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Overview

Agricultural land resources are important to Queensland, supporting regional communities and providing a resource base for food and fibre production.

The Queensland Government is committed to protecting the best of Queensland's cropping land resources. This land—strategic cropping land—is a finite resource that must be conserved and managed for long-term food and fibre production and regional growth. Currently, the state's strategic cropping land resources are subject to a range of competing land-use activities, including agriculture, mining and urban development. Some of these activities can result in permanent alienation or unavailability of this land for cropping.

On 23 August 2010, the Queensland Government released Protecting Queensland's strategic cropping land: A policy framework (SCL framework), outlining the Queensland Government's approach to protecting strategic cropping land. Strategic cropping land includes the best land currently being cropped as well as the best cropping land resources that could be cropped in future.

This new approach involves developing and implementing legislative and planning tools, including a specific Act of Parliament for strategic cropping land resources and a new State Planning Policy under the *Sustainable Planning Act 2009*. A key aspect of the SCL framework is identifying areas of strategic cropping land on-ground. The SCL framework highlighted that on-ground assessment against criteria would be necessary to identify strategic cropping land, and the criteria would be released as the SCL framework was further developed and implemented.

In April 2010, the Queensland Government announced the proposed criteria and thresholds to identify strategic cropping land. Protecting Queensland's strategic cropping land: Proposed criteria for identifying strategic cropping land provides the criteria that will be used in the drafting of new strategic cropping land legislation to be introduced in 2011. The report is available on the Department of Environment and Resource Management (DERM) website at www.derm.qld.gov.au

These criteria have been developed to reliably and consistently identify the state's best cropping land—land that is suitable for a range of crops in most seasons—and to minimise the assessment burden and costs to landholders and developers.

Department of Environment and Resource Management (DERM) soil scientists, Department of Employment, Economic Development and Innovation agronomists, and independent soil science consultants developed and refined these criteria. Collectively, the group have over 100 years of soil science experience across the state's key cropping areas.

This technical report accompanied the release of these criteria and explains the technical assessment undertaken to develop and refine these criteria and thresholds.

The technical assessment involved detailed checking of 128 sites across all five strategic cropping land zones. These sites covered a broad range of landscapes and cropping systems to assess the likely results across cropping areas of the state. While a few changes to the criteria were recommended to better define the strategic cropping land resource, it indicated the effectiveness of the approach and gave the government confidence that the proposed criteria would reliably identify Queensland's best cropping land.

An expert review was also undertaken to provide independent advice to DERM on this report and the criteria. The review included examining the appropriateness of the process used to develop the criteria, the thresholds and their suitability for the proposed policy, and an evaluation of the scientific basis for the criteria and thresholds. The report on the findings of the expert review, Protecting Queensland's strategic cropping land: An independent expert review of the criteria for identifying strategic cropping land, provides additional transparency about the science underpinning the criteria. The findings have been incorporated into this technical report and it is available on the DERM website at www.derm.qld.gov.au

DERM is currently finalising guidelines that will provide information for applying the proposed criteria at a property level and will be released in May 2011.

Executive summary

The foundation of the Queensland Government's Strategic Cropping Land (SCL) framework is a set of clear criteria and thresholds that define Queensland's best cropping land. To reflect regional differences in climate, land forms and cropping systems, five zones have been established across Queensland and specific criteria have been developed for each zone. In these zones, only land that meets the criteria will be protected under the SCL framework.

As part of the development of the criteria, DERM undertook a program of technical assessment to test the practical application of *draft* criteria and threshold values to ensure they accurately and reliably identified the best cropping land. The recommendations of this technical assessment have informed the Government's *proposed* criteria (the criteria proposed to be used in drafting the new SCL legislation. A comparison of the draft criteria and proposed criteria are shown in Table 1.

The objectives of the technical assessment were to:

i. test that the draft criteria accurately define SCL (including testing the hierarchy of the criteria and testing the definitions)
ii. test that the threshold values are set at the appropriate level to identify SCL
iii. make recommendations on the proposed criteria and thresholds.

On-ground assessments were undertaken in Coastal Queensland, the Granite Belt and the Darling Downs. Assessments of key areas in central and northern parts of the State, including the Wet Tropics, were undertaken using sites from DERM's Soils and Land Information (SALI) database. Although severe wet weather disrupted the full program of on-ground assessment, the first week of on-ground assessment, involving 48 sites, confirmed that utilising information from the SALI database was a technically robust and effective method to assess the draft criteria and thresholds. It is important to note that all sites assessed from the SALI database have been physically surveyed previously.

A total of 128 sites were assessed according to the draft SCL criteria. These comprised 50 sites for the Coastal Queensland zone, five sites for the Granite Belt zone, 54 sites for the Western Cropping zone, eight sites for the Wet Tropics zone and 11 within the Eastern Darling Downs zone that was excised from the Western Cropping zone.

The assessment identified several key changes to the zones, criteria and thresholds, which were adopted in the proposed criteria. The key recommendations were:

- Development of a new zone for the Eastern Darling Downs area - encompassing the area between Jandowae, Oakey, Warwick, Killarney and the Great Dividing Range. This area was recommended to be excised from the Western Cropping zone, with the slope threshold raised from 3% (as applied in the Western Cropping zone) to 5%. This new zone recognises that Eastern areas receive more reliable rainfall and have regionally distinct landscape features, and consequently farming systems, on these more sloping landscapes.
- Removal of the soil physical condition criterion - as it was found to be highly dependent on soil moisture conditions and recent land management operations (e.g. cultivation), and was therefore too subjective.
- Refining the soil depth criterion - to include weathered rock in the calculation of soil depth as it presents a limitation to crop yield but was not captured by the earlier soil depth definition.
- Changing the soil depth threshold - to provide consistency across zones and to better reflect the depth of soil required to provide sufficient soil depth for root exploitation by a crop plant. The proposed threshold value was recommended to be 600 mm for all SCL zones.

- Increasing the threshold for the depth of gilgai microrelief depressions - from 300 mm to 500 mm for all zones, to ensure high quality soils that were being reliably cropped were not excluded from SCL.
- Changing the salinity threshold for the Western Cropping zone and the new Eastern Darling Downs zone - from 1500 mg/kg to 800 mg/kg of chloride and the electrical conductivity threshold for other zones which was reduced from 1.0 dS/m to 0.56 dS/m to remove saline soils as SCL.
- Increasing the soil pH threshold - from 4.5 to 5.0 to ensure acidic soils that cause nutrient toxicity to crops were not defined as SCL. For non-rigid soils, the soil at 300mm soil depth must be greater than pH 5.0. This criterion also incorporates a threshold value for soil alkalinity. For rigid soils, the soil at 300mm and 600mm soil depth must be within the range of pH 5.1 to pH 8.9 inclusive.
- Removing the exchangeable sodium percentage component of the soil depth criterion - this was instead added to the threshold for the depth over which soil water storage is calculated for rigid soils. The salinity criteria were also added to the threshold for the depth over which soil water storage is calculated.
- Refining the definition of the wetness criterion - to remove ambiguity about the soil features that define it.
- Development of a new two-stage approximation soil water storage assessment – for Stage 1, a look up table was recommended based on soil textures as a simple, robust and cost effective assessment of soils that clearly have sufficient storage capacity (e.g. soils with high clay contents) or inadequate storage capacity (e.g. free draining sands). This avoids the need for assessors to undertake expensive laboratory tests and in-field measurements of soils that will clearly pass (or fail) the criteria. Stage 2 allows for more precise laboratory and field measurements where necessary. Where more precise soil water measurements are required, a combination of direct measurements and laboratory methods are recommended.
- Decreasing the soil water storage threshold from 100 mm to 75 mm for the Coastal Queensland zone to rectify the inappropriate exclusion of particular horticultural soils.

These changes were recommended in order to ensure that SCL criteria, when applied in the field, would result in soils being correctly defined as either SCL or not SCL. The draft criteria as defined prior to the field assessment would have resulted in areas of marginal crop land being inadvertently classed as SCL. The proposed SCL criteria and threshold values are outlined in Table 1 and are fully defined in Appendix 3.

Of the 128 sites assessed against the proposed criteria;

- 41% of sites were defined SCL, of which 94% were sites that represent commonly cropped soils.
- Of these 41% sites that were SCL, half were cropped at the time of the assessment. It is important to note that this statistic is influenced by site access constraints for the assessment – all except one of the sites not cropped were sited on research stations, road verges or had been returned to pasture from crop use as part of farm land management processes. Only one site which was available for cropping had no apparent history of recent cropping.
- 59% of the sites assessed were defined as not SCL, of which 53% were either cropped at the time of assessment or represent soils that are commonly cropped. These included a number of sites in the Coastal Queensland zone that were used for irrigated cane and horticulture.

Assessing whether land is SCL (or not) will invariably involve some field and laboratory evaluation. The criteria and thresholds all use standard field and laboratory methods. In this study over 63% of sites defined as not SCL were excluded on one or more criteria which can be measured in the field (i.e. slope, rockiness, soil depth).

The recommended changes to the criteria and threshold values were aimed at improving the assessment process and accurate identification of strategic cropping land. The outcomes of this assessment show the proposed criteria and thresholds define areas which will be high quality cropping land. Conversely, areas with steeper slopes, shallower soil profiles and thus reduced soil water store or subsoil chemical limitations that reduce plant and root growth - resulting in them being lower quality crop lands, will not qualify as SCL and the majority of these areas will be excluded on the basis of simple field tests.

In conclusion, the proposed criteria and thresholds will robustly define Queensland's best cropping land, consistent with the objective of the SCL framework.

Table 1: Comparison of draft criteria (pre-assessment) and proposed criteria (proposed for drafting of new SCL legislation) for identifying strategic cropping land

Criteria	Draft Criteria and Thresholds				Proposed Criteria and Thresholds				
	Western Cropping	Coastal Qld	Wet Tropics	Granite Belt	Western Cropping	Eastern Darling Downs	Coastal Qld	Wet Tropics	Granite Belt
1 Slope	<3%	<5%			≤3%	≤5%			
2 Rockiness	<20% for rocks >60mm diameter				≤20% for rocks >60mm diameter				
3 Gilgai microrelief	<50% of land surface being gilgai depressions of >300mm in depth				<50% of land surface being gilgai microrelief of >500mm in depth				
4 Soil physical properties	Ped Size <10mm				<criterion removed>				
5 Soil depth	>500mm			>300mm	≥600mm				
6 Wetness	Not Very Poorly Drained or Poorly Drained soils			Not Very Poorly Drained soils	Has Favourable Drainage				Has Satisfactory Drainage
7 Soil pH	pH ≥5 within 300mm of the soil surface	pH ≥4.5 within 300mm of the soil surface			For non-rigid soils, the soil at 300 mm and 600 mm soil depth must be greater than pH 5.0. For rigid soils, the soil at 300 mm and 600 mm soil depth must be within the range of pH 5.1 to pH 8.9, inclusive.				
8 Salinity	Chloride content < 1500 mg/kg within 600mm of the soil surface	$EC_{1:5}$ <1 dS/m within 300mm of the soil surface			Chloride content <800 mg/kg within 600mm of the soil surface		$EC_{1:5}$ <0.56 dS/m within 600mm of the soil surface		
9 Soil Water Storage (previously 'Moisture Availability)	≥100mm to a soil depth of ≤1000mm		≥50mm to a soil depth of ≤1000mm	≥25mm to a soil depth of ≤1000mm	≥100mm to a soil depth or soil physico-chemical limitation of ≤1000mm		≥75mm to a soil depth or soil physico-chemical limitation of ≤1000mm	≥50mm to a soil depth or soil physico-chemical limitation of ≤1000mm	≥25mm to a soil depth or soil physico-chemical limitation of ≤1000mm

Background

The Queensland Government is committed to protecting Queensland's best cropping land resources. Strategic cropping land is a finite resource that must be conserved and managed for long-term food production and regional growth.

On 23 August 2010, the Queensland Government released Protecting Queensland's strategic cropping land: A policy framework (SCL framework), outlining the Queensland Government's approach to protecting strategic cropping land.

