
- undertake a slope analysis
- plot isocline contours using GIS software and derive the candidate exclusion area polygons

- assess polygon size and width against the relevant zonal requirements and make any required adjustments and
- record and save results.

Reporting requirements

- report in detail the methodology and procedures used in the SCL criteria assessment process
- where exclusion areas are based on observations made at specific exclusion sites, for each exclusion site submit all the observation site and photographic information, as well as other data specified in this guideline
- where exclusion areas are based on on-ground measurements made using GPS equipment, submit the track of logged points used in the slope analysis
- for all methods, supply details on the capture, collation, processing and analysis of the data, including where relevant, details of the algorithms applied in the management an analysis of the data. For all methods that rely on the slope analysis of DEM data, submit geo-referenced photographs illustrating:
  (a) the nature of the terrain at all observation sites where on-ground measurements were made using handheld equipment
  (b) suitably illustrating the attributes of the more general terrain, and any obvious anomalous or unusual areas, where on-ground or remote sensing DEM data was used to determine compliance with this criterion
- identify at a suitable scale and in a suitable form the exclusion area where the gradient of the slope exceeds the applicable threshold (i.e. 3% in the Western Cropping zone and 5% in all other zones).

Rockiness

Measurement method

For the purposes of this criterion, only unattached rock fragments with an average maximum dimension larger than 60mm and outcropping bedrock are relevant. Coarse fragments less than 60mm diameters are to be ignored.

Charts for visually estimating the surface cover of surface coarse fragments and rock outcrops are provided in the 'Australian Soil and Land Survey Field Handbook' (NCST 2009) – see Figure 11, page 141 in that handbook.

Where the levels of rockiness are likely to be close to the threshold value for this criterion, the use of quantitative estimation methods, such as gridded and point-frame quadrats recording absence/presence on a specific number of points per m² (gridded quadrat) or lineal metre (point-frame quadrat), is encouraged.

Acceptable procedure for site measurement

- Rockiness is to be recorded as the average density within a 10m radius surrounding the site and
- Where there are multiple size ranges of coarse fragments, the total abundance of fragments greater than 60mm in diameter must be measured, and those fragments less than this size, ignored.

Reporting requirements

- The percentage abundance (as per cent cover) of surface coarse fragments and rock outcrops greater than 60mm in diameter is to be reported
- Submit all the observation site and photographic information and data for each exclusion site
- Georeferenced photographs of each site should be provided, with the soil surface photograph including a ruler, measuring tape or some other common item that provides a scale reference for the size of the coarse fragments present

- Identify at a suitable scale and in a suitable form the exclusion area where rockiness exceeds the threshold value.

Gilgai

Measurement method

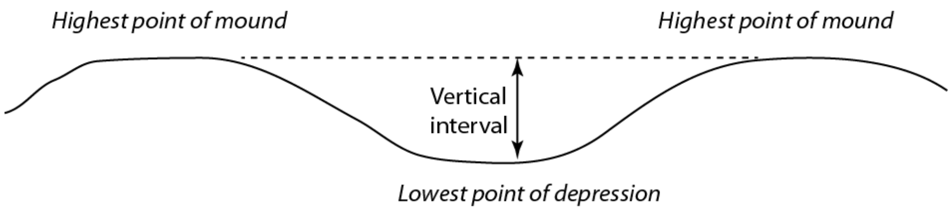
The key attributes of gilgai microrelief in the context of SCL are:

- the depth (vertical interval) of the gilgai depressions
- the areal extent of depressions within a particular area of gilgai.

If the average depth of gilgai depressions is deeper than 500mm, and if the depressions occupy more than 50% of a mapped area of gilgai terrain, then that area is non-compliant with the gilgai microrelief criterion.

The depth of the gilgai depression is measured in millimetres from the lowest point in the depression to the highest point on the adjacent mound or planar surface. This is illustrated in the following figure.

Figure A1-3: Gilgai microrelief and the depth of depressions



The depth of gilgai can be measured in two ways:

- by stretching a horizontal tape or rope between adjacent mounds and measuring the height from the tape to the lowest part of the intervening depression
- by use of a level and staff.

As the gilgai criterion is specified in terms of both vertical interval and proportional areal extent, to be disqualified as SCL requires both thresholds to be exceeded (i.e. greater than 500mm deep and depressions greater than 50% of the land surface).

