QUEENSLAND GOVERNMENT

Guidelines for Agricultural Land Evaluation in Queensland

Second Edition

Great state. Great opportunity.

Queensland Government

Prepared by

Department of Science, Information Technology and Innovation (DSITI) and the Department of Natural Resources and Mines (DNRM)

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List of Acronyms

AASS	Actual acid sulfate soil
ALC	Agricultural land class
APSIM	Agricultural Production Systems sIMulator (see www.apsim.info)
ASC	Australian soil classification
ASS	Acid sulfate soil
CEC	Cation exchange capacity
CLL	Crop lower limit (of soil water content)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DEM	Digital elevation model
DERM	Department of Environment and Resource Management
DNRM	Department of Natural Resources and Mines
DSITI	Department of Science, Information Technology and Innovation

DSITIA	(Queensland) Department of Science, Information Technology, Innovation and the Arts
DSM	Digital soil mapping
DUL	Drained upper limit (of soil water content)
EC	Electrical conductivity
ERD	Effective rooting depth
ESP	Exchangeable sodium percentage
FAO	Food and Agriculture Organization (of the United Nations)
GIS	Geographic information systems
GPS	Geographic positioning system
NCST	National Committee on Soil and Terrain
PASS	Potential acid sulfate soil
PAWC	Plant available water capacity
PAWCER	PAWC estimation routine (set of pedotransfer functions)
SALI	(Queensland Government) Soil and Land Information system
SAR	Sodium adsorption ratio
SILO	Scientific Information for Land Owners (climate data – see www.longpaddock.qld.gov.au/silo/)
UMA	Unique map area
USDA	United States Department of Agriculture
USLE	Universal soil loss equation

1 Introduction

Since 1990, when the *Guidelines for agricultural land evaluation in Queensland* was published, land resource assessment and land evaluation in Queensland has undergone considerable transformation, both in terms of concepts and practice. A number of milestone publications were produced during this period, such as the Australian Soil and Land Survey Handbook series – commonly known as the 'yellow', 'blue' and 'green' books. These provided a national standard for terminology and methodologies used in land resource assessment and associated activities. The five volumes in the series published to date are:

Volume 1: *Australian soil and land survey field handbook*, 3rd edition (NCST, 2009) – the 'yellow book', replacing earlier editions of McDonald et al. (1984) and McDonald et al. (1990)
Volume 2: *Guidelines for surveying soil and land resources*, 2nd edition (McKenzie et al. 2008) – the 'blue book', replacing the first edition of Gunn et al. (1988)
Volume 3: *Soil chemical methods – Australasia* (Rayment & Lyons, 2011) – the 'green book' replacing the earlier volume by Rayment and Higginson (1992)
Volume 4: *The Australian soil classification*, revised edition (Isbell, 2002) – the 'grey book' replacing the first edition of Isbell (1996) and referred to as the ASC
Volume 5: *Soil physical measurement and interpretation for land evaluation* (Coughlan et al. 2002) – the 'brown book'.

Since its publication, the *Guidelines for agricultural land evaluation in Queensland* (Land Resources Branch, 1990) has provided the framework and procedures for land evaluation in Queensland. It does not describe procedures for land resource assessment despite land resource assessment being an integral part of land evaluation. General approaches to land evaluation are covered in McKenzie et al. (2008) but there are no nationally adopted guidelines detailing specific systems for use. It was stated in the introduction to the 1990 document that 'This publication is likely to be the first of several attempts at standardising procedures of land evaluation.' There have been many changes in technology, methods and regulation since its production, therefore a revision of the 1990 document is overdue to meet the new challenges facing land evaluation in Queensland.

Some of the most notable innovations impacting on land evaluation in Queensland since the preparation of the original document include:

- desktop geographic information systems (GIS), mobile computing and global positioning systems (GPS) to support accurate geolocation and data recording/processing
- new land uses being adopted, as farmers and land managers diversify their agricultural production enterprises. For example, cereal cropping and small crops are being increasingly grown in the Burdekin River irrigation area, which was once almost exclusively sugar cane.
- improved methods of data storage, chiefly the construction of the governments land resource database known as SALI – the Soil and Land Information system (Biggs et al. 2000). The functionality of SALI has been expanded for use in GIS and integrated with other applications for displaying and examining data.
- improved methods of public data distribution (e.g. provision of data held in the SALI database via various web-based services)
- development of new spatial data sources and improvements in the quality of remotely sensed imagery, including high quality digital elevation models and derived products

- improved methods of data processing and interpretation, including increased use of geostatistics and advances in landscape modelling and digital soil mapping techniques
- the availability of land use mapping products for the whole state
- a general increase in land use pressure, and conflicts between agricultural and other land uses – for example coal seam gas extraction.

Furthermore there have been substantial alterations to the legislative framework impacting on the protection of agricultural land and agricultural land use in Queensland since 1990, particularly with the advent of the (now lapsed) State Planning Policy 1/92: Development and the Conservation of Good Quality Agricultural Land, the *Sustainable Planning Act (2009),* the *Strategic Cropping Lands Act (2011)*, the *Sustainable Planning and Other Legislation Amendment Act No. 2 (2012)* and the *Regional Planning Interests Act (2014)*.

1.1 Applications of land evaluation

Traditionally, land resource surveys and land evaluations by state or commonwealth agencies have been conducted across large geographic areas to support agricultural development. More recently, increased demands associated with mining and other intensive developments have resulted in many special purpose strategic surveys being conducted by both government and the private sector. Regardless of which organisation undertakes the work, data collected through soil surveys, land resource assessments and land evaluation studies is used for a variety of purposes, including:

- identifying the range of suitable crop options in existing cropping areas to facilitate diversification
- investigating new areas suitable for agricultural expansion
- feasibility studies for development of new dams and irrigation schemes
- regional planning, including the preparation of planning schemes and development assessment decisions by local government
- identification of areas prone to environmental degradation, including erosion, salinity and acid sulfate soils
- land valuations
- land clearing applications
- planning for rural industry expansion (e.g. irrigation schemes)
- on-farm management planning, particularly paddock and irrigation design based on soil properties
- environmental impact assessment
- non-agricultural suitability assessments (e.g. suitability for wastewater disposal)
- informing regulatory and extension service providers in areas such as environmental and restoration works, vegetation clearing, grazing and pastoral land management
- planning land management activities to obtain carbon credits (carbon farming)
- designing and planning major infrastructure e.g. roads, rail, ports, pipelines, power lines, communications cables.