This new approach involves developing and implementing legislative and planning tools, including a specific Act of Parliament for strategic cropping land resources and a new State Planning Policy under the *Sustainable Planning Act 2009*.

The SCL framework intends to protect the best cropping land resources (whether currently cropped or not) in the State so that they are available for cropping into the future.

A key part of the SCL framework is identifying areas of strategic cropping land on-ground. The SCL framework highlighted that on-ground assessment against criteria would be necessary to identify strategic cropping land.

The trigger maps under the SCL framework provide a landscape-scale indication of where strategic cropping land is expected to exist. These maps are based on the best soil, land and climate information currently available, and will be the starting point for determining whether an area is strategic cropping land. The current trigger maps are available on the DERM website at www.derm.qld.gov.au

While the trigger map is a broadscale indicator of likely cropping land, it is the on-ground assessment against the criteria that will define the extent of strategic cropping at a property level.

When a landholder whose land is not on the trigger map can show their land meets the criteria, they can apply to have the land considered strategic cropping land.

To reflect regional differences, five zones have been established across Queensland and specific criteria have been developed for each zone.
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Each criterion and the specific thresholds in each zone have been selected using existing science to identify the best land, but leave out unsuitable or poor quality cropping areas.

The zones only apply to the key cropping landscapes of Queensland. The SCL framework does not apply outside these areas.

Introduction

The Department of Environment and Resource Management (DERM) soil scientists have been working with other Queensland Government agencies and independent soil science consultants to develop appropriate criteria and thresholds to identify and protect the best of Queensland's cropping land resources.

As part of the development of the criteria, DERM undertook a program of technical assessment to test the practical application of *draft* criteria and threshold values to ensure they accurately and reliably identified the best cropping land. The recommendations of this technical assessment have informed the Government's *proposed* criteria. A comparison of the draft criteria and proposed criteria are shown in Table 1.

Guiding policy principles for identifying strategic cropping land

The criteria for strategic cropping land aim to identify Queensland's best cropping land. This includes soils that:

- are suitable for a range of crops
- are capable of reliably producing crops
- are capable of being cropped without excessive inputs, such as moderate use of fertiliser, standard cropping machinery and limited soil conservation measures, and
- do not generally require irrigation[1] for sustainable cropping.

Land that meets these guiding principles will be capable of being productively and sustainably cropped into the future based on their inherent attributes and management systems. These same characteristics will also ensure these areas are resilient to long-term changes, such as climate change and changes in the agricultural sector.

Objectives

The objectives of the technical assessment were to:

i. test that the draft criteria accurately define SCL (including testing the hierarchy of the criteria and testing the definitions)
ii. test that the threshold values are set at the appropriate level to identify SCL
iii. make recommendations on the proposed criteria and thresholds.

This assessment included a field program, a series of site assessments using the Department's Soil and Land Information (SALI) database and case studies of transects through key cropping regions.

The assessment was a technical assessment of the draft SCL criteria and thresholds for defining the land resource. As such, it was not designed to test the accuracy of the draft trigger map or minimum area issues, and therefore mapping is not considered in this report.

[1] The capacity for a parcel of land to be irrigated is dependent on many issues, including access to reliable water sources, the locality of the land, the configuration of the land and capacity to alter the land surface (e.g. levelling). This is further complicated by water being a tradeable commodity. Further, not all cropping requires irrigation, which depends on its locality (for example, higher rainfall areas in the Wet Tropics), prevailing weather conditions (i.e. wet seasons) and the type of crop being grown (e.g. dryland grains cropping). For these reasons, the availability (or otherwise) of irrigation water for cropping is not considered within the SCL framework or criteria.

Methods

The technical assessment was performed by soil scientists from Environment and Resource Sciences Division within DERM, regional soils and agronomy staff from DERM and DEEDI (Primary Industries and Fisheries) and land resource consultants from LRAM Pty Ltd (engaged by DERM for the project) with extensive soil science experience.

The technical assessment was based on draft criteria (see Table 2). These criteria have been hierarchically structured as inclusionary criteria with clear threshold levels i.e. when one criterion is not met, then the site area is not SCL and further assessment at that site ceases. The criteria are also ordered from those easily determined 'on ground' (e.g. slope) to those requiring laboratory analyses (e.g. salinity). This structure minimises assessment burden and costs to landholders and developers. Only when all of the criteria are met is the site SCL

The clear threshold levels are designed to ensure a clear result as to whether a site is SCL or not. These thresholds are specific to each SCL zone which encompass regional differences in climate, land forms and cropping systems across cropping areas of Queensland.

Field assessment

The field program sought to maximise the diversity of landscapes and regions sampled, and was modified to take into account the extensive heavy rainfall across the State in late 2010 and early 2011.

A number of sites were selected in advance, particularly those that represented widespread and important agricultural landscapes and for which soil descriptions and laboratory data were available. This facilitated an efficient appraisal at the site of the 'below ground' elements of the criteria being assessed, especially due to the extensive heavy rainfall which prevented soil cores being taken due to the saturated soil profile in many locations. Pre-selected sites included some that were expected to meet the SCL criteria as well as some that would not. In addition, a range of 'random' sites were sampled during the field assessments, at which full soil profile descriptions were made, and samples taken for subsequent laboratory analysis.

Cultivated and farmed sites were preferred where possible. However, a number of sites were located in road reserves and other public lands (where on-farm access was not possible). The expected variation in results (in particular, the higher salinity levels of uncleared sites) was reported and taken into account in the final analysis.

For each site, the following minimum information set was determined:

- Location, landscape and soil profile morphology.
- Evaluation of sites against the draft criteria and thresholds (as shown in Table 2).
- Observed land use (eg. crop, pasture, the crop type, land management system).
- Photographs of the locality and soil core (when sampled) from each site.
- Soil chemical data from the evaluation site or similar soils was also accessed where available.
- Observed implications for defining the SCL resource.

In the draft criteria, four zones were established to recognise the regional differences across Queensland:

- Western Cropping zone (Figure 1)
- Granite Belt zone (Figure 2)
- Coastal Queensland zone (Figure 3)
- Wet Tropics zone (Figure 4)

The field component was undertaken during the week of 6–10 December 2010, incorporating sites 1-48 as shown in Figures 1, 2 and 3. This was supplemented by a further six sites (sites 501 – 506) in March 2011. Field sites were located in the Lockyer Valley (Coastal Queensland zone), the Eastern Downs and Western Downs (Western Cropping zone) and the Granite Belt zone.

The field assessment was planned to continue in the week of 13–17 December 2010, covering further areas of the Inland Burnett and Coastal Burnett areas (Coastal Queensland zone) and the Central Highlands, Dawson-Callide area (Western Cropping zone). However, severe wet weather and flooding across these areas led to cancellation of the field program and was instead incorporated in the assessment of existing data as detailed below.

Assessment of existing data

An assessment of existing data was undertaken for key locations in the Coastal Queensland zone (Inland Burnett, Coastal Burnett and Mackay-Whitsunday areas), the Western Cropping zone (Central Highlands, Dawson-Callide), and the Wet Tropics zone. This assessment used site-based soils data contained within the DERM Soils and Land Information (SALI) database. A total of 74 sites were assessed in this manner. All these sites have been subject to previous physical survey.

Evaluation of the existing site data against the draft criteria was undertaken in the same manner as at field sites, except that it was not possible to photograph the site and make observations of the current land use. However, archive photographs and land-use information associated with the existing site data were utilised when available.

Transect assessment

The field assessment included some transect sampling across landscape gradients from areas that were not SCL to those that were SCL. These transects were assessed to provide an understanding of the application of the draft criteria and thresholds at the landscape level.

Three transects based on existing medium intensity soil surveys (1:50 000 to 1:100 000 scale) have been used to indicate the landscape context to the SCL framework. These transects were selected from the:

- Upper Tenthill part of the Lockyer Valley in Southern Queensland (Figure 12);
- Mt McLaren district of Central Queensland (Figure 13); and
- Gowrie and Oakey Creek Valleys in the Central Darling Downs just east of Oakey (Figure 14).

The traverses were selected to cover important cropping areas of Queensland that incorporate a diversity of soils and criteria levels. Transects were built in a Geographic Information System using soil mapping, topographic maps and satellite imagery.

The soil mapping data were extracted for each transect and overlaid on satellite imagery. A long section was created using available topographic information for each transect. Soil descriptions and chemical properties relevant to the criteria were then added from both published and unpublished data sets. In many cases the data are from similar soils but sampled and described elsewhere. For these reasons the long sections are a representation of the application of the framework and not necessarily a precise assessment of the lands covered by the transects.

Table 2. Summary of the draft SCL criteria as used in the technical assessment

Criteria	Measure	Method for a Standard Site	Zone			
			Western Crop.	Coastal Qld.	Wet Tropics	Granite Belt
1. Slope	Maximum slope for agricultural purposes in region	Measured using a clinometer (pp.18-19 from The National Committee on Soil and Terrain 2009). or equivalent	<3%	<5%	<5%	<5%
2. Rockiness	Dominant rock size and abundance	Use abundance charts and tape measure (pp.139-144 from The National Committee on Soil and Terrain 2009). Or equivalent methodologies	<20% for rocks >60mm diameter	<20% for rocks >60mm diameter	<20% for rocks >60mm diameter	<20% for rocks >60mm diameter
3. Gilgai microrelief	Depth of gilgai depressions	Gilgai microrelief measured with string and tape measure (pp.129-133 from The National Committee on Soil and Terrain 2009)	<50% covered by gilgai depressions of >300mm in depth	<50% covered by gilgai depressions of >300mm in depth	<50% covered by gilgai depressions of >300mm in depth	<50% covered by gilgai depressions of >300mm in depth
4. Soil physical properties	Surface structural units	Surface horizons with a natural structure grade of Strong and Ped Size >10mm (pp.171-181 from The National Committee on Soil and Terrain 2009)	Ped Size <10mm	Ped Size <10mm	Ped Size <10mm	Ped Size <10mm
5. Wetness	Drainage	Estimated from landscape position, soil permeability, soil wetness features (soil water status, gley colours, rusty mottles, etc) and observed duration of saturation after rain (pp.202-204 from The National Committee on Soil and Terrain 2009)	Not Very Poorly Drained or Poorly Drained	Not Very Poorly Drained or Poorly Drained	Not Very Poorly Drained or Poorly Drained	Not Very Poorly Drained soils
6. Soil depth	Depth to a physical barrier (hard R horizons, hard pan or gravel layer). For Western Areas, an additional criteria of depth to a strongly sodic soil with an exchangeable sodium percentage of >15% applies.	For R horizons (bedrock -p151 from The National Committee on Soil and Terrain 2009). For pans (pp.192-195 from The National Committee on Soil and Terrain 2009). For exchangeable sodium percentage, a sample of soil is analysed (methods of analysis vary according to soil type - see Chapter 15 Rayment & Lyons 2011)	>500mm	>500mm	>500mm	>300mm
7. Soil pH	A sample is tested with pH colour indicator fluid and barium sulfate or in the lab with a pH electrode	Field pH kit based on the method of Raupach and Tucker (p.198 from The National Committee on Soil and Terrain 2009). Alternatively a sample of soil	pH ≥5 within 300mm of the soil surface	pH ≥4.5 within 300mm of the soil surface	pH ≥4.5 within 300mm of the soil surface	pH ≥4.5 within 300mm of the soil surface

Criteria	Measure	Method for a Standard Site	Zone			
			Western Crop.	Coastal Qld.	Wet Tropics	Granite Belt
		is measured using a 1:5 soil water dilution (Method 4A1).				
8. Salinity	Chloride content (Western Areas) or electrical conductivity (Granite Belt, Coastal Queensland and Wet Tropics)	For chloride content a sample of soil is measured using acceptable methods (Methods 5A1- 5A4 are acceptable). For electrical conductivity a sample of soil is measured using lab method 4A1. See Rayment and Lyons (2011).	Chloride content < 1500 mg/kg within 600mm of the soil surface	EC <1 dS/m within 300mm of the soil surface	EC <1 dS/m within 300mm of the soil surface	EC <1 dS/m within 300mm of the soil surface
9. Soil water storage	The amount of plant available water to 1m or soil depth, which ever is shallower. Calculate by the difference of water potential 33 kPa (1/3 bar) and 1500 kPa (15 bar). In the Wet Tropics and Mackay 10 kPa should be substituted for 33 kPa	Estimated from available site data	≥100mm	≥100mm	≥50mm	≥25mm

The methods are based on National standards of assessment and are referenced below:

McKenzie, N., Coughlan, K. and Cresswell, H. (2002). Soil Physical Measurement and Interpretation for Land Evaluation.
Rayment GR. and Lyons DJ (2011). Soil Chemical methods - Australasia. CSIRO
The National Committee on Soils and Terrain (2009). Australian Soil and Land Survey Field Handbook. Third edition, CSIRO Publishing, Melbourne.