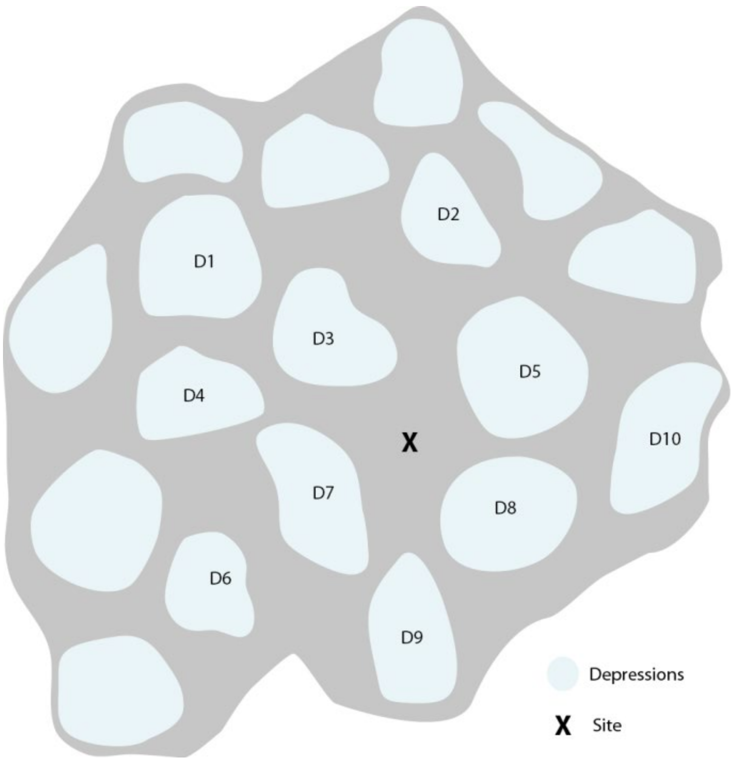
However, some areas of land with gilgai can exhibit substantial variability in gilgai features. Where depressions are not evenly spaced, additional measurements of the density of depressions should be taken in areas that are to be excluded due to this criterion. In such cases, additional sites may need to be assessed and the results recorded.

Acceptable procedure for site measurement

To determine if gilgai is severe enough to cause a site to become an exclusion site, the average depth of gilgai depressions and the density of the depressions need to be determined.

The depth of the ten depressions closest to the site (refer **Figure A1-4**) is to be measured and the average depth calculated.

Figure A1-4: An area of relatively uniform gilgai



The density of the gilgai depressions needs to be determined by one of the following methods:

- visual estimation on-ground. This may be done using the charts provided on page 141 of the Australian Soil and Land Survey Field Handbook (NCST 2009). However, if this proves difficult across large areas of land, the technique could be verified by capturing GPS points at the centre of depressions and plotting those on maps/imagery
- if available, high resolution imagery (greater than 1:40 000 scale) may be used in conjunction with the visual estimation charts

In the example shown in **Figure A1-4**, if the average depth of the 10 closest depressions (D1–D10) is greater than 500mm and if more than 50 per cent of the gilgai area consists of depressions, then the area is not SCL.

Reporting requirements

If the gilgai is being used to determine if a site qualifies as an exclusion site, then the following information needs to be reported:

- The depth measurements for the gilgai depressions (average depth of the ten closest depressions)
- The density of the gilgai depressions.

The area where the severity of gilgai is considered to exceed the threshold value must be identified at a suitable scale and in a suitable form.

Site representative, geo-referenced landscape photographs of the gilgai (including a clearly visible scale rod/tape to show depth of the depressions) will assist in assessing the application. This is particularly important in establishing the depth of gilgai depressions. Photographs are to be clearly labelled with the site identification.

Soil depth

Measurement method

Soil depth will usually be determined by:

- hand augering
- soil coring
- digging a soil pit
- inspecting a cutting or similar existing exposure.

The use of soil pits is to be encouraged, at least for a proportion of the detailed sites. Soil pits will generally allow direct confirmation of the presence of bedrock, weathered rock, hard pans and continuous gravel layers that constitute a physical barrier for the purposes of SCL criteria assessment.

With hand augering or soil coring, refusal can occur at depths that may not necessarily reflect the presence of a physical barrier as defined under this criterion. When these methods are used to establish the presence of soil depths less than 1000mm, refusal depth data for augers or coring tubes may need to be supplemented by other evidence (e.g. a proportion of sites having soil pits, or a characteristic sequence of weathered material extracted prior to the point of refusal).

The use of opportunistic exposures, such as cuttings, batters, pipeline trenches and gullies, can fulfil the function of purpose-dug soil pits, but consideration needs to be given as to how representative these opportunistic sites are of the soils in the subject soil unit.

Note, the soil depth criteria only relate to a physical barrier and not physico-chemical barriers to root development. Physico-chemical barriers relating to rooting depth are dealt with in subsequent criteria.

Acceptable procedure for site measurement

The soil profile needs to be exposed by an acceptable means. If a profile depth of 1000mm is reached without encountering a physical root barrier, then observations can cease.

The nature and characteristics of any potential physical barrier to root penetration should be established and documented.

Reporting requirements

- The method of exposing the soil profile and determining sampling depths should be recorded
- The resultant observed soil depth must be recorded to the nearest 50mm increment
- A description, and where possible photographs, of the specific type of physical barrier found must be provided (i.e. bedrock, weathered rock, hard pan and continuous gravel layer) including details of:
    - (c) The type and degree of cementation of any hard pan
    - (d) The size and abundance of coarse fragments within a gravel layer
    - (e) The nature of the bedrock or weathered bedrock material
- For each observation site submit all of the other observation site and soil profile information specified for detailed sites in this guideline.

Soil wetness

Measurement method

For the SCL criteria assessment, soil wetness is assessed by examining the subject soil profile for characteristics indicative of severely impaired soil drainage. Non-compliance with this criterion is demonstrated by identifying specific attributes of the soil profile associated with frequent or prolonged exposure to anoxic or anaerobic soil conditions (e.g. characteristic colours and/or mottling).

Soil colour is to be described for each horizon of the soil profile. The method for determining soil colour is provided in the Australian Soil and Land Survey Field Handbook (NCST 2009). The dominant (i.e. soil matrix) colour, and the colour of any mottles, needs to be recorded.