1.2 Purpose of these guidelines

This document is a revision of the original 1990 publication. The aim of this edition is to remove content that is no longer relevant, revise and add to the land use limitations and ensure the document can be used by a broader group of users – non-government as well as government. In brief, the purpose of this publication is to:

- summarise existing land evaluation systems
- describe a system of land classification appropriate to Queensland conditions
- recommend best practice methods for conducting land evaluation.

The guidelines provide the basis for a consistent approach to land evaluation by practitioners who undertake land evaluation studies. They will also allow users of interpreted land resource information to understand the methodology involved. This edition is a more succinct version of the original publication and presents a best practice approach to agricultural land evaluation. The original version remains accessible but should only be used as an historical reference. The authors appreciate that land evaluation techniques and client needs will change with time, circumstances and technology, therefore future updates of this publication can be expected. While these land evaluation guidelines have an agricultural focus, the principles also apply to certain non-agricultural land uses (e.g. areas suitable for rural residential development and land suitability for septic tank installation). Land evaluation should not be confused with land valuation, although the latter often relies on the former.

There are many published land evaluation frameworks for specific areas in Queensland e.g. Murtha and Smith (1994), Ross and Crane (1994), Wilson (1997) and Forster and Sugars (2000). There are also regional land suitability frameworks for various regional areas of Queensland, including each regional cropping area (DNRM & DSITIA, 2013). These should be read in conjunction with this document.

1.3 Key changes from previous version

There are a number of important changes in this document from Land Resources Branch (1990). These include:

- clarifying the definition of land suitability class 4
- clarifying the definition of the agricultural land classes
- subdivision of agricultural land classes A and C
- the inclusion of additional land use limitations.

2 Land evaluation systems

2.1 Principles of land evaluation

Land evaluation involves determining the potential of land for alternative (and possibly competing) forms of land use and identifying management requirements for sustainable use. To do this effectively in Queensland, certain principles have been identified as applicable. These principles draw on the Food and Agriculture Organization (FAO) Framework for Land Evaluation (FAO, 1976; 1980) that has been the primary approach used worldwide, and is described in key references such as Dent and Young (1981) and Landon (1984). The FAO framework does not by itself constitute an evaluation system, but is a set of guidelines by which local, regional and national evaluation systems can be constructed. The principles fundamental to all systems of land evaluation are outlined in the following sections.

Resource-related principles

Land evaluation:

- relates land use requirements to land resource attributes, noting that:
    - different land uses have different requirements
    - the land resource attributes must be assessed for each specific land use
- considers alternative land uses, to ensure that:
    - optimal land uses are recommended
    - the consequences of certain land uses are not overlooked
    - adequate resource data are collected, including for potential reinterpretation in the future
- interprets land resource information and presents land use recommendations in a form acceptable to a range of users
- reflects the quality of the available land resource information. The uncertainty associated with the evaluation is influenced by the:
    - scale of the land resource maps used
    - density of land resource observations
    - reliability of land attribute predictions
    - validity of interpretations/assumptions made during the evaluation process.

Management-related principles

Land evaluation:

- is based on the need for sustainable production, noting that:
    - the proposed land use should exclude management practices that lead to unacceptable levels of land degradation in the short, medium or long term
    - land evaluation is conservative in the sense that land degradation rates acceptable for the current use of land may not be tolerable when wider community interests are considered.
- incorporates specified management practices and infrastructure relevant to the study area, noting that:
    - the evaluation must consider the benefits and impacts of infrastructure and standard management practices that are accepted in a particular study area.

- is based on the existing condition of the land, noting that:
    - land should be evaluated according to its existing land use limitations and socio-economic factors and not according to its potential condition once the limitation/s are removed. For example, swampy land that has been drained at an uneconomic cost may be rated as class 2 land (see Section 3) while similar undrained land would be class 4.
    - this principle does not apply where removal of the limitation/s is an accepted, standard district practice, such as the use of fertiliser.
    - what constitutes accepted, standard district practice may change over time (e.g. the economics of removing rocks prior to crop establishment) and this should be considered when reviewing historical land evaluation information.

The concept of sustainability has evolved over time. Certain land management practices that were once considered appropriate may have been found to be unsustainable in the long term. Similarly, certain infrastructure required for an industry (e.g. a sugar mill) may no longer exist. While this does not change the specific suitability of the land, it may impact on the chosen land use. For instance, while an area of land may be suitable for cotton, it is unlikely to be grown unless there is a cotton gin within an economic transport distance.

Land evaluation makes no recommendations about the ‘best’ use of land other than indicating which crops or land use enterprises are most suitable. The choice of land use at a property level is a management decision that takes into account factors such as landholder expertise, preference and economic situation; market prices and trends; and seasonal rainfall (actual and predicted). Similarly, while land evaluation can be used to determine if land is generally suitable for agriculture, it makes no statement about the preferred overall use of the land (e.g. for agriculture, housing, infrastructure, industry or environment). These are matters for the wider community in the context of regional planning.

2.2 Current systems of land evaluation

Land evaluation systems have been reviewed by Landon (1984), Rossiter (1996), Shields et al. (1996) and others. The FAO style of land evaluation has been criticised by some for its qualitative and empirical base. Shields et al. (1996) and Ringrose-Voase (2008) outlined a case for more quantitative integrated systems of land evaluation. van Gool et al. (2008) discussed the strengths and weaknesses of the FAO style of assessment, concluding that there is generally an overlap between conventional and quantitative approaches with each system using varying degrees of quantification.

Approaches to land evaluation that attempt to quantify the effects of land properties on land productivity are referred to as parametric – as discussed in Land Resources Branch (1990) – or inductive, as described in Shields et al. (1996). Although there are currently no such systems recommended for specific application in Queensland, it is highly likely that land evaluation in the future will incorporate more quantitative approaches, along with various types of simulation modelling. These approaches will likely follow the process of digital soil assessments described by Carré et al. (2007).

2.2.1 Land capability and land suitability classifications

Modern land evaluation practice grew out of the agricultural land capability classification adopted by the United States Department of Agriculture (USDA) system (Klingebiel & Montgomery, 1961). The term land suitability was adopted by FAO (1976). In Australia, the terms have been used inconsistently, as discussed by van de Graaff (1988). Following on from van de Graaff (1988), the definitions adopted here are as follows:

Land capability classification evaluates the potential of land for broadly defined land uses (e.g. cropping, pastoral, non-agricultural) whereas *land suitability* classification assesses the potential of land for a specific land use (e.g. furrow irrigated cotton).

Both land capability and land suitability assessments rely on the best available description of primary attributes of mapping units obtained during a land resource survey. These attributes are converted into land use limitations (see Section 3 for further detail).