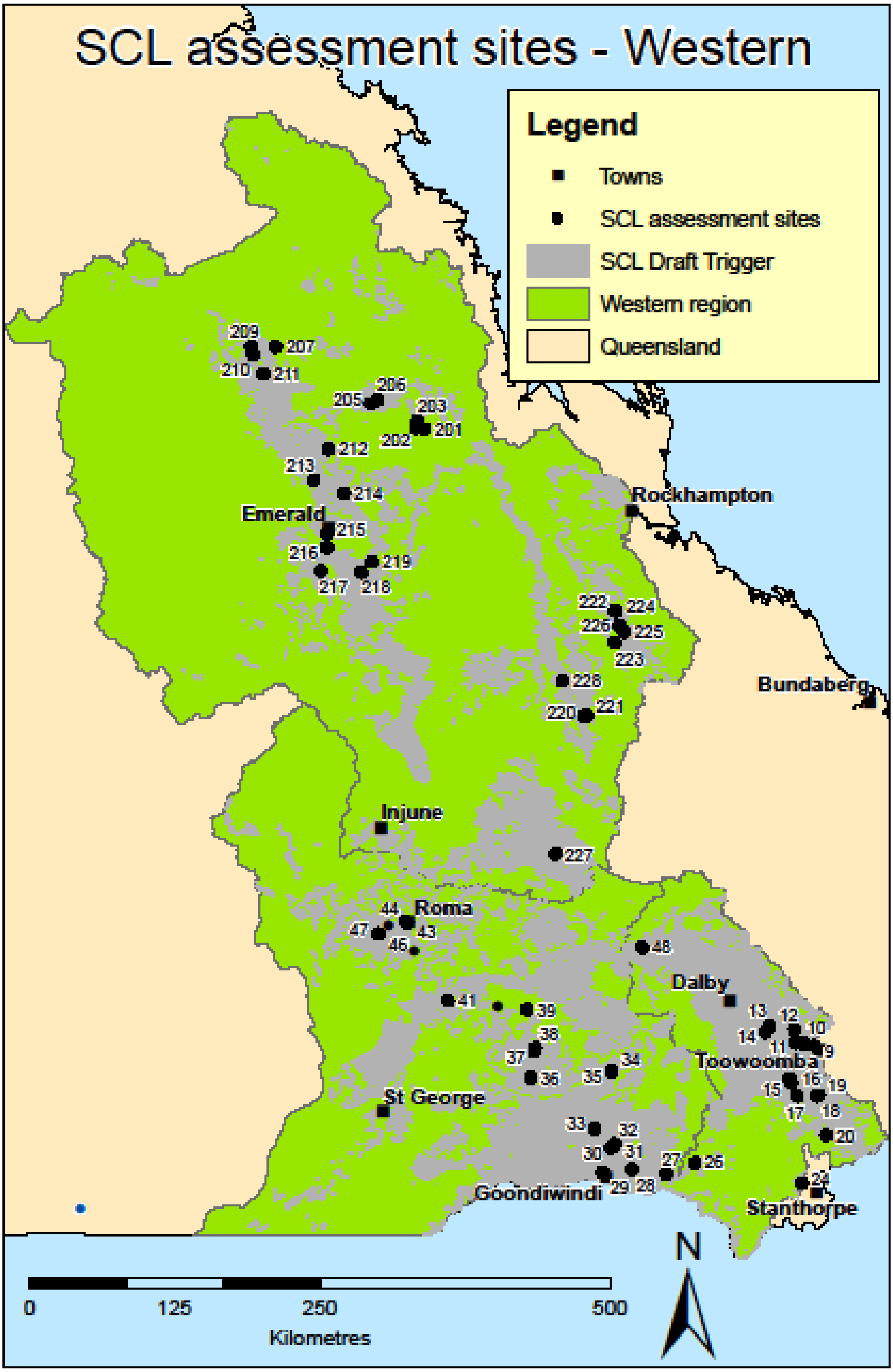

Figure 1: Location of sites assessed in the Western Cropping zone

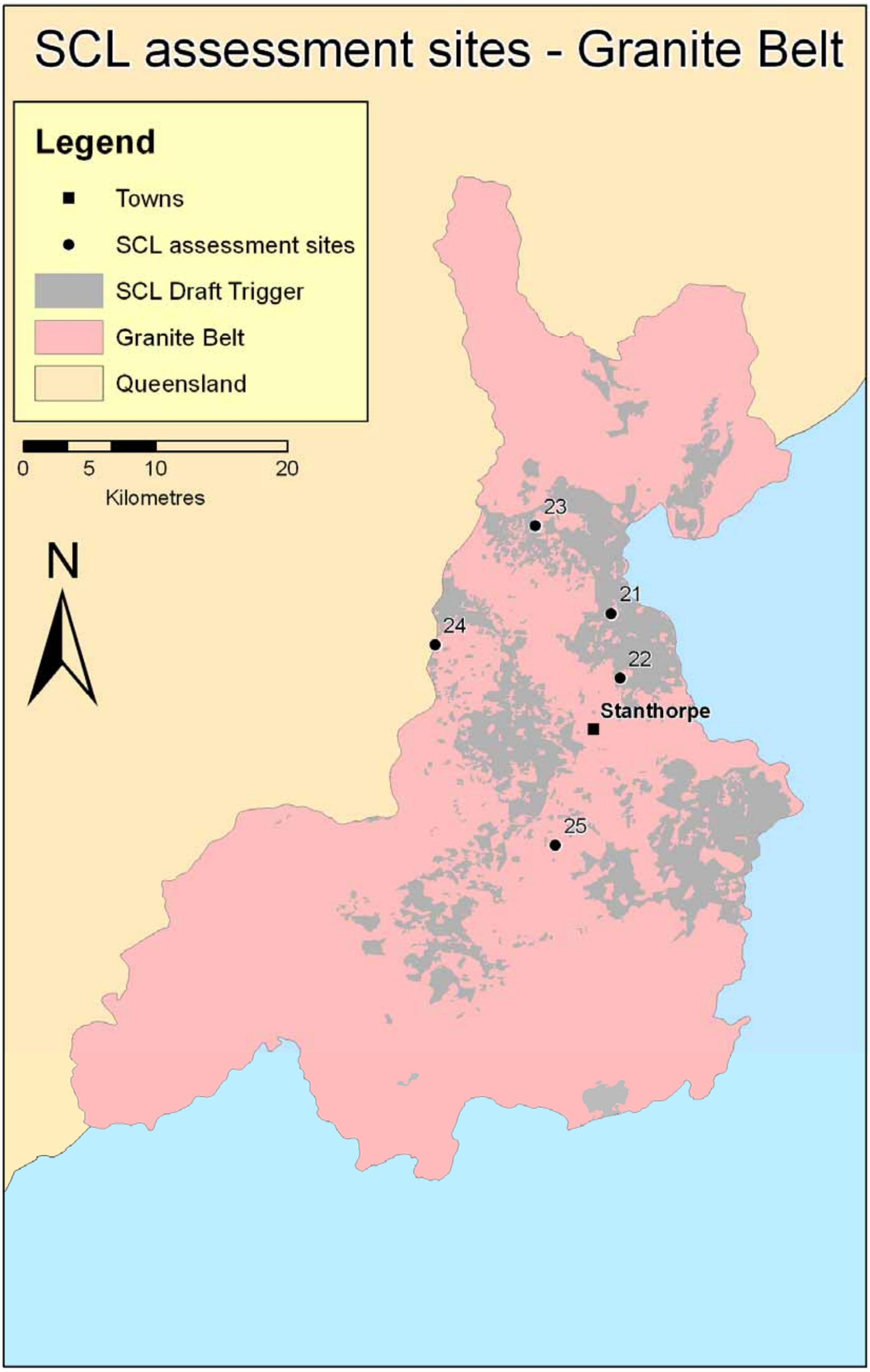

Figure 2: Location of sites assessed in the Granite Belt zone.

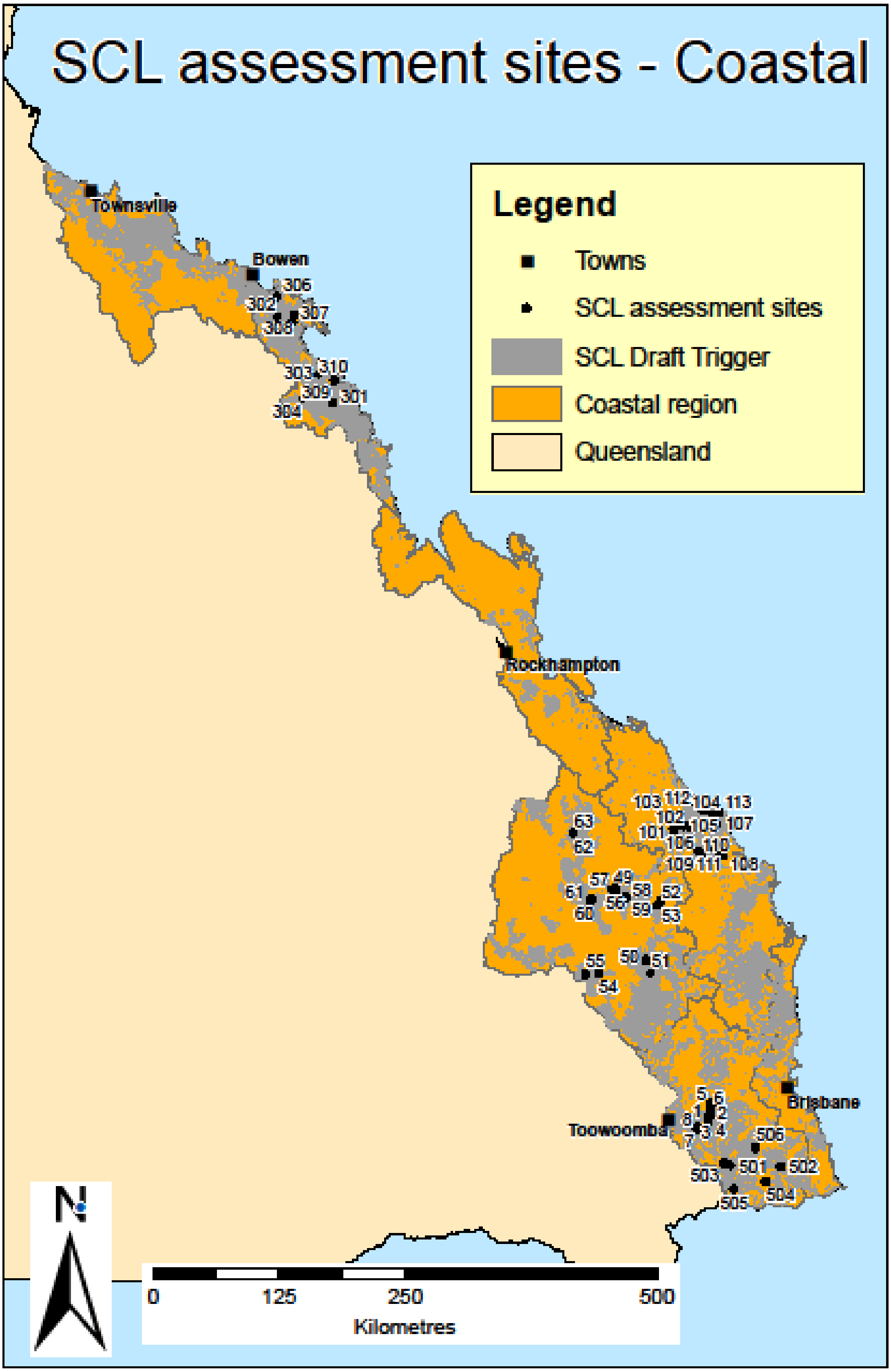

Figure 3: Location of sites assessed in the Coastal Queensland zone.