Acceptable procedure for site measurement

The soil profile is to be exposed and the colour of the soil matrix and of all mottles is to be described using the hue, value and chroma notation for the closest matching colour chip in a standard soil colour chart (Fujihira Industry Company, 2001 or Munsell Colour Company 2000).

Figure A5: Example of standard soil colour chart (Munsell Colour Company)

Aside from the recording of the matching colour chips, the abundance and contrast of mottles need to be described according to the Australian Soil and Land Survey Field Handbook (NCST, 2009) to fulfil the requirements of demonstrating non-compliance with the soil wetness criterion.

Colour patterns due to biological or mechanical mixing, or other inclusions, are not considered as a disqualifying factor when verifying SCL.

Reporting requirements

- the method of exposing the soil profile and determining sampling depths needs to be reported
- the colours of the soil matrix and all mottles in identifiable soil horizons need to be recorded
- all colours (including those of mottles) must be described and reported in the moist soil state other than for conspicuously bleached horizons (i.e. where greater than 80% of the soil layer is white or almost white), where the dry soil colour must also be reported
- the presence or absence of weathered rock or bedrock directly below a conspicuously bleached layer must be reported
- the abundance and contrast of any mottles is to be recorded
- a ‘nil’ abundance for mottles should be reported if mottles are not present
- the depth from the soil surface to the top of the waterlogged horizon (if present) should also be recorded – to a maximum soil depth of 300mm in the Granite Belt zone and 1000mm in all other zones
- for each observation site submit all of the other observation site and soil profile information specified in this guideline.

Soil pH

Measurement method

To demonstrate non-compliance with this criterion, soil pH will need to be measured by a suitably accredited or quality assured laboratory, using method 4A1 in Rayment & Lyons (2011). As there are no other robust or repeatable methods of equating pH values with the pH1:5 values obtained using method 4A1, alternative methods of determining soil pH are not acceptable.   Alternative analytical methods are not only unacceptable for evaluation soils for this criterion, but also when considering whether soil pH is a limitation on effective rooting depth in criterion 8 (soil water storage).

While soil pH can be measured in the field using Raupach or similar pH indicator reagents, the accuracy and reliability of these in-field pH tests is not sufficient for testing against the SCL criteria. Nonetheless, colour indicator pH tests can still provide useful in-field guidance when considering sampling and testing strategies.

Acceptable procedure for site measurement

- the soil profile is to be exposed, samples collected at sampling depths of 300mm and 600mm (note sampling interval discussion in section 5.6.3 of the main guideline)
- the soil samples prepared for submission to a laboratory for the analysis of soil pH

Reporting requirements

- the method of exposing the soil profile and determining sampling depths must be recorded
- pH1:5 values at 300mm and 600mm soil depths must be reported
- copies of laboratory certificates need to be provided
- confirmation of the sampling depths and the analytical method must be provided
- for each observation site, submit all of the remaining observation site and soil profile information specified for analysed sites in this guideline

Salinity

Measurement method

Two standard laboratory methods for measuring soil salinity are used in determining compliance with this criterion. These methods, which involve the analysis of soil samples taken from a depth of 600mm at each site, are:

(8) The concentration of chloride ions (Cl-) measured in a 1:5 soil/water suspension, and expressed in mg Cl/kg of soil (as per Method 5A2 in Rayment & Lyons, 2011)

(9) The electrical conductivity of a 1:5 soil/water suspension (EC1:5), measured in dS/m (as per Method 3A1 in Rayment & Lyons, 2011).

Importantly, method 1 (chloride) is the only acceptable analytical method for evaluating soil salinity in the Western Cropping and Eastern Darling Downs zones, while Method 2 (electrical conductivity) is the only acceptable method for evaluating soil salinity the other three zones.

Acceptable procedure for site measurement

- the soil profile is to be exposed, soil samples collected at a sampling depth of 600mm
- the samples prepared for submission to a laboratory for the appropriate analysis of soil salinity

The sampled soil profile depths may be the same as used in sampling for the soil pH criterion or any another appropriate set of depth of depth intervals (e.g. 0 – 100, 100 – 200, 200 - 400 & 400 – 600mm). However, sampling should not occur from depth intervals of a thickness greater than 300mm. Where salt ‘bulges’ occur at locations such as the base of the root zone, sampling at overly wide depth intervals can result in a failure to observe the peak salinity levels due to the dilution of any of the more saline material with less saline soils from above or below the 'salt bulge'. For similar reasons, sampling across soil horizon boundaries should be avoided.

An indicative $EC_{1:5}$ value can be obtained in the field with a suitable probe device and salinity meter. However, the accuracy and reliability of in-field measurements is not sufficient to assess the soil salinity criterion. Chloride values cannot be measured accurately in the field, even for indicative purposes.

Reporting requirements

- the method of exposing the soil profile and determining sampling depths should be recorded
- copies of laboratory certificates need to be provided
- analytical results are to be reported as:
  - (i) Chloride content in mg/kg for the Western Cropping and Eastern Darling Downs zones
  - (ii) $EC_{1:5}$, using units of dS/m, for Coastal Queensland, Wet Tropics and Granite Belt zone
- confirmation of the sampling depth and analytical method must be provided;
- for each observation site submit all of the remaining observation site and soil profile information specified for analysed sites in this guideline.