Land capability assessment based on the USDA system has been used extensively for broadscale land system studies in Queensland, e.g. Gunn et al. (1967), Vandersee (1975). The major disadvantage of the land capability approach is that an objective comparison between alternative land uses for the same land is not possible. This is because land uses are only defined in general terms and there is an implicit priority of uses: cultivation is considered to be the most important, followed by grazing, with recreation and wildlife conservation at the lowest level (van Gool et al. 2008). Therefore, no proper judgement for detailed land use planning or management can be made using a land capability system, although it remains useful for regional land planning. Modified systems of land capability classification have also been used for soil conservation planning and for property management planning where the principal land use has already been determined.

Recommended system for *land capability* classification in Queensland

Land capability classification in Queensland is the evaluation of land attributes for arable, pastoral and other agricultural land uses involving current technology and agronomic management practices. It is recommended for studies where evaluation for a limited range of agricultural land uses is required at a small- or broadscale (1:250,000 or smaller) over large areas. The land capability classification used is based on Rosser et al. (1974), which is a slight modification of the Klingebiel and Montgomery (1961) scheme, and is reproduced in Section 5. It may continue to be used where appropriate.

Recommended system for *land suitability* classification in Queensland

Land suitability classification consistent with the FAO method is recommended for studies where more specific information at medium or large scales (1:100,000 or larger, i.e. more detailed) is required. Land suitability classification in Queensland is the evaluation of soil and land attributes based on the requirements of a specified land use using current technology and management. In this context, a land use is the combination of a crop and its management options (e.g. dryland maize, furrow irrigated cotton, trickle irrigated apples). In some cases the growing season – summer or winter – may also be specified. Socio-economic factors are considered in general terms only, either at the start of the study or in the definition of the level of inputs required to overcome each limitation. In most cases, land suitability classes do not equate to actual crop yields or costs and benefits. The land suitability method is outlined in Section 3.

2.2.2 Land classification for regional land planning

Methods of land classification for planning purposes have developed from the need for systems to have direct application for policy makers attempting to protect agricultural land, and due to recognition of the economic contribution of agricultural production. Such systems combine assessments of land suitability for a number of uses into a single land classification. Using a land evaluation framework limits the subjectivity associated with the delineation of agricultural land, allowing improved planning outcomes.

Queensland has used a variety of approaches as a basis of protecting agricultural land and to support the agricultural sector since the early 1990s, including the lapsed State Planning Policy 1/92, statutory regional planning, the Strategic Cropping Land framework, the Agricultural Land Audit, State Planning Policy 2014 and reforms to the *Vegetation Management Act 2013*. The land resource has been characterised by a variety of terms such as 'good quality agricultural land', 'versatile cropping land', 'strategic cropping land' and 'important agricultural areas'. Agriculture is recognised as an important state interest and as such, there is a commitment to protecting resources from inappropriate development and minimising the encroachment of non-agricultural uses. This ensures that viable tracts of agricultural land are maintained while improving opportunities for increased production and diversification.

A system of agricultural land classification is central to state planning policies and supporting regulations. The system of agricultural land classification for land planning used in Queensland is similar to land capability in that ultimately only major land use categories are assessed (although these may be derived from land suitability classes, if available). It is a simple hierarchical system that enables the best agricultural resources to be identified for planning purposes. The agricultural land classification system for planning is outlined in Section 6.

2.3 Steps in agricultural land evaluation

Land evaluation requires detailed land resource information, collected as part of a land resource survey. Land resource surveys describe different landscape entities (soils, land units, land systems) depending on the scale of the survey. For more detail, refer to texts such as McKenzie et al. (2008). In Queensland, land evaluation has generally been conducted as an integrated project that includes both land resource assessment and land suitability/capability components. When conducted in such a way, there is an iterative feedback process between the two components, as they occur concurrently. As more use is now being made of legacy land resource data, it is increasingly common for the resource assessment and land evaluation phases to be distinctly separated in time and carried out by different people. The quality of any land evaluation process will be therefore limited by the quality and quantity of land resource data available to it. McKenzie et al. (2008) provide a comprehensive overview of land resource survey and land evaluation.

2.3.1 Step 1 – Resource assessment and mapping

Land resource assessment involves a survey of soil and land resources, the collection of associated primary data and the production of maps (which depict different landscape entities depending on the scale). Primary soil and land resource data in Queensland is compiled and recorded using the standards described in the *Australian soil and land survey field handbook* (NCST, 2009) and its predecessor texts.

A land resource map usually displays map units in a geomorphic framework, although any soil or land attribute can be mapped. A conventional land resources map uses polygons to cartographically display the different map units and uses a legend to identify and describe the map units. When the unique set of soil and land attributes associated with an individual polygon are described and collected, the polygon is referred to as a unique map area (UMA). This practice developed when computers enabled the efficient collation and storage of such data in a 'UMA database'. The advantage of the UMA approach is that many different soil/land attributes can be described and analysed for each UMA and variability within soil types can be captured explicitly.

For example, UMAs that are mapped as the same soil type may be different in other land attributes such as degree of rockiness and slope. Desktop GIS enables the rapid processing and analysis of UMA databases.

It is the unique attributes attached to UMAs that are used to assess land suitability. The older style surveys with maps that simply display 'identical areas' cannot be used for land evaluation purposes until the necessary additional land attribute information is attached to the polygons and a UMA database created.

Digital soil mapping (DSM) is an alternative approach that uses raster-based rather than polygon-based information systems. It differs from traditional soil mapping in that the outputs are usually single soil attributes (e.g. pH, soil depth) predicted for individual cells (pixels) in a raster image. Data extraction, manipulation and comparison are conducted far more efficiently using rasters compared to polygons, and estimates of uncertainty can be routinely produced.

Importantly, DSM is now being used as a tool for assessing soil functions, processes and capability. The use of DSM outputs can also be used operationally in agricultural land evaluation (see Bartley et al. 2013, Kidd et al. 2014 and Harms et al. 2015). Whether based on pixels or polygons, the UMA and land evaluation principles are the same.

2.3.2 Step 2 – Land suitability/capability

The process of land suitability/capability assessment commences with the selection of land uses and an explicit description of their requirements. This applies particularly to land suitability assessment but also to capability assessment, where the requirements of the relevant arable, pastoral and other uses need to be defined. For example, some crops have a requirement for stone-free soils. Understanding the requirements of land uses is important to ensure that all appropriate data is collected during the land resource assessment process.