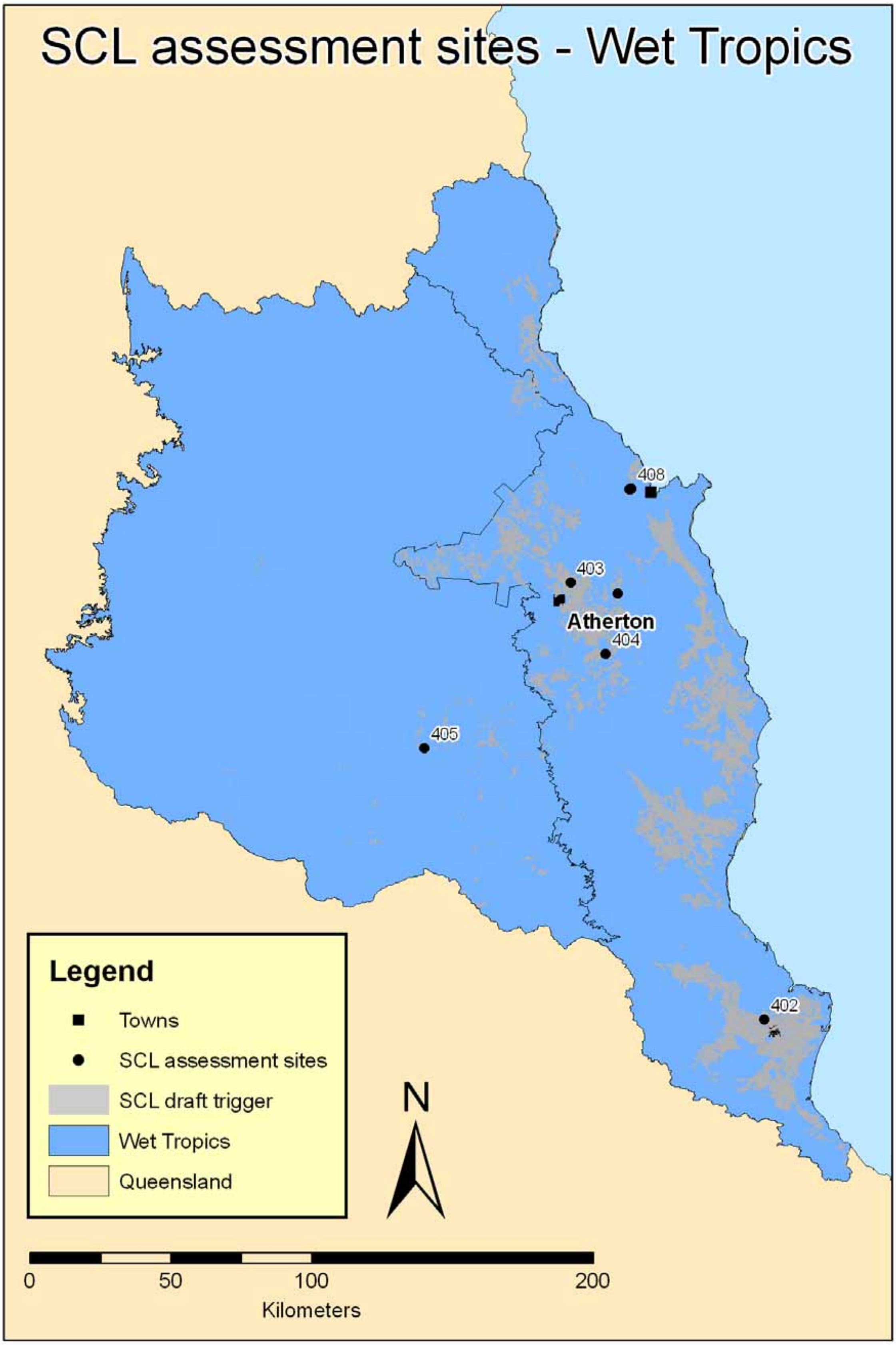

Figure 4: Location of sites assessed in the Wet Tropics zone.

Results

Assessment of draft SCL criteria

Field officers undertaking this assessment had extensive discussions about how to apply the draft criteria consistently within, and between, SCL zones. These discussions were focussed on ensuring that robust soil science was incorporated into the criteria that could clearly and cost-effectively define Queensland's best cropping land.

The sections below detail the key discussion points raised for each criterion during the assessment, before providing a summary of the key recommendations and the potential implications of adopting the recommendations. The recommendations are summarised in Table 5, with a full outline of these recommended criteria for each SCL zone provided in Appendix 3.

Criterion 1: Slope

Slope is an impediment to cropping, with increasing limitations with higher slopes due to soil erosion and the operation of machinery.. Slope was found to be a useful criterion for initially separating soils that are clearly not SCL from the better quality cropping land. Slope is a "stable" physical feature that is only modified by agricultural practices in exceptional circumstances.

Slope values that are clearly above or below the threshold value can confidently be used to designate land as SCL or not SCL. Simple slope measuring instruments such as a clinometer or abney level are generally accurate to ± 1%. Consequently for sites and landscapes with slopes that are close to the threshold (within 1%) more accurate instruments/techniques may be needed (e.g. tripod and staff, dumpy levels, precise tape measurements of distance and height). The accuracy and use of various slope measurement techniques will require detailed explanation in the supporting guidelines.

The selection of sites on a parcel of land needs to be sufficient to cover the full variation in slope and to estimate the most common slopes present. For example, the face of a contour bank or irrigation channel may be steep, but not representative of the median slope of an area. The supporting guidelines need to set out how slope is measured at a site.

The assessment identified a number of sites on the eastern Darling Downs where long term and highly productive cropping is practised, which would be excluded from SCL solely on the basis of a maximum 3% slope limit. This had the effect that, at these sites, a single cropping system located on soils with relatively uniform characteristics would be separated as partially SCL and partially not SCL on the basis of the slope threshold alone. During field assessment these issues were discussed and a range of factors were found to be significant in formulating a relevant recommendation. These factors include:

- The more reliable rainfall patterns in the eastern Darling Downs mean that conservation cropping practices can provide greater protection against run-off by maintaining more ground cover. This results in more water entering the soil with each rainfall event than occurs in the western Darling Downs. The field evaluation confirmed that in the lower rainfall areas to the west (e.g. the rolling downs country of Roma), slopes of greater than 3% were less intensively cropped.
- Whilst the type and intensity of soil conservation practises does increase with increasing slope in western areas, this does not appear to preclude soils from being cropped up to the 5% level in the eastern Darling Downs.
- It was found that soils of over 5% slope were less consistently used in the eastern Darling Downs, however, it is also likely that other soil features identified

by other criteria may well be contributing to this (for example shallower soils, increased rockiness).

In light of these findings, it is recommended that the eastern Darling Downs be defined as a separate zone to the Western Cropping zone, with the new zone having a slope threshold of 5%.

A broad-scale analysis using a Digital Elevation Model (DEM) indicated that increasing the slope threshold in the Eastern Darling Downs would result in an estimated additional area of approximately 100,000 hectares of SCL assuming that slope was the only differentiating criteria.

The threshold value for red horticultural soils was also identified as an issue and is considered in a separate section, below, as it requires consideration of multiple criteria (refer to section titled Red Horticultural Soils).

Application of the draft slope criteria threshold excluded 19 sites. Under the proposed criteria threshold, the number of sites excluded on slope grounds declined to 13. These changes resulted from the establishment of the Eastern Darling Downs zone as a separate zone to the Western Cropping zone and the proposed definition of slope thresholds be specified as 'equal to or less than' rather than 'less than' for clarity of field definition.

Recommendations

1. Retain the slope criterion.
2. Establish an additional 'Eastern Darling Downs' zone based on the thresholds for the Western Cropping Zone but raising the slope threshold for the Eastern Darling Downs to 5%.

Implications

- On the Eastern Darling Downs there are cropping systems that are often continuous from 0% to 5% and these would be fragmented if a 3% cut-off is implemented.
- A slope threshold increase from 3% to 5% for the Eastern Darling Downs increases the number of SCL zones to five with the establishment of an additional SCL zone boundary that represents these sloping lands. The boundaries of the new Eastern Darling Downs zones have been established (see Figure 11).

Criterion 2 – Rockiness

Rockiness is an impediment to cropping (for example, through damage to cultivation equipment) that increases in severity as the abundance and size of the rock fragments increase. Though stone picking can remove loose rock fragments, there is an economic and physical limit to this practice.

Rockiness is an easily observed feature that can be modified to some extent by stone picking (see Figure 5) but there is a level at which rockiness will remain as a permanent impediment to cropping.

The site assessment identified only one site which failed the draft and proposed criteria. Although not a major SCL discriminator for this assessment, field evidence suggests it will be useful in preventing substantial areas of stony lands with low cropping potential from being defined as SCL. Localities near assessment sites where rockiness is a potential constraint include the Granite Belt (site 24), Bundaberg (site 101), central Queensland (sites 217, 221, 223), Mackay (sites 309, 310) and Coalstoun Lakes (site 52).

Figure 5: Rock-picked land at Coalstoun Lakes

The rockiness criterion was found to be consistent across regions as its impact is not related to climate or other soil factors. The threshold was found to be appropriate to define the SCL resource in all zones. For clarity of field definition using the standard rock density charts in Australian Soil and Land Survey Field Handbook (The National Committee on Soil and Terrain 2009), it is recommended that the rock density be 'equal to or less than' rather than 'less than'.

Recommendations

3. Retain the rockiness criterion and threshold.

Criterion 3 – Gilgai microrelief

Gilgai microrelief is a readily recognisable feature, and as an SCL criterion is intended to cater for the impacts on agricultural practices caused by gilgai microrelief in soils that shrink and swell with changing water content. Such soils are usually described as Vertosols or cracking clay soils. Gilgai microrelief ranges in type (e.g. crabhole gilgai, linear and melonhole gilgai) and severity (i.e. the size and depth of the gilgai depressions). It is often referred to as 'gilgai' or 'gilgai microrelief'.

Gilgai microrelief can be ameliorated by blade ploughing, laser levelling and continuous cultivation. However microrelief can re-form over time following the amelioration work. Amelioration is generally regarded to be uneconomical and therefore not attempted where the microrelief is most severe.

Site assessment found 26 sites clearly exhibited gilgai microrelief, of which four failed the draft threshold and three failed the proposed SCL threshold (i.e. sites 34, 35 and 208). Minor gilgai microrelief was observed at other sites (e.g. site 2 in the Lockyer Valley) however these were not a significant impediment to cropping activities and can be mechanically removed permanently (i.e. they do not readily re-form).

Strong gilgai microrelief of 500mm or deeper is commonly associated with wetter areas or with soils containing elevated salinity and sodicity levels (Isbell 1962, Webb *et al.* 1977, McKenzie *et al* 2004). Such soils have limited cropping potential (see Figure 6) and were most commonly encountered in the Western Cropping zone (e.g. severe melonhole gilgai in the Tara - Meandarra area). This was the only zone where cropping failure was observed due to gilgai microrelief. Severe gilgai microrelief is less common in other SCL zones, although examples have been documented in the Rockhampton and Inland Burnett areas.

Figure 6: Severe melonhole gilgai microrelief near Moonie (Western Cropping zone) with a vertical interval of approximately 1.8m (Site no. 34)

Based on combined field experience and cropping observations throughout the State, the assessment team concluded that most gilgai microrelief with a vertical interval of:

- between 300 and 500 mm - can be very productive cropping soils after levelling, and typically will not re-form after levelling; but
- greater than 500 mm would generally fail on other SCL criteria such as salinity or wetness following rain due to ponded water, and typically will re-form after levelling.

It was agreed that as gilgai microrelief is a simple and cost effective feature to identify, the criterion should be retained in its current form but that the vertical interval threshold be increased from 300 mm to 500 mm. This will also ensure that areas of strong gilgai microrelief are definitely excluded from SCL if no other criteria prove to be discriminating.