Soil water storage

Measurement method

Measured parameters

For the purposes of assessing mapped SCL against the SCL criteria, soil water storage is calculated by summing the amount of water that is capable of being stored in each soil horizon or layer within the effective rooting depth in a soil profile and that is available for plant use.

The effective rooting depth is whichever represents the lesser of the following:

- a depth of 1000mm or
- the depth at which a physico-chemical limitation is encountered or
- the depth of a physical barrier

The presence of a physico-chemical limitation on rooting depth is represented by the following:

- a chloride content of more than 800mg/kg for any soil in the Western Cropping zone or Eastern Darling Downs zone or
- an $EC_{1:5}$ value of more than 0.56 dS/m for any soil in the Coastal Queensland zone, Granite Belt zone or Wet Tropics zone
- a $pH_{1:5}$ value of 5.0 or less for any soil in any zone
- for rigid soils in any zone that are (1) not sandy loam or lighter textured soils, and (2) have a CEC value greater than 3 cmol+/kg and have:
  - (i) a $pH_{1:5}$ of more than 8.9 or
  - (ii) an exchangeable sodium percentage value of more than 15 or
  - (iii) a calcium to magnesium ratio of 0.1 or less

For the purposes of determining compliance with this criterion, a physical barrier is the same as what constitutes a limitation on soil depth in criterion 4 (i.e. the presence of bedrock, weathered rock, hard pans and continuous gravel layers).

Allowable measurement methods

Having established the effective rooting depth, these guidelines then provide two standard methods for estimating soil water storage. These methods are:

1) soil texture lookup table and

2) the PAWCER pedotransfer function.

The first method is an adaptation of the soil lookup table used in the original SCL framework. The principal change in this current framework is the requirement to undertake a laboratory-based particle size analysis to determine soil textures, rather than relying on the more subjective hand texturing of soils to determine the appropriate texture class.

The second of the standard methods is another, but more refined estimation method, rather than a direct measurement method. It uses the PAWCER pedotransfer function developed by Littleboy (1997). This method again relies on laboratory-derived values for the percentage clay and percentage sand in each layer of soil in the soil profile. It also requires an analysis to derive the soil's gravimetric water content at a pressure deficit of 1.5 MPa, which notionally equates to the permanent wilting point or crop lower limit in a soil (i.e. the lowest soil moisture content at which a plant might still be able to extract moisture from the soil).

An advantage of this particular pedotransfer function is that provides a more reliable estimate of soil water storage than the revised soil lookup table method, with only a modest increase in laboratory analysis costs. Owing to the more robust soil water storage estimates provided by the pedotransfer function, under these guidelines it is the method of assessing this criterion when estimates obtained using the revised lookup table method fall within a margin of ±15 per cent of the applicable zonal threshold value.

Should neither of these standard methods be considered suitable for an applicant's needs, an applicant can put a proposal to the assessment agency for the use of another well-proven method for evaluating soil water storage. However, the acceptability of these methods – particularly in respect to non-rigid soils – is not guaranteed and agreement must be reached with the assessment agency before perusing this approach.

Irrespective of which of the available methods are used to estimate soil water storage, the first stage of the assessment against criterion 8 of the SCL criteria is to determine the effective rooting depth in the subject soil. This will require exposing the soil profile and collecting samples for description and analysis. This can be done by hand augering, soil coring, digging a soil pit or sampling a cutting or similar existing exposure. Although initially appearing more costly, the benefits provided in terms of access, observational opportunities and ease of sample collection mean that soil pits can be more cost effective and their use is encouraged.

The soil samples collected at each site will need to be sent for laboratory analyses that to enable the subsequent estimation of soil water storage. The number of soil samples should remain the same, but the required analyses will vary slightly depending upon the method chosen to estimate soil water storage.

Soil water storage

Soil texture lookup table

To estimate the soil water storage using the soil texture lookup table requires first determining the texture class for each horizon or sampled depth interval in a soil profile. This involves the following being undertaken for each sample:

- a particle size analysis made using the most appropriate of the 517 prefix tests in McKenzie et al. (2002) or using AS 1289.3.6.3–2003
- determination of the clay, silt and sand fractions based on the particle diameter thresholds in NCST (2009)
- determination of the soil texture class using the ternary chart or Marshall diagram in NCST (2009)
- applying the soil texture classes in the lookup table to determine soil water storage in each soil layer

PAWCER pedotransfer function

The algorithms used to calculate the soil water storage value using the PAWCER pedo-transfer function (Littleboy, 1997) are as follows:

$$SWS = \sum_{i=1}^{n} \frac{(DUL_i - LL_i) \times BD_i \times \Delta d_i}{100 \times \rho_{H_2O}}$$

Where:

SWS = soil water storage (mm) to the effective rooting depth

n = the number of sampled depth intervals in the root zone

i = depth interval for layer 1 (surface layer) to n (deepest layer)

DUL_i = gravimetric water content at drained upper limit (%w/w)

LL_i = gravimetric water content at lower limit (%w/w)

BD_i = bulk density of soil in interval i at DUL (g/cm³)

Δd_i = thickness of depth interval i (mm)