Data relating to land use requirements is integrated with soil and land attributes data for each UMA, to derive the land suitability or capability for each UMA. The land evaluation methodology employed depends on the type of land evaluation being undertaken. The methodology for land suitability assessment is discussed in Section 3, the methodology for the land capability assessment is described in Section 5, and the method for agricultural land classification is discussed in Section 6.

2.3.3 Step 3 – Report/output phase and data storage

Land evaluation data and outcomes can be presented in a number of different formats depending on the aims of the project and the requirements of the clients. Guidelines for data presentation and reporting are provided by Eldershaw (1996) and Imhof et al. (2008). Example land evaluation publications for reference include Wilson et al. (1999), Grundy and Heiner (1999) and McCarroll and Brough (2000).

Within the Queensland government, all data associated with soil survey and land evaluation projects are stored in the SALI land resource database. This data is available to the public (see www.qld.gov.au/soils). It should be noted that specific terminology relating to land evaluation has changed over time, and that some older publications may use terminology and definitions that differ from these current guidelines.

3 Method of land suitability assessment in Queensland

The land suitability assessment process described in this section is Step 2 of an integrated land resource assessment project (see Section 2.3). However, the same general approach applies if the land suitability assessment is conducted *after* the land resource assessment.

3.1 Land suitability class definitions

Five land suitability classes are defined for use in Queensland, with land suitability decreasing progressively from class 1 to class 5. These classes are used to describe an area of land in terms of suitability for a **particular land use** which allows optimum, sustainable production using current technology, while minimising degradation to the land resource in the short, medium or long term.

Land is considered less suitable as the severity of limitations for a specified land use increase, reflecting:

- reduced potential for production
- increased inputs required to achieve an acceptable level of production
- increased inputs required to prepare the land for successful production
- increased inputs required to prevent land degradation.

The five land suitability classes are summarised below and described in detail in Table 1.

Class 1 Suitable land with negligible limitations
Class 2 Suitable land with minor limitations
Class 3 Suitable land with moderate limitations
Class 4 Unsuitable land with severe limitations
Class 5 Unsuitable land with extreme limitations

Table 1: Land suitability classes

Class	Suitability	Limitations	Description
1	Suitable	Negligible	Highly productive land requiring only simple management practices to maintain economic production.
2	Suitable	Minor	Land with limitations that either constrain production, or require more than the simple management practices of class 1 land to maintain economic production.
3	Suitable	Moderate	Land with limitations that either further constrain production, or require more than those management practices of class 2 land to maintain economic production.
4	Unsuitable	Severe	Currently unsuitable land. The limitations are so severe that the sustainable use of the land in the proposed manner is precluded. In some circumstances, the limitations may be surmountable with changes to knowledge, economics or technology.
5	Unsuitable	Extreme	Land with extreme limitations that preclude any possibility of successful sustained use of the land in the proposed manner.

The first three classes of land (classes 1 to 3) are considered **suitable** for the specified land use, as the benefits obtained from that land use in the long term should outweigh the inputs required to initiate and maintain production. Class 3 land may be as productive as class 1 or 2 land; however, increased inputs (e.g. fertiliser, land preparation and maintenance operations) would generally be required. It is not uncommon to find in a land resource survey that there is no land assessed as suitability class 1 for a particular land use.

Class 4 land is considered **currently unsuitable** for the specified land use, due to the severity of one or a number of limitations. It is implied that the inputs required to achieve and maintain production outweigh the benefits of production in the long term. This land may be upgraded to a suitable class if future agronomic, edaphic or engineering studies show it to be economically viable and environmentally sustainable. Changes in climate, economic conditions or technology may alter the level of management inputs required to achieve satisfactory long-term productivity.

Class 5 land is considered **unsuitable** for the specified land use, as it has limitations that singly or in aggregate are so severe that the benefits would not justify the inputs required to initiate and maintain sustainable production in the long term. Such land is unlikely to ever be suitable for the specified land use.

3.2 The process of land suitability classification

The land suitability assessment process classifies each mapping unit (UMA) delineated in the resource assessment phase according to its suitability for each selected land use. In this document, the process is described as occurring in a sequential manner, but in reality (and ideally), the tasks often occur in parallel, as shown in Figure 1. This is particularly the case for the tasks of constructing the suitability rule matrix and populating attributes and limitations for UMAs. Furthermore, there is an iterative interaction between the two groups of tasks. While Figure 1 illustrates the process of land suitability assessment, the same general approach applies to land capability assessment.

3.2.1 Description of soil and land attributes

Land resource assessment (see Section 2.3.1) involves the description of soil and land attributes for each map polygon. Depending on the type of mapping, these attributes may be captured via a general description of a soil or land type; or specifically, as in the case of UMA mapping. Attributes include landform, slope, soil depth, rockiness etc. Some attributes are specific to certain soil types, while others are not. For instance, certain soil types may always be stone-free, while other soil types may have a wide range of stoniness. Similarly, certain soil types may occur only on a narrow range of landforms or slopes, while others may occur on a variety.

Attributes may be distinguished as generally soil-related or those that relate to landscape (non-soil) attributes. Table 2 illustrates how values for these two types of attributes could be allocated to UMAs – based on both soil type and land information. Similarly, some soil and landscape attributes are essentially static over time (e.g. slope), whereas others may be dynamic (e.g. salinity).