Recommendations

4. Retain the gilgai microrelief criterion.
5. Raise the threshold to 500 mm vertical interval.

Implications

- Retaining the existing criterion with a revised threshold provides an effective and cost efficient way of excluding areas that do not meet the requirements of SCL.

Criterion 4 – Soil physical properties

This criterion refers to the natural structural units of the surface soil, and was intended to apply only to non-rigid Vertosol soils (cracking clay soils) that are self-mulching. 'Self-mulching' refers to the small stable, though loose, surface aggregates that often occur where the surface soil of Vertosols is subjected to repeated wetting and drying. Extensive areas of the best cropping soils in Queensland have this feature, and it generally provides an attractive and friable seedbed with good soil seed contact for fine-seeded crops. However, some Vertosols have a very coarse surface-mulch that makes them unsuitable for a wide range of crops. This limitation provided the rationale for including 'soil physical properties' in the draft SCL criteria.

The wording of the draft criteria resulted in this criterion being unintentionally applied to all soil types. This led to potential misinterpretation of the threshold value and a decision was made to only apply this criterion to cracking clay soils (Vertosols), consistent with the intent of the criterion.

Surface soil structure is a difficult criterion to practically and reliably apply as it can be readily modified by soil management practices (cultivation, compaction and smearing) as well as by soil moisture content caused by antecedent rainfall or irrigation. Soil structure changes according to the moisture content of the soil make consistent recognition of the size threshold difficult. In addition, there can be confusion between natural surface aggregates and 'clods' of soil formed by cultivation.

For this reason, 'soil physical properties' was regarded as an unstable and unreliable SCL criterion. The assessment team concluded that there is no viable means of expressing the intent of the criterion in a definitive and consistent manner. It was therefore concluded that soil structure should be removed as a criterion in all zones.

Recommendation

6. Remove the soil physical properties criterion.

Implications

- The SCL assessment process would be improved as this criterion would be problematic to reliably and consistently implement.
- There will only be a minor impact on the extent of SCL, as the Vertosols with a very coarse surface mulch often have subsoil features such as elevated sodicity or reduced soil water storage that will cause them to fail on other SCL criteria.

Criterion 5 – Soil depth

Soil depth was found to be a useful discriminating criterion for initially separating soils that are clearly not SCL from better quality cropping land. Soil depth was also found to be a stable feature to measure as it generally does not change with standard agricultural management practices and would only be modified by excessive soil erosion.

The draft SCL criteria incorporated exchangeable sodium percentage (ESP) in the soil depth criterion for the Western Cropping zone, although this was intended for rigid soils only (i.e. those soils that don't crack or shrink-swell). The ESP sub-criterion (on rigid soils) was observed to be a strong discriminator of SCL with several sites exceeding the defined threshold. ESP was initially included in the soil depth criterion as it can reduce the size of the root zone, even though depth to any physical barrier may be much greater. However, the assessment team agreed that it would be better to place ESP as a sub-criterion with soil water storage (Criterion 9) where its effect on the root zone (rooting depth) is more appropriate. In addition, ESP can only be accurately determined by a relatively expensive laboratory test. Shifting ESP to

Criterion 9 achieves the same overall outcome of excluding poorer quality soils, with the advantages of better reflecting the effect of ESP on crop growth and reducing assessment cost.

Consideration was given as to whether the presence of 'weathered rock' should be included as part of the definition of soil depth. As opposed to hard rock, weathered rock is generally soft rock that can be dug with hand tools, at least when wet. Weathered rock is generally regarded as a limiting factor for the roots of crop plants (e.g. at site 5 where roots were not observed to penetrate the weathered rock).

It was agreed that weathered rock was an important part of the soil depth criterion as it is clearly observable, and was generally considered to effectively exclude areas of lower productivity (for example, sites 505 and 506). The assessment team believe that including weathered rock as a limitation in the soil depth criterion would result in a small net reduction in the area of SCL. This is supported by the transect analysis of the Oakey/Gowrie valleys in the Eastern Darling Downs.

One minor issue that was identified at site 23 in the Granite Belt was where raised beds (or mounds and furrow) are being used for cropping. As the soil depth in furrows would be a shallower depth than the mounds, this may affect the consistent assessment of this criterion. It was agreed that averaging the depth between the mound and furrow would be a way of reaching a consistent conclusion, albeit with a small increase in assessment requirements for these situations. It is appropriate that this matter is addressed in the supporting guidelines.

Some consideration was given to whether the soil depth criterion should be excluded as a standalone criterion, and instead included in the soil water storage criterion (Criterion 9) to consider all plant-root limiting features in a single criterion. However this would remove the value of assessing the relatively simple soil depth criterion that can be done before the need for more expensive soil tests. However, it was agreed by the assessment team that an adjustment of the soil depth threshold was warranted to make soil depth more consistent with other SCL criteria where testing is done at 600 mm soil depth.

Recommendations

7. Retain the soil depth criterion.
8. Adjust the soil depth threshold for all the zones to 600mm for more consistency with other criteria.
9. Remove ESP from the definition of soil depth.
10. Include weathered rock in the definition of soil depth.

Implications

- Retaining the soil depth criterion provides a simple and cost-effective means of excluding sites that would ultimately fail the soil water storage criterion.
- Moving the ESP component from the soil depth criterion to the soil water storage criterion allows for a simple and more cost-effective exclusion of shallow soils earlier in the SCL assessment process. This avoids the need for expensive ESP analysis early in the criteria, but ensures these sodic soils are still excluded as SCL. The result of this ESP change is a more efficient criteria structure but with no nett change in the total area of SCL.
- The inclusion of weathered rock as a component of soil depth effectively removes some poorer quality cropping soils while retaining better quality cropping land as SCL.
- The changes to this criterion resulted in the number of sites failing the soil depth criteria fell from 13 (based on the draft criterion thresholds) to 5 (using the proposed

criterion thresholds). However, these soils are still excluded in the revised soil water storage criterion in the proposed criteria.

- Changing the threshold to 600 mm for all SCL zones will have no impact on the total area of SCL in all zones, with the exception of the Granite Belt where the total area of SCL is reduced. This consistent soil depth of 600 mm deep is considered appropriate as it is the minimum depth of soil that will pass the soil water storage criterion.
- Cropping soils in the Granite Belt range from 250 mm to >1000 mm deep. Therefore 600mm is considered to be a mid-range for the best cropping soils.

Criterion 6 – Soil wetness

Soil wetness is a measure of poor drainage that is generally associated with low lying landscape positions. Although soil wetness occurs in relatively small areas, it is an effective criterion as it excludes areas that cannot be productively cropped.

In the draft SCL criteria, soil wetness was defined in terms of the site being 'poorly drained' and/or 'very poorly drained'. These categories are described in terms of both general site drainage characteristics as well as soil profile indicators such as mottling and gley colours (National Committee on Soil and Terrain, 2009).

The site assessments illustrated that these descriptors are generally appropriate tools for SCL determination of the soil wetness criterion. However, it was observed that the negative construction of the definition (for example, 'the soil is not poorly drained') was adding confusion. Further, there was also potential for confusion of the terms 'poorly drained' and 'very poorly drained', which are long-standing and established definitions in the Australian Soil and Land Survey Handbook (National Committee on Soil and Terrain, 2009). These factors highlighted potential advantages in using different terminology that was distinctly different and phrased in a positive manner.

A total of 19 sites failed the draft wetness thresholds based on the Australian Soil and Land Survey Handbook definitions. The changes to the definitions resulted in 16 sites failing under the proposed thresholds. Most sites failed on the presence of mottling in the subsoils, however, some sites (e.g. sites 29, 302) failed because of the presence of a conspicuous bleach.

The assessment team debated whether the bleach sub-criterion should be retained as part of the definition of soil wetness. A clear anomaly was observed in the Granite Belt zone, where many soils derived from granite have a bleached soil colour but may actually be well drained in the Granite Belt zone only. The definitions of soil wetness therefore need to be refined. In terms of the presence of a conspicuous bleach, this could involve either:

- removal of the bleach requirement for all soils that do not have a clay subsoil within one metre of the soil surface or
- only use bleach as part of the criterion where it does not directly overlie rock or weathered rock.

As there may be limited information on the period of waterlogging at most locations, soil colour parameters are considered preferable to use as indicators for the soil wetness criterion. For this reason, the assessment team recommends that reference to the period of waterlogging are removed.

Soil wetness may also have characteristic vegetation indicators (see Figure 7) or landscape indicators (see Figure 8), and can be associated with expressions of dryland salinity (e.g. saline seeps). However, in many situations (such as a cultivated paddock) these supplementary indicators are not available or not obvious (see Figure 9). There was some discussion as to whether these should be included in the soil wetness criterion. The benefit of incorporating landscape and vegetation indicators is that they may negate the need for soil cores to be taken and therefore expedite assessment in these instances. However, objective landscape indicators that consistently delineate poor and very poor drainage cannot be clearly defined or described. Further, the inclusion of vegetation indicators would introduce botanical identification requirements into a soil assessment framework, and vegetation indicators can change significantly over time and with different management practices.

On balance, the inclusion of such indicators in the criteria cannot be supported; nonetheless in some circumstances these indicators may be useful in the initial mapping of soil units prior to sampling against the criteria, and this warrants consideration in the accompanying guidelines. Landscape and vegetation information may also be useful as supporting information for soil colours and use of such information should be considered in the guidelines.

Figure 7: Backswamp depression in the Lockyer Valley with indicator vegetation of rushes (Site no. 4)

Figure 8: Soil wetness and salinity (Site no. 17) associated with a narrow constriction of alluvia on the Eastern Darling Downs

Figure 9: An area (Site no. 47) with few vegetation or landscape indicators of wetness; however, soil-based wetness indicators and cropping limitations are evident.

Recommendations

11. Retain the soil wetness criterion.
12. Rely solely on soil colour as indicators of the wetness criterion and amend the soil colour definitions to address issues with using bleach.
13. Restructure the definitions to positive statements (i.e. to avoid the term 'not poorly drained', etc); and replace the term 'poorly drained' with 'favourable drainage', and the term 'very poorly drained' with 'satisfactory drainage'.
14. Incorporate into the guidelines when and how vegetation and landscape indicators might be used for initial identification of possible wet areas and to support the diagnostic attributes of soil colour.

Implications

- The assessment team consider that the amendments to this criterion improve the accuracy and reliability with which this criterion is applied.

Criterion 7 – Soil pH

pH is widely accepted to be an important soil property that affects the utilisation of soil for a range of cropping purposes.

Strongly acid soils are not common in the Western Cropping zone where only one site (site 12) was excluded on the basis of this criterion. However, strongly and extremely acid soils are more common in the other SCL zones where the soils tend to be more naturally acidic and poorly buffered. In the other SCL zones, nine sites had pH ≤ 5 and of these three sites had pH <4.5 within 300 mm of the surface.

The draft criteria specified that the threshold value of pH occurred anywhere within the top 300 mm of soil. However, soil pH close to the soil surface can be readily modified by standard agricultural practices e.g. liming of acid soils and the Soil pH criterion is potentially unstable if applied within this affected layer. The assessment found that that it would be preferable to consider the pH at an actual depth (i.e. 300 mm) as the key objective of applying the pH criterion is to address subsoil acidification as a source of toxicity and impediment to root proliferation. Furthermore, limiting measurement to an appropriate depth below the surface places it in a zone less susceptible to change by agricultural treatments (e.g. liming).

Highly sodic soils have major physical, soil water and nutritional problems and can be generally identified by high pH values or alkalinity. Measuring pH is relatively simple and will be required in most cases, so addition of an alkaline threshold is useful as a means to exclude unsuitable soils. By considering the soil pH at two depths (300mm and 600mm) it provides important information on both pH trends and rooting depth limitations. If the soil is less than pH 5.0 at 300 mm then some restriction in root zone depth would be expected. From the knowledge and expert opinions of the assessment team, and in discussion with the external reviewer, the following soil pH threshold values are recommended:

i. Soil acidity - for non-rigid soils, the soil pH at 300 mm and 600 mm soil depth must be greater than pH 5.0

ii. Soil acidity and alkalinity - for rigid soils, the soil pH at 300mm and 600mm soil depth must be within the range of pH 5.1 to pH 8.9, inclusive.