= $z_{i+1} - z_i$ (mm)

z_i = upper limit of interval i (mm)

z_{i+1} = upper limit of interval i +1 (mm)

= lower limit of interval i

ρ_{H_2O} = density of water (assumed to be 1 g/cm³)

The gravimetric water content at the drained upper limit is given by:

$$DUL_i = (0.995 + 0.0011 \times S_i) \times 13.2 \times e^{-2.845 \times (z_i + z_{i+1})/2000} + (1.0054 + 0.0041 \times C_i) \times \theta_{1.5\mathrm{MPa}_i}$$

Where:

S_i = sand fraction in interval i (%w/w)

= fraction soil particles 0.02 – 2.0mm diameter

C_i = clay fraction in interval i (%w/w)

= fraction soil particles 0.0002 – 0.002mm diameter

$\theta_{1.5\mathrm{MPa}_i}$ = gravimetric water content of soil in interval i at -1.5MPa (%w/w)

The bulk density of the soil can be measured directly by a suitable laboratory analysis, or estimated using the pedotransfer function given by:

$$BD_i = \frac{85.82 + 0.12 \times C}{DUL_i + 37.4} \quad \text{where } BD_i < 1.7, \text{ else } BD_i = 1.7$$

To determine the required variables in the PAWCER equations involves the following analyses being undertaken for each sample:

- a particle size analysis made using the most appropriate of the 517 prefix tests in McKenzie et al. (2002) or using AS 1289.3.6.3–2003
- gravimetric water content at -1.5 MPa as determined using the most appropriate of the 504 prefix code, soil water characteristic methods in Mckenzie et al. (2002)
- optionally, soil bulk density as determined using the most appropriate of the 503 prefix code, bulk density methods in McKenzie et al. (2002)

Acceptable procedure for site measurement

Effective rooting depth

The soil profile is to be exposed, the soil profile described, and soil samples collected at suitable sampling depth intervals to a profile depth of 1000mm or a shallower depth where a physical root barrier (consistent with that required for criterion 4) is encountered.

The sampled depth intervals in the upper 600mm of the soil profile can be the same as used in sampling for the soil pH and salinity criteria. Over the full extent of the sampled profile, sampled intervals should be no less than 50mm, ideally 100mm, and span no more than 300mm. The sampled depth intervals can be either continuous (e.g. 0 – 100mm, 100 – 200mm, 200 – 300mm, etc.) or discontinuous (e.g. 200 – 300mm, 500 – 600mm etc.).

If discontinuous samples are submitted for analysis it may be beneficial to retain the additional un-submitted samples in case the analysis of one of the submitted samples from lower in the soil profile shows a marked deviation in an analyte value compared to the sample next highest in the sampled profile. In such a case it might be beneficial to undertake an analysis of the un-submitted sample in case the observed change occurred in that intermediate layer.

Samples should not be taken across clear or abrupt textural changes between soil horizons, and especially not across the interface between an A horizon and the B horizon in texture contrast or duplex soils (i.e. Sodosols, Chromosols and Kurosols).

The soil samples sent for laboratory analyses should be tested for the following analytical tests:

- $pH_{1:5}$
- Chloride (Western Cropping zone) or $EC_{1:5}$ (all other zones)
- CEC or ECEC, exchangeable sodium percentage and Ca:Mg ratio (rigid soils only);
- Particle size analysis
- Gravimetric water content at a pressure deficit of -1.5 MPa (only required for the PAWCER pedotransfer function option)

The results of the physico-chemical analyses need to be interpreted to ascertain whether a physico-chemical limitation exists and at what profile depth that limitation occurs. It is important to remember that the exchangeable sodium percentage and Ca:Mg ratio as limitations is that the CEC value needs to be in equal to or greater than 3 cmol+/kg and the soil must be of a finer texture than a sandy loam for these parameters to be considered.

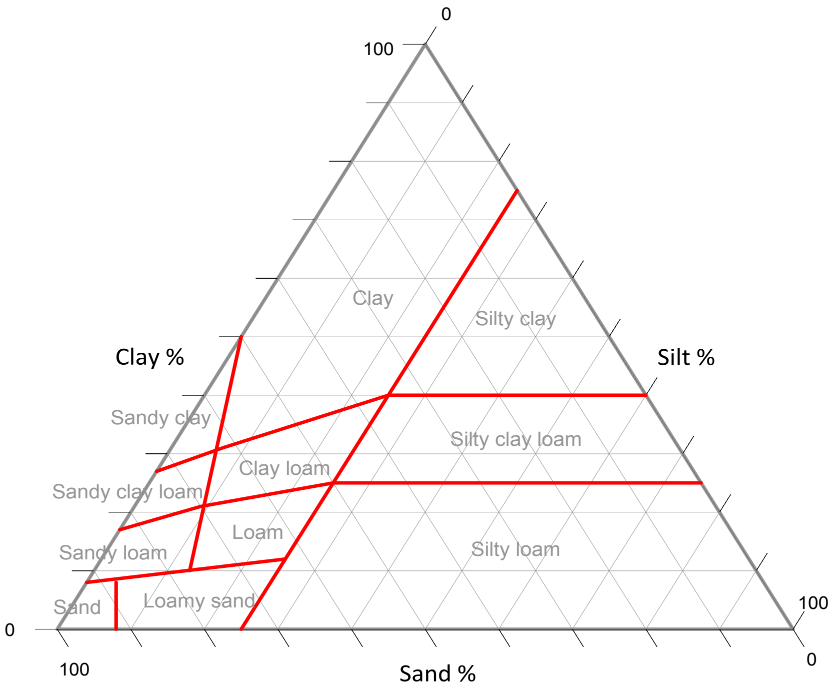
Soil texture look up table

If the soil texture lookup table method is to be used to estimate soil water storage, it is necessary to determine the soil textures in each sampled horizon or layer for the laboratory particle size analysis data.