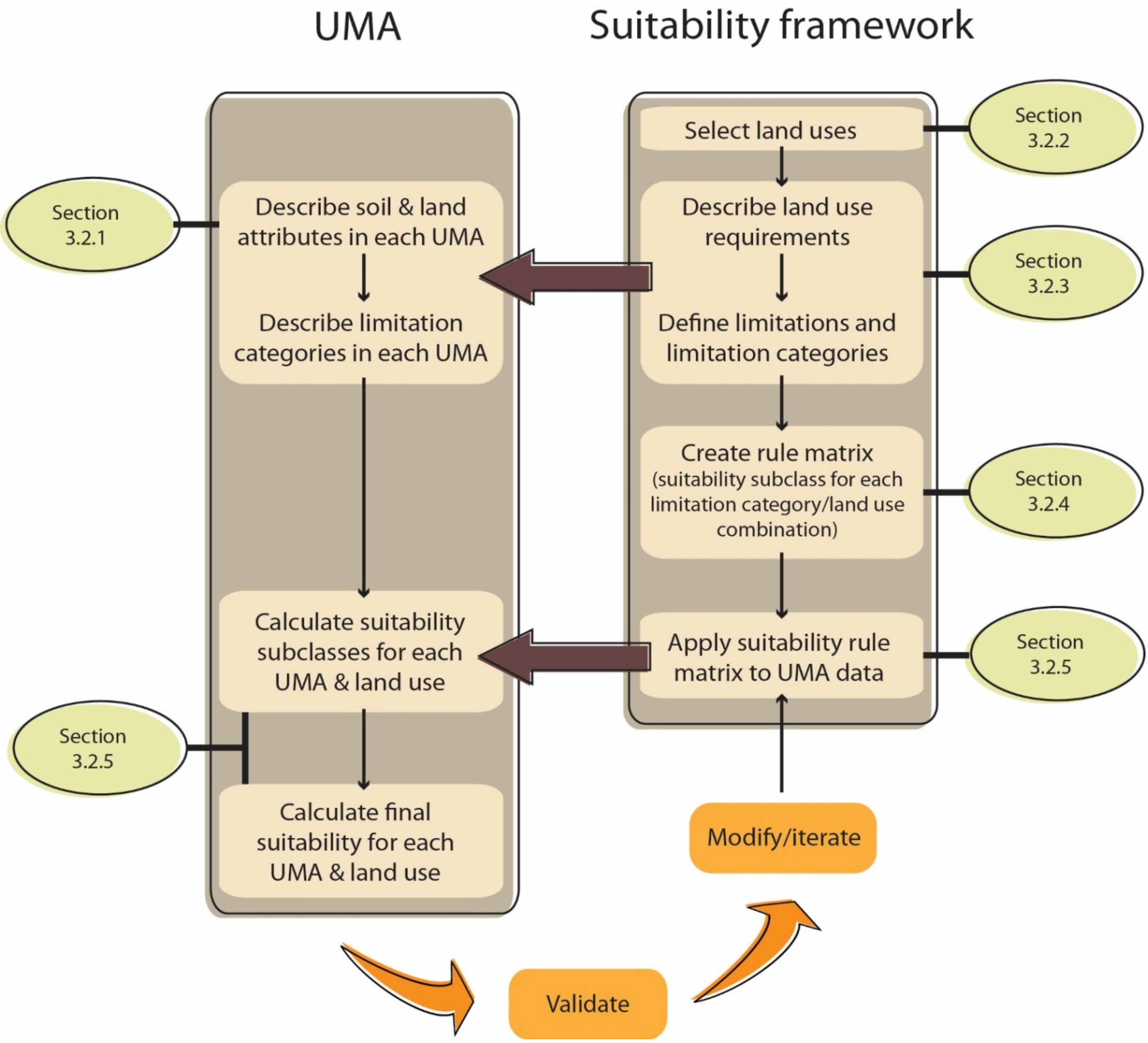

Figure 1: Process of land suitability assessment. The development of the suitability framework and the attribution of UMAs (unique map areas) occurs concurrently.

Table 2: Example of soil and land attributes for different UMAs

UMA	Dominant soil type in the UMA	Soil attributes			Landscape attributes		
		PAWC* (mm/1.2 m)	Nutrient status	Subsoil sodicity	Slope (%)	Flooding	Frost
1	Soil type X	125	Moderate	Sodic	2	1 in 5 years	Frosted
2	Soil type Y	50	Moderate	Strongly sodic	1	none	Frosted
3	Soil type Z	125–130	Low	Non-sodic	4	none	Frost-free

* plant available water capacity

For each attribute, it is useful to identify the full range of expression that occurs across the entire study area. This can be conveniently done for an entity such as a soil type and assists in both communication and the correct assessment of land suitability; Table 3 provides an example. While a wide range of soil and land attributes can be described in land resource assessment, the selection and description of appropriate attributes in suitability assessment is guided by the land use requirements of the selected land uses, as described in Section 3.2.2.

Table 3: Attribute range for individual land resource units

Soil type	Attributes					
	PAWC (mm/1.2 m)	Nutrient status	Subsoil sodicity	Slope (%)	Stone size and abundance	Flooding
Soil type W	75–100	Moderate to low	Non-sodic	0–1	None	1 in 5 years
Soil type X	100–125	Moderate	Sodic	0–3	None	Every year to 1 in 5 years
Soil type Y	50–100	Moderate to low	Sodic to strongly sodic	1–5	None	None
Soil type Z	100–150	Low	Non-sodic	2–7	0–20% pebbles	None

3.2.2 Selection of land uses and description of land use requirements

The initial step in any land suitability exercise is the selection of the land uses to be assessed. A ‘land use’ is a combination of crop type (or pasture type) and management system. A land use must be defined in a sufficient level of detail to identify the differences in species or management that result in different land use requirements (e.g. peanuts may require rock-free soil, adequate soil aeration and good soil drainage). Many species/crop types have similar requirements for optimum growth (e.g. root vegetables), but others have distinct differences. In some cases, individual cultivars of a particular crop type may have distinctly different capacities to tolerate certain conditions (e.g. frosting or salinity). In other cases, different management systems (e.g. spray irrigation vs. furrow irrigation) have different land use requirements, even for the same crop. Where species/crop types have no difference in land use requirements, they may be grouped together.

Any such grouping of crops/land is an iterative process involving other aspects of the land suitability process.

Specifying land use requirements captures quantitative and qualitative knowledge in an explicit manner. The description of land use requirements will come from the literature, experience and consultation with agricultural practitioners. The original selection of land use requirements should not be regarded as final, as observations during the course of field work, together with knowledge gleaned from land managers, may lead to additions and/or modifications to the original set of land uses and their requirements. This is one of the reasons why it is more appropriate to conduct land resource assessment and land suitability/capability assessment in parallel.

3.2.3 Describing land use limitations and diagnostic attributes

The inherent properties of the land that are used to assess land use requirements (and hence determine land suitability) are called **land use limitations** (shortened here to 'limitations'). In a strict sense they are not limitations unless their level of expression has a limiting effect on plant growth or crop management. Limitations can be regarded as land use requirements stated in a negative sense (e.g. rockiness, wetness, frost).

Limitations are not usually measured directly, but are assessed via appropriate soil and land attributes described during the land resource assessment. The attribute/s chosen to describe each limitation are referred to as diagnostic attributes. It is important to understand this component of the land evaluation process when conducting the land resource assessment, so that the appropriate soil and land attributes are recorded.

When considering diagnostic attributes, it is useful to distinguish between simple and complex attributes:

- Simple diagnostic attributes are those easily observed and measured in the field or the laboratory (e.g. pH, slope). These are sometimes referred to as land characteristics.
- Complex diagnostic attributes are those made up of several contributing diagnostic attributes. In the literature, these are sometimes referred to as 'land qualities' or 'dynamic characteristics' and are generally difficult to measure directly – rather, they are inferred or calculated.