The draft thresholds were found to be appropriate (at pH 5.0) in the Western Cropping zone but considered to be too low (at pH 4.5) for the other zones. A pH of 5.0 is scientifically accepted as the critical pH at which elements such as aluminium and manganese can be released from the soil in amounts toxic to plants (Slattery *et al* 1999), and is therefore recommended as the threshold for all zones.

Recommendations

15. Retain the soil pH criterion.
16. Require measurements of soil pH at two depths – 300mm and 600mm.
17. Change the soil acidity threshold level of pH >5.0 at 300 mm and 600 mm soil depth for all soil types in all zones.
18. Incorporate a soil alkalinity threshold level of pH 8.9 (measured at both 300 and 600 mm soil depth) for rigid soils in all zones.

Implications

- These changes resulted in an increase in the number of sites failing the criterion from 2 sites to 15 sites, most of which are soils that become strongly acid below 300 mm.
- Changing the definition to pH >5.0 at 300 mm soil depth more accurately reflects the knowledge of soil acidity impacts on agricultural performance. The change will potentially result in a slight increase in the total area of SCL.
- Incorporating an alkalinity threshold for rigid soils is an efficient means of excluding unsuitable soils.

Criterion 8 – Salinity

Soil salinity refers to the presence of soluble salts in the soil profile. Saline soils are those soils which have sufficient levels of salt in the root zone to adversely affect plant growth.

Two common methods of measuring soil salinity are:

i. the electrical conductivity of a 1:5 soil/water suspension ($EC_{1:5}$), measured in dS/m and
ii. the concentration of soluble chloride (Cl) – one of the component salts – in a 1:5 soil/water solution, measured in mg/kg.

One of the problems in using $EC_{1:5}$ as an indicator of soil salinity is that all soluble salts, including gypsum, are detected in the soil solution. Whilst existing predominantly in soil as crystals, gypsum readily dissolves when soil is diluted with water in the laboratory resulting in inflated $EC_{1:5}$ measurements. For this reason, it has been found that chloride concentration is a preferable indicator of salinity in areas where gypsum may be present (i.e. in the Western Cropping zone and new Eastern Darling Downs zone). In addition, recent research (Dang *et al*., 2008) has shown that chloride concentration is a better indicator of subsoil constraints to the growth of grain crops which predominate in western areas. Chloride is an easily measured surrogate of salinity, but is not the only parameter that restricts plant root growth.

Measuring the electrical conductivity of a soil 'saturation extract' (EC_{se}) is another way of reducing the influence of gypsum associated with $EC_{1:5}$ measurements. However, a saturation extract method is a more costly and complicated laboratory method.

The technical assessment illustrated that soil salinity is an effective discriminator of SCL (using chloride concentration in the Western Cropping zone and electrical conductivity in all other zones). However, it was found that the chloride concentration threshold used for the Western Cropping zone was set too high, which meant that only the most extremely saline sites were being excluded from SCL. It became clear that the threshold needed to be lowered substantially from 1500 mg/kg to 800 mg/kg, which is consistent with levels of subsoil chloride quoted in the literature that reduce soil water extraction by plants (Dang *et. al* 2008), This level of chloride equates to an electrical conductivity of 0.56 dS/m, however the use of electrical conductivity ($EC_{1:5}$) as an indicator of salinity in the Western Zone is not preferred because of the potential effect of gypsum in these soils.

The electrical conductivity threshold (for other zones) was also found to be too high, and it was concluded that the draft criteria threshold of 1.0 dS/m should be lowered to 0.56 dS/m. This critical level of ($EC_{1:5}$) is consistent with the equivalent level of chloride recommended above for the Western Cropping Zone and also consistent with the recommendations for moderate salinity effects in clay soils (Salinity Management Handbook [Salcon 1997] and other literature).

Salinity levels lower than this threshold value will have greater effects in sandy soils. However, elevated salinity levels in non-clay textured soils are relatively uncommon in Queensland and are normally restricted to coastal environments with marine influences or to areas of secondary salinisation/salt scalding in inland areas. Such areas are highly likely to fail other criteria (e.g. wetness), which negates the need for imposing a different salinity level for these sandy soils.

In addition, the depth at which the electrical conductivity criterion is applied (300 mm) was deemed to be too shallow. It is recommended that the depth be increased to 600 mm (which then becomes a common depth for the salinity criteria for all zones). In fact, the electrical conductivity criterion as it stood in the draft criteria did not exclude any of the assessed sites from SCL. Preliminary analysis of the assessed sites using the revised thresholds for salinity indicates that reducing the chloride concentration would result in four sites in the Western Cropping zone changing from SCL to non-SCL status.

Other options for the salinity criterion discussed by the assessment team included whether salinity is averaged over the designated depth (in 100 mm increments) or simply relates to a maximum value observed anywhere within that 600 mm depth. It was considered that the presence of soluble salts occurring anywhere with the designated depth at the threshold level will affect plant production and so this has been adopted as the method for assessment.

The field assessment confirmed the importance of the salinity criterion not applying to a treed (uncleared) landscape where natural salinity levels are often high. This is because salts are soluble and move down the soil profile when more water is allowed to enter the soil after the removal of trees. A number of studies investigating land use change have established that the clearing of trees for cropping leads to the flushing of salts further down the soil profile. References that have measured or modelled this flushing effect in Queensland include the Brigalow Catchment Study (Thorburn *et al.* 1991) and deep drainage studies in the Queensland Murray Darling Basin (Tolmie and Silburn, 2004; Tolmie *et al.* 2004; Yee Yet and Silburn, 2003).

As a consequence of this, the guidelines need to explicitly state that sampling sites must be located in cleared landscapes to ensure salinity measurements reflect the actual crop growing conditions.

Recommendations

19. Retain the salinity criterion
20. Lower the chloride threshold in the Western Cropping zone (and new Eastern Darling Downs zone) to 800 mg/kg
21. Lower the electrical conductivity threshold (where it applies) to 0.56 dS/m
22. Adjust the electrical conductivity threshold (where it applies) to take effect over 600 mm soil depth
23. Clearly specify in the guidelines the method for assessing the threshold values and the need to locate sampling sites to cleared areas.

Implications

- The changes to the salinity criterion resulted in 18 sites failing the threshold, compared to 6 in the draft threshold, with most of these sites being in the Western zone.
- Lowering the salinity thresholds for both chloride and electrical conductivity will reduce the area of land defined as SCL.
- Applying the threshold to take effect within the upper 600 mm of the soil would also reduce the area of land defined as SCL.

Criterion 9 – Soil Water Storage

Under dryland conditions, moisture availability for crop production is dependent on incident rainfall and a soil's ability to store some of the rainfall for later use by plants. Not all water stored in a soil can be extracted by plant roots. Within a particular rainfall regime, moisture availability is assessed in terms of soil's water storage capacity, which is an estimate of the proportion of total water stored in a soil that is available for plant use. For the purposes of this document and the proposed criteria, the term soil water storage is used.

Soil water storage is expressed in a fashion similar to rainfall, i.e. millimetres (mm) of water in the soil to a specified depth. The amount of water that can be stored in a particular soil depends on the properties of the soil profile (e.g. texture, structure, bulk density, clay type). As soil properties change with depth, the soil water storage is determined at specified depth increments down the profile or for each distinctive soil layer. These values are then summed to derive soil water storage for the root zone.

There are various options (ordered from simple to complex) for determining the soil water storage at a specified depth or for a particular soil layer:

1. Estimate soil water storage based simply on the texture of the soil profile. During the course of the field assessment, a soil texture-based look-up table (Table 3) was developed to provide an approximate yet simple assessment of the soil water storage. The look-up table lists the estimated amount of water expected to be stored in each 100 mm increment of the rooting depth of soil for different field texture groups, to a maximum depth of 1000 mm.
2. Use an algorithm to calculate soil water storage based on soil physical properties derived from standard laboratory measurements (such as clay, sand and 1500 kPa moisture content). While various regression algorithms have been developed in Australia for this purpose, for Queensland the most relevant algorithm is the Plant Available Water Capacity Estimation Routine (PAWCER) developed by Littleboy (1997) and also described in Littleboy (2002). PAWCER is a modification of the functions derived by Shaw and Yule (1978), with significant improvements. The Shaw and Yule equations were derived from a limited dataset dominated by soils of high clay content, whereas PAWCER incorporates sand content and was tested using a wider range of soils from the cereal growing areas of Queensland and NSW. In addition, PAWCER uses an exponential function that simulates the decrease in available soil water storage with depth (as bulk density increases and root density lessens). However, to apply the algorithm in the SCL framework, the physio-chemical subsoil constraints also need to be determined to allow the soil depth over which water is extracted to be estimated. The accuracy of the PAWCER equation may be reduced when applied to soil types not included in the original derivation, such as Sodosols and Ferrosols.
3. Laboratory measurement of soil water potential of 1500 kPa (15 bar) that simulates the dry field conditions or the lower limit of stored water storage. DERM's SALI database has 1500 kPa information for many soils. The use of 10 kPa or 33 kPa soil potentials to

represent a drained upper limit of stored water in soils is not supported due to the difference between the free-drainage of in-situ soils and those disturbed by sample and laboratory preparation methods.

4. Direct measurement of soil water storage in the field, which involves wetting a small plot of soil thoroughly and then allowing it to dry out fully (usually with the growth of a crop). Moisture measurements through the soil profile are taken progressively over a period of up to six months to obtain the moisture content of the wet soil profile and dry soil profile and hence calculate soil water storage by difference. The gravimetric water content is converted to volumetric water content by multiplication of the soil bulk density down the soil profile (commonly predicted from the maximum soil water content). While this represents a reliable method for defining soil water storage, direct field measurements are costly, require an understanding of soil water movement, and are time consuming to complete. Appropriate methods for direct measurement will be outlined in the SCL Guidelines document.
5. A hybrid of Method 3 (laboratory measurement of the lower limit via 15 bar) and Method 4 (direct measurement of upper drained limit). Depending on the existing data, the drained lower limit can be determined using a laboratory measured soil water potential of 1500 kPa (Method 3), while direct measurement could be used to determine the drained upper limit (wet soil profile) for the soil. The difference between these values provides a reliable estimate of the soil water storage.

Soil water storage has been measured in the field (i.e. Method 4) for a range of soil types that are used for cropping in Queensland (e.g. Dalgliesh and Foale, 1992. updated 2002, Gardner and Coughlan 1982, Gardner et al. 1998, Bridge and Bell 1994, Buck unpublished, Shaw and Yule 1978). The field measured soil water storage shows a wide range of variability and represents differences due to the soil types examined as well as subsoil restrictions on water storage and availability. For example in strongly sodic soils and/or salty soils (commonly Sodosols and many Grey Vertosols) the roots of crop plants are unable to extract all the water that is available in the soil. However, where soil water storage assessment methods such as the PAWCER and laboratory methods do not directly account for physico-chemical constraints in the subsoil, then these method should only be used to a depth where these subsoil constraints occur.

There are a number of important soil properties involved in soil water storage and plant access to stored soil water, including both soil texture and physico-chemical properties.

Soil texture

Although physical features such as soil structure are known to modify soil water storage, soil texture is generally considered the dominant determinant that influences the capacity to store water in the profile.

In order to support the implementation of the policy and recognising some of the complexities associated with measuring soil water storage, a look-up table was derived to provide a first stage assessment of the soil water storage for a range of soils that have had their field texture determined (Table 3).

The values for soil texture classes are based on the accumulated knowledge of the assessment team and their interpretation of the available literature where measured soil water storage data are published, and the expanding database of sites where soil water storage has either been measured or estimated using laboratory data in the SALI database. The values in Table 3 are closer to the lower end of the soil water storage range for soil textures.

The look-up table was designed to allow users to estimate the water storage in the profile based on the estimated stored water expected in 100 mm increments of soil for the different soil texture groups. It provides an initial assessment of the water storage required to meet this criterion while avoiding the need for expensive laboratory testing of soils that would have insufficient soil water storage levels or that have adequate soil water storage levels. Importantly, they do not attempt to capture the range of experimentally measured soil water storage values.