The proportional mass of clay, silt and sand fractions based on the particle diameter thresholds in NCST (2009) need to be determined. These particle size fractions differ from those used in geotechnical surveys.

The determination of applicable soil texture classes can be readily be undertaken by plotting the percentages of clay, silt and sand from the particle size analysis in a ternary soil texture chart like shown in Figure A1 - 6 (adapted from page 163 of NCST, 2009). Adjustments should be made for any significant amount of coarse fragments (i.e. greater than 2mm) in the analysed samples.

Figure A1-6: Ternary soil texture chart of Marshall diagram (NCST, 2006)



Having determined the applicable soil textures, these are then applied in the soil texture lookup table shown below to determine the soil water storage value for each sampled soil layer.

Table A1-2: Soil texture lookup table

Soil texture	Soil water storage
sand; clayey sand; loamy sand	4mm/100mm
sandy loam	5mm/100mm
loam; silty loam; sandy clay loam	6mm/100mm
clay loam; clay loam, sandy; silty clay loam	8mm/100mm
silty clay; clays with <45% clay fraction	10mm/100mm
clays with ≥45 % clay fraction	12mm/100mm

Where soil water storage estimates are made using the lookup table, the calculated values will need to be more than 15% below the applicable threshold value to demonstrate that a soil fails to comply with the soil water storage criterion. If the calculated values fall within this margin of the threshold value, it will be necessary to use the PAWCER pedotransfer function to estimate of soil water storage.

The PAWCER pedotransfer function

To use the PAWCER pedotransfer function it is necessary to have the same data for the proportional mass of clay, silt and sand fractions in each contiguous soil layer as is used in determining the soil texture when using the lookup table approach.

In addition, the laboratory derived estimate of the permanent wilting point (i.e. the gravimetric moisture content at -1.5 MPa) in each of the sampled layers is required. These values are substituted directly into the associated equations to determine the plant available SWS value for each soil layer. The layer values are them summed to the effective rooting depth to provide the SWS value for the full profile.

The following provides examples of determination of soil water storage made using the soil texture lookup table and the PAWCER pedotransfer function.

Example of soil water storage estimation

The following provides examples of the physical attribute data obtained from the laboratory analysis of a duplex or texture contrast soil. This data will be used to illustrate:

- the measurement methods available for determining effective rooting depth
- an acceptable procedure for undertaking those measurements
- the reporting requirements for the soil water storage criterion

Soil profile	Profile depth	Clay	Silt	Sand	$\theta_{1.5MPa}$
	0.0 – 0.2m	15%	15%	70%	9%
	0.2 – 0.3m	21%	5%	74%	13%
	0.3 – 0.8m	42%	8%	51%	11%
	0.8 – 1.0m	38%	9%	53%	11%

The soil in the table has the following attributes:

- it is a duplex or texture contrast soil (i.e. a rigid soil),
- it is deeper than 1000mm (i.e. there is no physical barrier associated with bedrock, weathered rock, hard pans or continuous gravel layers present at a depth less than 1000mm),
- it has a cation exchange capacity in all soil layers >3 cmol+/kg, and
- all layers are finer textured (clayeyer or siltier than a sandy loam)

Consequently, only the physico-chemical limitations need to be considered in determining the effective rooting depth.

The potential physico-chemical limitations include the following:

- elevated soil chloride concentrations (i.e. greater than 800 mg/kg)
- extremes of soil pH (i.e. $pH_{1:5}$ equal to or less than 5 and equal to or greater than 9)

- strongly sodic conditions (i.e. ESP greater than 15%)
- Extremely low exchangeable calcium and magnesium ratios (i.e. Ca:Mg equal to or less than 0.1)

The following table lists the results of relevant chemical analyses undertaken on samples collected from the exemplar soil profile.

Depth interval	Limitation	Soil texture	Lookup table	Soil water storage
0 – 200mm	no	loam	5mm/100mm	1 x 5 x 200/100 = 10mm
200 – 300mm	no	sandy clay loam	6mm/100mm	1 x 6 x 100/100 = 6mm
300 – 500mm	no	light clay	10mm/100mm	1 x 10 x 200/100 = 20mm
500 – 800mm	yes	light clay	10mm/100mm	0 x 10 x 300/100 = 0mm
800 – 1000mm	yes	light clay	10mm/100mm	0 x 10 x 200/100 = 0mm
TOTAL soil water storage				**36mm**

If the soil had greater than 10% cent coarse fragments (gravel) in the soil profile, the values in the table would need to be adjusted proportionately.