For example, the wetness limitation is assessed by considering a range of complex and simple diagnostic attributes, some of which are shown in Table 4.

Table 4: Example of soil and land attributes used to assess the wetness limitation

Complex soil/land attribute	Example diagnostic attributes
Soil permeability	Soil texture, soil structure, soil porosity, soil colour, depth to and degree of mottling
Site drainage	Landform, topographic position, slope, infiltration rate, depth to watertable, vegetation species present

Limitations are assessed individually for each UMA and are used to create a suitability rule-set (see Section 3.2.4). A detailed list of limitations and their related soil and land attributes is described in Section 4 and each limitation is fully discussed in Section 4.2.

3.2.4 Determining the effect of limitations on a land use

The core of a land suitability assessment is the development of suitability rules that describe degrees of expression of a limitation for each land use (Figure 1). The suitability rules are described in a matrix that places a relevant land suitability class from 1 to 5 (a suitability subclass) against each level of expression of a limitation (a limitation category) for each land use.

Determining the limitation categories

Limitations are divided into categories that relate to their degree of expression – generally in order from the least to greatest degree of expression. Table 5 provides an example of categories for the soil water availability limitation. The M1 category would not function as a limitation at all, whereas the M6 category would generally be severely or extremely limiting for non-irrigated land uses. Different limitations are likely to have a different number of categories. Establishing these categories is usually an iterative process and is guided by both natural breaks in the distribution of diagnostic attributes (and thus in limitations that use these attributes) as well as land use requirements. The natural breaks and the range of attributes are compiled via summary tables such as Table 3. It is often useful to summarise limitation categories that apply to different soil types, as in Table 5.

Table 5: Example of limitation categories and soil groups for the soil water availability (M) limitation

Soil water availability limitation categories (PAWC to 1.2 m)					
M1	M2	M3	M4	M5	M6
>150 mm	125–150 mm	100–125 mm	75–100 mm	50–75 mm	<50 mm
Soils A, K, H	Soils Z, C, E	Soils X, D	Soils W, F, G	Soils Y, M, N	Soils L, O

The limitation categories are then matched to the land use requirements of each crop/land use

For limitations such as rockiness and flooding, there is a degree of uniformity in categories used in Queensland, while with limitations such as soil water availability there is more variation – due to regional differences in soils and climates. The determination of appropriate limitation categories can be assisted by validation against known land use/crop performance for certain areas.

Determining suitability subclasses

This step (see Figure 1) involves matching the established limitation categories to the land use requirements for each of the land uses being investigated. Each limitation category is given a ranking from 1 to 5 (i.e. from most suitable to least suitable), which is termed a suitability subclass. A suitability subclass must be derived for each limitation category for each land use. Table 6 illustrates suitability subclasses relating to the soil water availability limitation for four different land uses. The collective set of suitability subclasses is commonly referred to as the suitability rule-set.

Table 6: Example of land use suitability subclasses (rules) for the soil water availability (M) limitation for four land uses

Limitation category* (PAWC to 1.2 m)	Suitability subclass for dryland wheat	Suitability subclass for dryland cotton	Suitability subclass for irrigated cotton	Suitability subclass for irrigated carrots
M1 (>150 mm)	1	1	1	1
M2 (125–150 mm)	2	2	1	1
M3 (100–125 mm)	2	3	2	1
M4 (75–100 mm)	3	4	2	1
M5 (50–75 mm)	4	4	3	1
M6 (<50 mm)	5	5	4	2
* the limitation categories are as per Table 5				

Table 6 shows that the soil water availability limitation categories M1 to M4 are assessed as suitable for dryland wheat (i.e. suitability subclasses 1–3). However, the M5 and M6 limitation categories are assessed as unsuitable (subclasses 4 and 5) for dryland wheat. For irrigated carrots however, the soil water availability limitation does not reach a level of expression beyond subclass 2 due to the shallow rooting depth of that crop and the assumption that irrigation water will always be available.

Establishing suitability subclasses for a particular land use may take a considerable amount of research. Information collected during the land resource survey will be used, along with literature reviews and consultation (e.g. with extension officers, researchers, agronomists, economists, farmers, graziers and other informed specialists). Local experience should be collated from a number of sources to determine its consistency and relevance. Suitability subclasses for similar land uses may already have been established in previous land suitability studies. These may be applicable if the land resources and the region can be matched.

Determining critical thresholds

In Table 6, the suitability subclass 1/2 boundary represents the attribute level at which the limitation starts to influence productivity or affect crop management in some way. For each limitation, there is also a critical threshold that determines if land is ultimately suitable or unsuitable for a specific land use (i.e. the class 3/4 boundary). Critical thresholds may be related back to a particular attribute value. For example in Table 6, a PAWC (to 1.2 metres soil depth) of 75 millimetres is the critical threshold for dryland wheat; a lower value makes land unsuitable for dryland wheat. However, for irrigated cotton, a PAWC of 50 millimetres is the critical threshold that determines if land is unsuitable for irrigated cotton. **Establishing the subclass 3/4 threshold is the most important decision in ranking the limitation categories for a specific land use.**

Critical thresholds will obviously vary for different climates and different regions. Critical thresholds may also change over time as technology improves (e.g. new plant varieties are developed that tolerate soil acidity or waterlogging). It is therefore important that the derivation of the critical thresholds within the suitability framework is fully documented. Published data used to define critical values within the suitability framework may include scientific publications that provide research results such as Peverill et al. (1999), or industry publications such as: *Manual of canegrowing* (Hogarth & Allsopp, 2000) or *Edible horticultural crops* (Hackett et al. 1982). For aspects of the salinity limitation, plant salt tolerance information may be obtained from the *Salinity management handbook* (DERM, 2011).

Critical thresholds may be established quantitatively – where measured yield restrictions or additional cost structures are known for a particular district – or quantitatively, based on data obtained during the land resource survey. Quantitative modelling may also be used to supplement or validate the determination of critical thresholds. These models may examine erosion potential under different combinations of attributes or the effects of reduced moisture supply on crop yields. The experience of farmers and agronomists is helpful in providing data on critical thresholds for limitations in a particular area.

3.2.5 Determining suitability class

The ultimate objective of land suitability classification is to allocate a final suitability class (on a scale of 1 to 5) to each UMA, for each specified land use. The suitability subclasses for all limitations that apply to a land use must be considered. The overall suitability class is usually determined by the most severe suitability subclass that applies in a particular UMA. Table 7 illustrates, for one UMA, several limitation categories and the associated suitability subclasses for a range of crops.