The values in Table 3 were used for the site assessment of SCL as reported in Appendix 2.

Table 3: Estimated values of average soil water storage for field soil textures per 100 mm depth for field soil textures up to 1000 mm soil depth.

Soil texture	Estimated soil water storage per 100 mm of soil depth
sand; clayey sand; loamy sand	4 mm
sandy loam	5 mm
loam; silty loam; sandy clay loam	6 mm
clay loam; clay loam, sandy; silty clay loam	8 mm
light clay; light medium clay	10 mm
medium clay; medium heavy clay; heavy clay	12 mm

Note: Soil water storage is calculated by summing the millimetres of water for each 100 mm increment from the surface to a soil physico-chemical limitation, physical barrier or a depth of 1000 mm - whichever is the shallower.

It is recommended that further development of decision tools and methods be undertaken to improve the level of certainty when determining the soil water storage across a range of soil textures and soil types expected when implementing the SCL framework.

Estimation of soil water storage down a profile

Several physico-chemical attributes are known to restrict root growth. For each attribute, an accepted threshold value that should not be exceeded is recommended to determine the depth over which soil water storage is estimated. The same threshold values as used for criteria 7 (pH) and criteria 8 (Salinity) are used in the Soil Water Store criterion. These are:

- chloride level of more than 800 mg/kg in the Western Cropping zone and Eastern Darling Downs zone or
- an $EC_{1:5}$ of more than 0.56 dS/m in the Granite Belt zone, Coastal Queensland zone and Wet Tropics zone
- pH of 5.0 or less

The soil salinity threshold values are derived from the Salinity Management Handbook (Salcon 1997) and are based on the upper limit for moderately tolerant crops for 40%-60% clay soils. These are the most common soils likely to be encountered on SCL. Lighter textured soils are less commonly saline unless influenced by coastal marine conditions or outbreaks of salinity

In addition to the above thresholds, exchangeable sodium percentage and the ratio of exchangeable Ca to exchangeable Mg has been found to adversely affect the soil structure of rigid soils.

ESP is a laboratory measure of soil sodicity. The Ca:Mg ratio represents the ratio of exchangeable calcium to exchangeable magnesium. Both attributes can be determined from a single laboratory analysis of exchangeable cations. Elevated soil sodicity causes clay dispersion resulting in structural degradation and restricted penetration by water and plant roots. Very low Ca:Mg ratios have been found to cause similar degradation problems in a number of Australian soils.

ESP and Ca:Mg ratio are not applied to soils that shrink and swell with changing moisture content as similar effects on reduced water and root penetration have not been observed in these soils which have the ability to crack and reform their structure with each wetting and drying cycle.

An Exchangeable Sodium Percentage (ESP) of more than 15 or a Ca:Mg ratio 0.1 or less in rigid soils (i.e. soils that do not shrink and swell with changing moisture content) should also be used to determine the depth of soil over which Soil Water Store is calculated.

The draft threshold values of soil water storage that were assessed varied across the zones: 100 mm for the Western Cropping and Coastal Queensland zones, 50 mm for the Wet Tropics zone and 25 mm for the Granite Belt zone. The assessment found these thresholds to be generally appropriate for all zones, except the Coastal Queensland zone.

Under the draft thresholds for this criterion a significant number of high value cropping soils in the Fassifern and Lockyer Valleys would have failed. As a result the threshold value for the Coastal Queensland zone was decreased from 100 to 75mm.

Across all of the sites assessed, the changes in threshold for the coastal zone and the inclusion of physico-chemical limitations on the depth of soil water is extracted from, had minimal effect on the number of sites failing this criterion - despite the fact that anomalies such as occurred in the Coastal Zone were reduced. 52 sites failed both the draft threshold and the proposed threshold. However, it is important to note that a further 36 sites were within 15% of the threshold when Table 3 was used. Of these 36 sites, 23 had passed on all other criteria, and therefore required further testing to ascertain their SCL status.

Regardless of the method used to estimate soil water storage at a given depth or for a specific layer, calculation of the total water storage down the entire root zone should be rounded to the nearest 5 mm to accommodate the generalised nature of all soil water storage estimates.

Recommendations

24. Retain the soil water storage criterion.
25. Change the criterion name from 'moisture availability' to 'soil water storage', which removes the potential for confusion with existing soil science terminology.
26. Adopt the soil water storage look-up table (Table 3) as a method for the initial assessment of soil water storage based on field soil textures.
27. Where soil water storage of the look-up table (Table 3) is within 15% of the threshold and this is the only criterion likely to change the SCL status, then the hybrid method (Method 5) should be used to estimate the drained lower limit and drained upper limit.
28. The PAWCER tool is recommended for further development so that it can be used on full range of soil encountered in the SCL zones before it can be used in the SCL framework.

29. Reduce the soil water storage threshold for the Coastal Queensland zone from 100 mm to 75 mm.

Implications

- Adoption of the look-up table as a first stage estimate of soil water storage will simplify the process and allow a consistent and efficient identification of soils that either significantly fail or pass the criterion.
- The use of the +/- 15% discretion around the threshold value of soil water storage based on the soil texture look-up table will reduce the necessity for additional measurements for soils that are clearly below or exceed the minimum soil water for strategic cropping land.
- Provisions to allow assessors to use more detailed methods where they disagree with look-up table result, or where a soil is close to the threshold (+/- 15%), will retain rigour and reduce the potential cost of many SCL assessments.
- Until the PAWCER model is enhanced for a wider range of cropping soil types, the methods for determining the storage limits depend on either laboratory and field measurements. In particular, using field measurements to define the lower limit is costly and very time consuming, which may delay the outcomes of SCL assessments where there is a dependency on this criterion. For this reason, a combination of laboratory and field measurements (Method 5) is recommended.

Zones and zone boundaries

Granite Belt

The boundary of the Granite Belt zone was refined to better reflect the agroclimatic zone, based on the field inspections and advice from agricultural experts from the Department of Employment, Economic Development and Innovation.

The revised western boundary follows the geology/land resource boundary, which generally relates well to the climatic boundary. Areas of granite to the north-north-west of Dalveen (e.g Leslie Dam, Greymare) are excluded as their climatic regime is different. Granitic areas to the north-east of Dalveen, while not climatically identical to the central Granite Belt, are more temperate/higher rainfall than the north-western granite, and have been included. This ensures the boundary is consistent with the criteria for the high quality cropping areas in the zone.

On the eastern/southern side the zone is defined by the Queensland-NSW border. On the southern side, the zone includes areas of rugged terrain that are encompassed by the Girraween National Park (and thus will not be SCL). The revised boundary is shown in Figure 10.

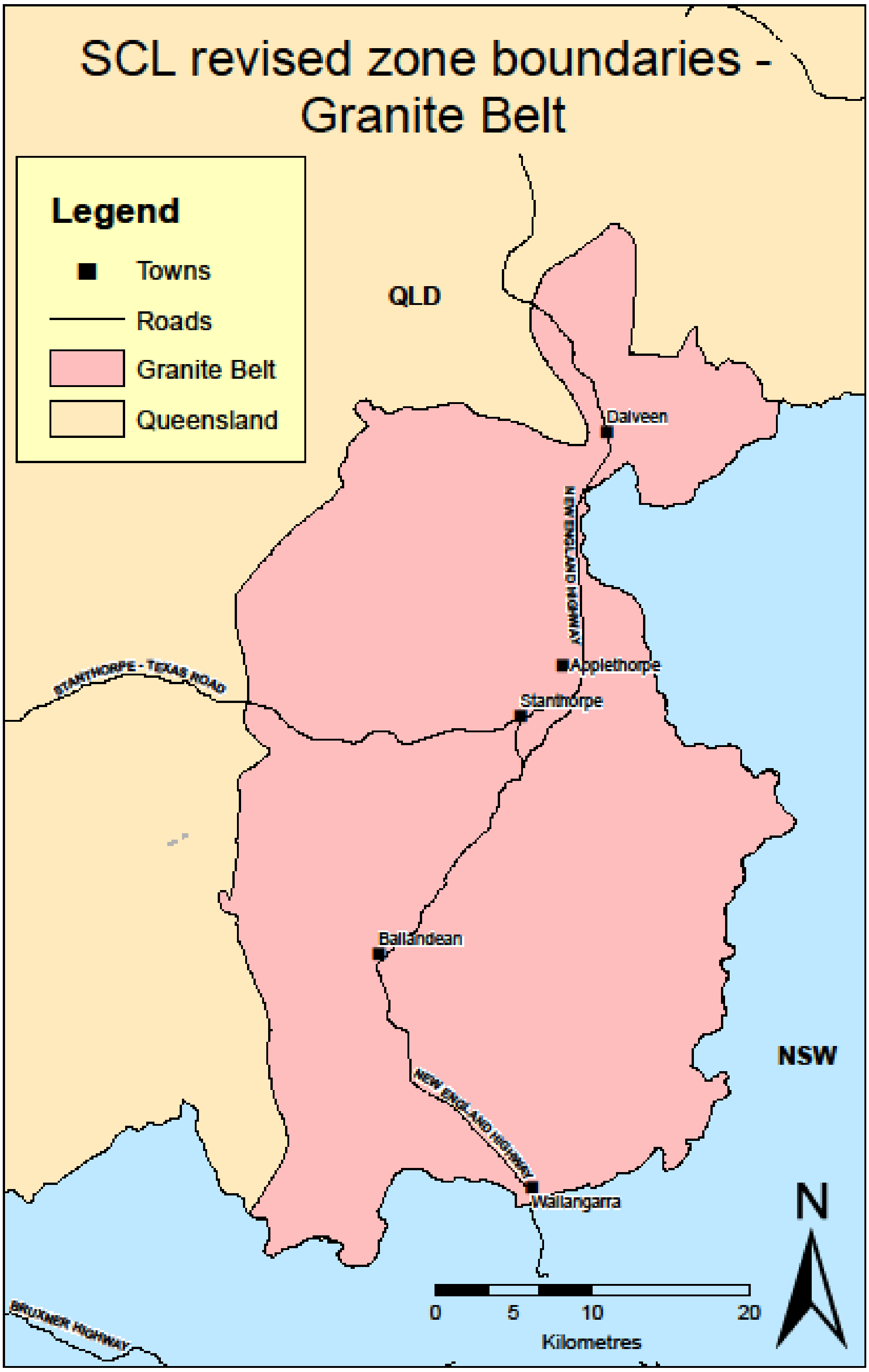

Figure 10: Revised boundaries of the Granite Belt zone

Division of Western Cropping zone

As discussed in the earlier consideration of the Slope (criterion 1), it is recommended that the Eastern Darling Downs is separated from the Western Cropping zone based on slope.

This new zone accommodates areas of more reliable rainfall and has regionally distinct landscape features, and consequently farming systems, on these more sloping landscapes.

The Eastern Darling Downs zone (Figure 11) has been delineated using features consistent with the climatic and landscape characteristics that differentiate the Eastern Darling Downs from areas further west:

- Land Resource Mapping for the area between Bell and Killarney was used to identify the main upland areas that were dominated by Basalt geology.
- Climate data was examined to identify the main climatic features in the area. Mean annual rainfall increases by between 10 and 20% east of Oakey and Dalby, and the average number of wet days per year increases by up to 20%. On this basis the boundary was set at between Jandowae and Oakey using mainly gazetted roads and along the eastern side of the Condamine River from Pittsworth to Killarney.
- Areas to the east (and hence higher rainfall), and often more steeply sloping have been included within the Eastern Darling Downs zone that contain uplands derived from other geological sequences such as Walloon Coal Measures and Marburg Formation Sandstones. Some areas of these geological sequences contain a range of lower quality soils less suited to cropping and which are unlikely to fulfil other SCL criteria other than slope.
- The boundary between these other landscape units and the basalt and alluvial landscapes is complex and a compromise using the gazetted roads has been used to ensure this area can be clearly and unequivocally determined.