To ascertain compliance with criterion 8, the total soil water storage value needs to be compared to the applicable zonal threshold value (e.g. 100mm in the Western Cropping zone). For a soil water storage value determined using the soil texture lookup table to be non-compliant with criterion 8, the calculated value needs to be more than 15% or 15mm below the applicable zonal threshold value (i.e. less than 85mm in the Western Cropping zone)

The soil water storage values for each of the five layers, as determined using the PAWCER pedotransfer functions, the presence or absence of a physico-chemical limitation, and the total soil water storage for the soil profile to the effective rooting depth, are shown in the following table. If the soil had greater than 10% coarse fragments (gravel) in the soil profile, the values in Table A1 - 6 would need to be adjusted proportionately.

Depth interval	Limitation	SWS_i	Soil water storage
0.0 – 0.2m	no	27mm	27mm
0.2 – 0.3m	no	10mm	10mm
0.3 – 0.5m	no	21mm	21mm
0.5 – 0.8m	yes	21mm	0mm
0.8 – 1.0m	yes	10mm	0mm
TOTAL soil water storage			**58mm**

Again, to ascertain compliance with criterion 8, the total soil water storage value in the table is compared to the applicable zonal threshold value (e.g. 100mm in the Western Cropping zone).

Reporting requirements

- the method of exposing the soil profile and the sampled depth intervals must be recorded
- if less than 1000mm, the soil depth must be recorded to the nearest 50mm increment; and a description of the specific type of physical barrier found must be provided
- the results of laboratory analyses for the following analytes need to be provided:
    i. $pH_{1:5}$
    ii. chloride (Western Cropping zone) or $EC_{1:5}$ (all other zones)
    iii. cation exchange capacity (rigid soils only)
    iv. exchangeable sodium percentage (rigid soils only)
    v. Ca:Mg ratio (rigid soils only)
    vi. particle size analysis
    vii. soil moisture content at -1.5 MPa (for PAWCER pedotransfer option only)
- details of the soil profile depth at which any physico-chemical limitation on effective rooting depth was considered to occur
- the results of the calculation of soil water storage values plus results of any intermediate calculations sufficient to demonstrate how the total soil profile values were derived
- copies of laboratory certificates must be provided
- confirmation of the analytical methods used must be provided
- for each observation site submit all of the remaining observation site and soil profile information specified for analysed sites in this guideline

Appendix 2: Reporting requirements for each observation site

Exclusion site

The recorded information and data for each site should be presented on a coherent basis in or as an appendix to the report supporting the verification application. The reported information should include the following:

- a unique – and preferably meaningful – site identification code (e.g. E2/06 for site 6 in exclusion area 2)
- GPS coordinates of the exclusion site and the applicable spatial datum (e.g. 605 900 mE 7 380 000 mN, Zone 55S, UTM WGS84 or -23.687366°, 148.038652°, GDA94)
- the zonal criteria the exclusion site is non-compliant with
- the methodology used to make the necessary measurements
- the recorded value for the measured attribute (e.g. slope = 3.5%; or surface cover of rocks 60mm = 50%; or gilgai depressions 600mm deep and >60% of land surface)
- two clearly labelled photographs showing:
  (iii) the nature of the general environs of the site, and
  (iv) suitable photographic evidence best illustrating the level of non-compliance encountered at the exclusion site.

Where photographic evidence is being used site to support non-compliance that relates to a scalar variable (e.g. diameter, depth, area, gradient, etc.), an item able to provide some form of a scale reference should be visible in the image. A ruler, measuring tape or surveyor's staff make ideal reference objects, but common or everyday items, such as a pen, notebook, camera lens cap, shovel or soil auger, can also be suitable for providing an indication of the relative scale.

When exclusion sites are being used for verification of the slope criterion, sites should be selected on a grid or statistically valid random basis, or by using a suitable series of transects that run directly up and down the slopes being measured. While preliminary stratification of the survey area is acceptable in selecting slope-based exclusion sites, free survey techniques are generally inappropriate in such instances.

Detailed site

The following information and data is to be collected for each detailed site and presented on a coherent basis in or as an appendix to the report supporting the verification application:

- a unique (and preferably meaningful) site identification code (e.g. D/08 for site 8 in project D)
- GPS coordinates of the detailed site and the applicable spatial datum (e.g. 605 900 mE 7 380 000 mN, Zone 55S, UTM WGS84 or -23.687366°, 148.038652°, GDA94)
- date of the site inspection
- nature of exposure (auger, pit, core, batter, etc.)
- landform pattern and element
- slope gradient
- site disturbance/modification
- current land use and/or land cover
- surface rock (abundance and size of coarse fragments)
- microrelief – including element sampled if some form of microrelief present
- soil surface condition (cracking or self-mulching)
- soil profile description, involving for each soil horizon:

(i) upper and lower depth

(ii) boundary distinctness between soil horizons

(iii) mottle abundance and distinctiveness

(iv) colour of the soil matrix and abundance, size, contrast and colour of any mottles

(v) soil texture

(vi) ped structure, grade and consistence

(vii) abundance, nature, form and size of segregations

(viii) abundance and size of coarse fragments (i.e. gravel, pebbles, cobbles, stones and boulders)

(ix) pan presence and form

- at least two clearly labelled photographs showing:
  a) the nature of the general environs and soil surface at the site
  b) the attributes of the exposed soil profile, including a scalar reference, such as a tape, surveying staff or calibrated sample tray

It is also suggested that a number of other soil and site attributes be recorded as part of any verification process. These might include the following:

- Substrate lithology
- Vegetation associations
- Permeability and drainage
- Horizon name and notations
- Australian Soil Classification (ASC) order
- Root presence/absence
- Field pH
- Field $EC_{1:5}$

An example for a detailed site of the basic format and the required level of detail for site and soil descriptions as well as the use of photographs to support those descriptions:

Project: SCL	**Site:** 13
Location: GDA 94 zone 56, 300 000 mE 7 000 000 mN **Described by:** Bill Smith **Date:** 17-Jan-14	
Site description	

Geology: Qa - alluvium
Landform Pattern: alluvial plain
Element: levee
Permeability: moderately permeable
Microrelief: zero or none
Microrelief Component: no record
Drainage: imperfectly drained
Slope: 1 %
Rock Outcrops: no bedrock exposed
Surface Coarse Fragments: few 2-10%, small pebbles 2-6mm, ironstone
Surface Condition: hard setting
Disturbances: cultivation – rain-fed

ASC Classification: Brown Dermosol

Profile Morphology

Horizon	Depth (m)	Description
A1	0.0 to 0.05	Dark greyish brown (10YR4/2) moist; fine sandy clay loam; very few <2% rounded siltstone small pebbles 2-6mm ferruginised; massive structure; few 2-10% medium 2-6mm ferruginous nodules; clear to
2A1b	0.05 to 0.3	Very dark grey (10YR3/1) moist; fine sandy clay loam; very few <2% rounded siltstone small pebbles 2-6mm ferruginised; massive structure; very few <2% medium 2-6mm ferruginous nodules; clear to
2A2eb	0.3 to 0.4	Brown (10YR4/3) moist; pale brown (10YR63) dry; fine sandy clay loam; very few <2% sub-rounded siltstone small pebbles 2-6mm ferruginised; massive structure; very few <2% medium 2-6mm ferruginous nodules; clear to
2B21b	0.4 to 0.75	Brown (10YR5/3) moist; very few <2% fine <5mm faint orange (7.5YR6/6) mottles; light clay; very few <2% sub-rounded siltstone small pebbles 2-6mm ferruginised; platy moderate 5-10mm structure; very few <2% medium 2-6mm ferruginous nodules; clear to
2B22b	0.75 to 1.0	Light yellowish brown (2.5Y6/4) moist; very few <2% fine <5mm distinct orange (5YR7/6) mottles, very few <2% fine <5mm prominent red (2.5YR5/6) mottles; light clay; very few <2% sub-rounded siltstone small pebbles 2-6mm ferruginised; platy moderate 5-10mm structure; very few <2% medium 2-6mm ferruginous nodules; very few <2% medium 2-6mm manganiferous laminae

Analysed sites

Guidance for soil sampling provided by McKenzie & Ryan (2008) suggests that for the purposes of a general soil survey, it is recommended that the maximum sampling interval should be 100mm in the upper 300mm of the soil profile. Likewise, below that depth the maximum sampling interval should be 300mm. These generic recommendations should be considered when sampling analysed sites for an assessment against the SCL criteria.

Other matters applicants need to consider in deciding on a suitable sampling regime include:

- what criteria are the analyses looking to verify, and what analytical tests are involved

- how many samples are to be taken and analysed, and the likely costs of those analyses
- whether sampling is to be of individual soil horizons (e.g. A1 horizon, A2 horizon, B2 horizon, etc.) or based on standardised profile depth intervals (e.g. 0 – 100mm, 200 – 300mm, 500 – 600mm, etc.)
- whether the samples are taken on a continuous basis through the entire profile or centred on specific, but discontinuous profile depths or layers
- are the soils uniform, gradational or texture contrast soils, and are the horizon boundaries gradual or diffuse
- what are the risks of too great a sample interval diluting material from a narrow non-compliant layer of soil, or of too small a sample interval missing a non-compliant layer of soil

Irrespective of whether sampling is horizon or depth interval based, all samples should be taken within single soil horizons (i.e. depth interval samples should not cross major soil horizon boundaries).

Check sites

Where the defining attributes of the characteristic soil in a map unit can be readily identified by obvious superficial features (e.g. surface soil colour, surface soil texture, surface condition, presence of gilgai, etc.), check sites can provide a quick and reliable means of identifying the areal extent of a map unit.

On the other hand, where the soil attributes confirming whether the check site is within a homogeneous soil unit require the exposure of part or all of the soil profile, the check site will effectively become another detailed site. In this latter case, provided the total number of detailed sites is increased accordingly, there may be no need to have observation sites that are designated as check sites.

Those attributes that confirm that a check site belongs to a particular soil type or map unit need to be recorded for each check site, along with the unique identification (e.g. C16 for check site 16). The GPS coordinates of the check site and the applicable spatial datum (e.g. 605 900 mE 7 380 000 mN, Zone 55S, UTM WGS84) must also be recorded and submitted. However, simply submitting a site identification and some location coordinates for a check site, without any evidence of the confirmatory site or soil attributes observed, does not provide sufficient information for an assessment against the SCL criteria and is liable to be discounted or disregarded in that assessment. Hence the nature of the nature of the confirmatory evidence obtained at check sites needs also to be stated (e.g. self-mulching, surface cracking, black clay surface soil).

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Further information

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