Table 7: Example of UMA suitability derivation for five land uses and five limitations

UMA 121	Limitation categories	Suitability subclasses for different land uses				
		Sugarcane	Peanuts	Wheat (dryland)	Banana (irrigated)	Rambutan (irrigated)
	M4 (soil water availability)	2	3	3	1	1
	R3 (rockiness)	3	5	4	2	1
	W3 (wetness)	3	3	3	3	2
	E2 (water erosion)	2	3	3	2	1
	P2 (soil physical factors)	2	4	3	2	2
Overall suitability class		**3**	**5**	**4**	**3**	**2**

Note: the suitability subclasses are examples only and are not to be taken as prescriptive.

The UMA in Table 7 has been assessed as class 2 (suitable land with minor limitations) for rambutan, and class 3 (suitable land with moderate limitations) for banana and sugarcane. However it is class 4 (currently unsuitable) for dryland wheat and class 5 (unsuitable land) for peanuts. The class 4 rating for dryland wheat is due to the rockiness limitation. Two limitations (soil physical factors and rockiness) make this UMA unsuitable for peanuts; however it is allocated as class 5 due to the most severe limitation (rockiness). The E2 (water erosion) category is more limiting for cultivation crops such as peanuts than for a tree crop such as rambutan.

The example in Table 7 illustrates how the matrix of limitation categories and suitability subclasses functions as a set of rules to determine overall suitability classes. It also shows how the overall suitability class could be changed by amending the suitability subclasses. It is advisable to begin with a preliminary rule-set that can be tested and reviewed in the field and in consultation with local farmers, research officers and extension officers. The rule matrix used to determine the overall land suitability classes within a particular survey area or region is often referred to as a suitability framework. It can be quite a large numeric matrix – for example 10 limitations, with a total of 65 limitation categories multiplied by 15 land uses equals 975 rules.

3.2.6 Suitable land area modification factors

One result of the land evaluation process is to calculate the total area of land suitable for specific land uses. However, simply adding up the total area of UMAs deemed to be suitable for a land use may cause an overestimation of the actual land area that is suitable. This could be due to the presence of infrastructure or natural features that are too small to be delineated on the maps at the given scale. In such cases it may be necessary to adjust the calculation of suitable area by applying a modification or adjustment factor. This is simply a number between 0 and 1 (with one decimal place). Such modifications may apply to specific UMAs or to specific land uses and are generally used only in detailed land evaluation assessments (e.g. scale of 1:25,000).

Two possible modification factors are outlined below:

- The *effective land factor* is used to modify the total area of land suitable for a specific land use. For example in a furrow irrigation system, approximately 10% of the arable land is lost due to irrigation infrastructure such as head ditches and tail drains. A factor of 0.9 is consequently applied to the area of each UMA that has been deemed suitable for a furrow irrigated crop. For example, a UMA with an area of 100 hectares would actually have only 90 hectares of suitable land for furrow irrigated crops.
- The *available land factor* is used to apply a one-off reduction in suitable land area within a particular UMA or group of UMAs. Examples of its use would be where features such as a dam, packing shed or a small area of rocky outcrop occur and are not mapped out as separate UMAs due to scale limitations.

It is possible that both modification factors could apply in an individual UMA. Any use of such modification factors should be defined and documented, along with the rationale for their use.

3.2.7 Some issues to consider

The sections above present the process for best practice land suitability assessment. There are of course many variations of this ‘ideal’ approach as no two land suitability projects are the same. The following section deals with some issues that are commonly encountered.

Dominant and subdominant soils

Each UMA will usually consist of a dominant entity – usually a soil type. In general, the attributes and limitations of the dominant entity are used to determine the suitability, in order to reduce complexity in the process. For example, a UMA containing a dominant soil (70% of the UMA) that is rocky and a subdominant soil (30% of the UMA) that is not rocky would have a rockiness limitation that related to the level of rockiness of the dominant soil. If a UMA contains co-dominant entities with significantly different attributes then standard practice is to use the limitations related to the least suitable entity.

Double accounting and flagging

Double accounting implies that the effect of a limitation may be inadvertently assessed more than once in a way that falsely downgrades the classification. For example, soil depth is relevant to both the soil water availability (M) limitation as well as the soil depth (Pd) limitation. If soil depth has been accounted for in the M limitation, the Pd limitation should be applied only when soil depth limits some other aspect of plant growth or management operations (e.g. the ability of a tree crop to withstand strong winds).

In some circumstances the effects of a limitation may be unclear – for example, recharge potential (in secondary salinity). In such cases a suitability subclass of '0' may be applied rather than a value of 1–5, simply to 'flag' the limitation.

Limitations difficult to predict in the field

Some land use limitations are difficult to predict in the field, or may only become evident after the land is used in a certain way (e.g. landslip or secondary salinisation). Therefore on a UMA basis, it may not be possible to fully assess these limitations within a land suitability classification framework. One option is to highlight land that is known to be susceptible to these hazards separately from the suitability classification (such as on a GIS map overlay). Decisions on the preferred future land use may then be made with a clear awareness of the susceptible areas. In other cases it may be possible to describe a limitation, but difficult to spatially delineate it. In this instance, it may be described within a suitability framework but not assessed for each UMA. For example, the effects of frost on crop types may be well known, but there may be insufficient microclimate knowledge in the survey area to clearly identify frost prone lands.

Crisp subclass boundaries

One of the criticisms of conventional land suitability techniques is that the thresholds between suitability classes (and limitation categories) imply that crisp (clear or distinct) boundaries exist. For example in Table 6, the class 3/4 threshold of plant available water for dryland wheat is 75 millimetres. This implies that a soil with 76 millimetres PAWC is suitable for dryland wheat whereas a soil with 74 millimetres PAWC is not suitable. Obviously such a crisp subclass boundary is never observed in the field – crop growth and productivity are commonly gradational characteristics. However, the practicalities of the land suitability approach described in this text are such that crisp subclass boundaries must be created.

Calculation size

The various steps involved in determining suitability classes for each land use can lead to the generation of large data sets. For example, an assessment involving 10 limitations with 65 limitation categories, 15 land uses and 2000 polygons, would generate 65 x 15 x 2000 suitability subclasses (= 1,950,000). While this is not necessarily a challenge to modern computing capacity, it illustrates that care must be taken in managing data to ensure the correct land suitability calculations are made.