The assessment team also considered whether further north-south subdivision of the Western Cropping zone (especially of the Darling Downs and Central Queensland) was warranted to accommodate regionally specific differences in landscape and soil characteristics. While the geographical boundary is reasonably clear (the Condamine-Dawson catchment boundary) and the two localities share similar soils and landscapes, there is no clear soil or land use system break across this boundary. The cereals based farming system with opportunistic pulse and oilseed crops extends across the boundary (along with cotton in better quality soil areas with access to irrigation). The boundaries of the area exhibit a shift towards winter dryland cropping in the west and summer based systems in the north. However, there is no key boundary that demarcates Central Queensland Cropping systems from Darling Downs systems for the simple reason that they are both cereal and grain based systems. Further, no clear evidence or consensus could be obtained on what thresholds for which criteria could or should be different between Central Queensland and Darling Downs. Consequently, it was decided to retain the Western Cropping zone definitions.

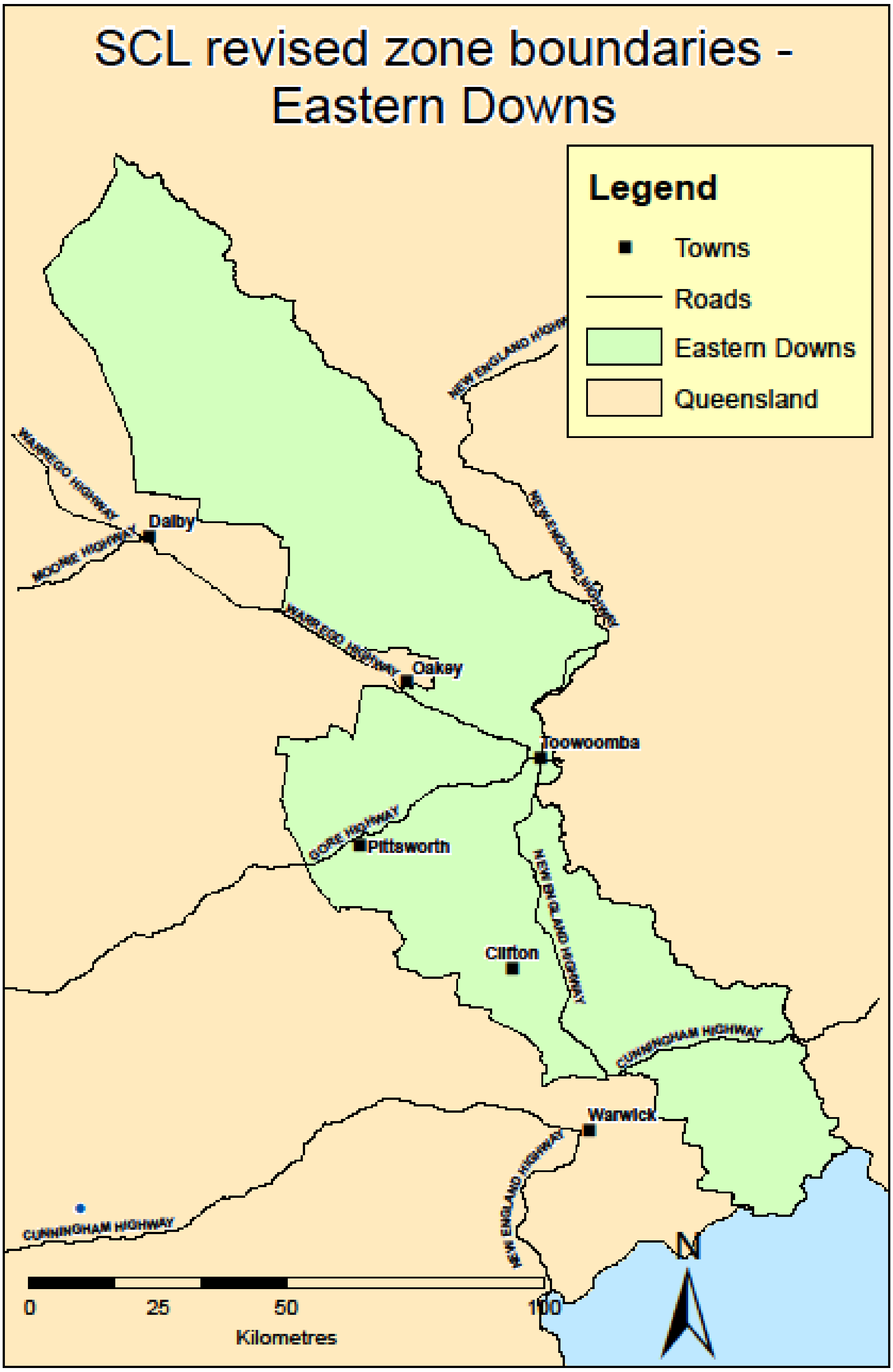

Figure 11: Revised boundaries of the new Eastern Darling Downs zone

Red horticultural soils

The assessment identified that some areas of deep, well drained and stable soils in the Coastal Queensland and Wet Tropics zones would be excluded by the 5% slope threshold. These soils occur in landscapes that are highly regarded for horticultural tree, vine and row crops because of their microclimate (frost free), deep drainage and low erodibility. Such well drained soils are important to the horticulture sector and can support a wide range of crops. They are often cultivated on slopes >5% and therefore a slope threshold of 8% would be an appropriate upper limit for sustainable cultivation on these soils, above which cropping is largely restricted to perennial forms of horticulture.

The most suitable of these soils are the 'red soils' which include loamy and sandy Red Kandosols (e.g. south east Queensland, coastal Burnett), Red Chromosols (e.g. in the Sunshine Coast lowlands) and deep well structured Red Ferrosols that are found at a range of sites across Queensland including the Kingaroy area in the Burnett catchment, Mount Tamborine, Blackall Range and the Atherton Tablelands.

Sites with red soils were assessed in south east Queensland (site 5), Bundaberg/Childers (sites 105, 109, 113), the inland Burnett (sites 50, 53, 56) and the Wet Tropics (site 401). The sites include a number of both cropped and uncropped areas.

In most areas of the Coastal Queensland zone, these red soils require access to at least supplementary irrigation water for perennial horticulture. However where irrigation is applied, these soils support cropping with high productivity. In coastal parts of the Wet Tropics the need for supplementary irrigation is less and these areas are used for both horticulture and dryland cropping.

The possibility of including a separate category of 8% slope for Red Ferrosol soils was discussed by the assessment team. The inclusion of this group of valuable horticultural soils would add complexity to the relatively simple assessment of slope, and increase the risk of inconsistency in the application of the framework (e.g. if the identification of Red Ferrosol soils was required to determine the slope threshold). It would also include a group of soils that generally require supplementary irrigation to sustain their productivity, and this would be inconsistent with the overall SCL criteria approach of not including soils that depend on irrigation for their productivity.

The possibility of raising the slope criteria threshold to 8% for all soils in the Coastal Queensland and Wet Tropics zones was also considered, which could potentially result in areas of poorer quality soils being designated as SCL. However, many would be excluded by other criteria such as soil depth and soil water storage. Note that no such sites were represented in the assessment.

Recommendations

30. Retain the 5% slope threshold for the Coastal Queensland and Wet Tropics zones.

Implications

- Retaining the 5% slope threshold for all soils would:
    - result in an area of horticulturally significant soils not being classed as SCL
    - ensures a simpler and more consistent application of the criteria and threshold
- Not altering the slope threshold to 8% for Red Ferrosols only would:
    - result in a small area of horticulturally significant soils not being classed as SCL
    - ensures a simpler and more consistent application of the criteria and threshold.

Transect analysis

Three transects based on existing medium intensity soil surveys (1:50 000 to 1:100 000 scale) were used to provide a landscape context to the SCL framework. These transects were selected from the:

- Upper Tenthill part of the Lockyer Valley in Southern Queensland (Figure 12);
- Mt McLaren district of Central Queensland (Figure 13); and
- Gowrie and Oakey Creek Valleys in the Central Darling Downs east of Oakey (Figure 14).

The assessment of the transects (Figures 12, 13 and 14) was based on the draft criteria and thresholds.

In overall terms, the results of the transects show a reasonable correlation between areas defined as SCL by the draft criteria and current land use. Soils which are consistently cropped under dryland conditions meet SCL criteria and only soils which are intermittently cropped or used for pasture fail. This broad correlation starts to break down if the depth to weathered rock is not included as a delimiter for soil depth and if the depth to a dispersive (strongly sodic) layer is not included in the criteria. Both of these elements have been included in the proposed criteria, which further strengthens this correlation.

Upper Tenthill transect

The Upper Tenthill long section shows three elements that fail the SCL criteria on slope. Two of these steeper elements also fail on soil depth. These elements are not used for cropping. Another element (Element 4) fails on soil depth due to the presence of dispersive (strongly sodic) subsoil which reduces the depth of soil that thus reduces storage of soil water for plant use. This element fails soil depth and soil water storage criteria. Element 4 lies within the alluvial plain of Tenthill Creek and is used for irrigated cropping. Element 5 fails on soil physical properties but passes the soil water storage criterion when using either a laboratory test (1/3 bar and 15 bar) or look-up table (Table 3). However, the soil is reported as having only 75 mm soil water storage, which would fail the criterion based on a regression equation.

None of the other transects contain rigid soils that fail because of sodicity. However, in the Western Cropping zone there is a higher frequency of sodic soils which are likely to be excluded by this criterion. These sodic soils are at best only pasture quality lands – the inclusion of sodicity in the criteria (draft and proposed) ensures these soils are not defined as SCL.

Mt McLaren transect

In the Mt McLaren data set from Central Queensland, four of the five elements either partly or entirely fail to meet SCL criteria. Elements 1 and 4 generally fail the slope criterion and entirely fail rockiness and soil depth (and thus soil water storage) criteria. Elements 2 and 3 pass the slope criteria but partly fail on rockiness, soil depth and hence soil water storage. Element 5 passes all criteria but is located in a flood plain that is considered to be highly suited to cropping.

Element 3 is the main cropping soil on the basalt landscape of the Central Highlands. Soil depth is variable within this element and some areas are less than 500 mm deep. Reliable long-term cropping is questionable on such shallow soils and their failure to pass the SCL criterion is considered appropriate. Unless weathered rock is included in the definition of soil depth all of these shallow soil profiles will be included as SCL. Elements 1, 2 and 4 are not considered suitable for cropping and do not pass the SCL criteria except for deeper, less stony areas of Element 2. The floodplains (Element 5) in this part of the Central Highlands are subject to flooding, with some areas prone to lengthy inundation and potential for erosion by floodwater. These areas are less frequently used for cropping. Although flooding was considered as a criterion, data on flood impact and frequency is generally difficult to obtain and therefore was could not be used as a criterion.

Gowrie-Oakey Creek

In the Gowrie-Oakey Creek data set, a much larger number of elements are present. Assuming a slope limit of 3%, six out of 14 elements (approximately 30% of the traverse section) fail to meet the SCL criteria of slope, soil depth or rockiness.

For four of the six elements that failed, the increase in the slope threshold to 5% for the Eastern Darling Downs together with the inclusion of weathered rock (in this case weathered basalt) as a defining feature for soil depth mean that these four elements are defined as SCL by the proposed criteria. The two elements that fail irrespective of soil depth, fail because of rockiness or low soil water storage.

One of the region’s best cropping soils (Waco) would occasionally fail the soil physical properties criterion in the draft criteria. It appears that the soil physical properties being used can vary depending upon previous land use and rainfall conditions, which highlights the potential uncertainty of measuring this criterion. The removal of the soil physical properties criterion in the proposed criteria removes this issue.

The current land use relationships for this transect show a reasonable correlation to the SCL criteria if weathered rock is counted as a basis for limiting soil depth. All areas of SCL are cropped and the only area which is not SCL is irrigated to overcome the soil water storage limitations. Conversely if the soil depth limitation is lessened, then areas which are dominated by dryland pasture will be defined as SCL.

For this transect lifting the slope criteria to 5% on the Eastern Darling Downs in the proposed criteria increases the area ranked as SCL, however it appears that few of the soils between 3% and 5% would pass the threshold for SCL provided the definition of soil depth includes weathered material as a limitation.