Use of suitability subclass ‘0’

A suitability subclass of zero ‘0’ may be used for certain limitations. There are four possible usages:

- to ‘flag’ the limitation where there is uncertainty about whether it should be a value of 1–5
- where there is insufficient information available to separate suitability subclasses 1, 2 or 3 e.g. for furrow irrigation. All suitable soils are given subclass ‘0’.
- where a particular subclass that applies elsewhere in the study areas is not relevant in a particular UMA. For example, when considering discharge potential (Ss), all upper slopes might be given a subclass ‘0’, while lower slopes with existing salinisation may be given a subclass of 5.
- where a particular subclass is not relevant for a particular land use (e.g. certain climate limitations applying to dryland crops may not apply to irrigated crops in the same area).

4 Land use limitations

4.1 Introduction

A list of limitations has been compiled by land resource officers with experience in a wide range of crops in districts throughout Queensland. It is derived from understanding the requirements for crop or pasture growth, machinery use, land preparation, irrigation and the prevention of land degradation. Once limitations were identified, diagnostic attributes were assigned to each land use requirement (Table 8). Table 8 may be used as a checklist from which to identify limitations that are relevant to a particular study area.

Not every limitation listed is relevant to each land evaluation study, geographical region or land use type. Limitations need not be incorporated into the land evaluation framework when:

- particular land uses are not relevant to the study area (e.g. irrigation cropping where no suitable water supply is available or likely to be available)
- diagnostic attributes that determine the limitation do not vary significantly at local or regional scales, such as frost within frost-free areas
- diagnostic attributes cannot be reliably correlated to the mapping units at the mapped scale.

Some limitations (climate C, nutrients N and soil physical factors P) are generally composite limitations, made up of several component sublimitations. A composite limitation, such as ‘P’, may be used on its own in suitability studies, or the specific sublimitations may be used individually (e.g. Pa – soil adhesiveness, Pc – soil compaction, Ps – soil surface condition). It is generally recommended that the specific limitations are dealt with independently, especially for the climate limitation, as this enhances transparency in the methodology and makes the suitability framework easier to apply.

The development and use of various land suitability frameworks in Queensland has revealed that some limitations have universal application, that is, they occur in all land suitability assessments. The most important limitations in Queensland are those that relate to erosion, use of machinery (slope), wetness and soil water availability. The importance of the soil water availability limitation is not surprising, as most dryland cropping systems in Queensland are limited more by moisture availability than any other factor.

In Table 8, it is obvious that some diagnostic attributes are used for determining suitability subclasses for many different limitations. It is often convenient to use soil type (either from formal or informal classification schemes) to rapidly assign diagnostic attributes and/or limitations. This is particularly the case where field restrictions prevent access to every UMA in a survey. Reliability codes can be used to signify where attributes or limitations have not been validated in the field. Table 8 also includes indicators for certain limitations that may not relate directly to quantification of the limitation (e.g. vegetation type for secondary salinity).

Table 8: Limitations, land use requirements and diagnostic attributes for agricultural land uses in Queensland

Code	Limitation	Land use requirement/s	Diagnostic attributes and indicators
A	Wind erosion	Minimal soil loss or plant damage from wind erosion	• Surface soil texture, structure and coherence • Rainfall • Potential evapotranspiration • Frequency of strong winds • Percentage of fine aggregates (<1 mm) • Surface cover
C	*Climate*	*Favourable climate*	
Cp	Precipitation	Adequate seasonal rainfall for dryland cropping; minimise irrigation frequency for irrigated applications	Mean annual rainfall or mean rainfall during growing period
Ct	Temperature	Favourable temperature conditions to meet crop requirements during growing period	• Mean monthly temperature during growing period • Mean monthly maximum and minimum temperatures during growing period • Frequency and occurrence of days when temperature is outside a critical range during growing period or at flowering
Cs	Climate stress	Free of temperature extremes that could damage crops and compromise production	• Frequency, timing and severity of heatwaves • Average number of days with maximum temperatures above or below a certain level at critical periods during growth e.g. fruit setting
Cf	Frost	Frost-free for specific periods	• Frequency and timing of severe frosts • Frequency and timing of light frosts • Landform, aspect and landscape position (e.g. hillslope, plain)

Code	Limitation	Land use requirement/s	Diagnostic attributes and indicators
Cr	Solar radiation	Adequate solar radiation during growing period	• Mean daily sunshine hours during growing period • Mean monthly net radiation or total sunshine hours during growing period • Cloud cover and mean number of rainy days during growing period • Landscape aspect (e.g. north/south facing slopes)
Ch	Humidity	Favourable humidity during growing period	• Mean daily relative humidity during growing period • Average rain days during growing period
Cw	Wind	Favourable wind conditions during growing period	• Landscape orientation and position • Mean daily and monthly wind speed during growing period • Slope, elevation • Extent of open space in the surrounding area
D	Acid drainage water hazard from acid sulfate soils	Minimal environmental and agronomic damage from acid drainage water	• Site factors restricting runoff, infiltration and permeability • Substrate properties • Soil elevation • Soil texture • Self-neutralising capacity • Depth to saturated zone • Presence of potential acid sulfate soils (PASS)
E	Water erosion	Minimal soil loss due to water erosion	• Slope – % slope and slope length • Soil erodibility (USLE ‘K-factor’) • Slope/soil type combinations • Quantity, intensity, distribution and frequency of erosive rainfall • Soil surface condition • Infiltration rate

Code	Limitation	Land use requirement/s	Diagnostic attributes and indicators
Es	Subsoil erosion	Minimal soil loss and land degradation from subsoil erosion	• Depth to dispersible B horizon • Dispersion and slaking tests • Exchangeable sodium percentage (ESP) in upper part of B horizon • Electrical conductivity (EC) in upper part of B horizon • Cation exchange capacity and Ca/Mg ratio of upper part of B horizon • Soil texture • Slope
F	Flooding	Minimal impact of damaging floods	• Frequency of flooding • Period of inundation • Landform, proximity to stream/watercourse • Rainfall intensity/duration • Erosive flooding – depth and velocity of flood flows
I	*Water infiltration*	*Efficient use of irrigation water to effectively wet up (recharge) the soil profile and minimise deep drainage and runoff*	
If	Infiltration – furrow irrigation, deep drainage	Efficient furrow irrigation – minimise deep drainage and prevent waterlogging at top end of furrow	• Infiltration rate • Soil profile permeability class or direct permeability measurement • Soil surface physical factors (see P limitation) including water repellency • Slope • Surface horizon thickness, texture and structure • Depth to impermeable or slowly permeable B horizon • Depth to and degree of mottling
Ir	Infiltration – soil profile recharge	Efficient irrigation – ease of soil profile recharge (wetting up of soil profile)	As above, excluding slope
M	Soil water availability	Adequate water storage in the soil profile to maintain plant growth *(applies mainly to dryland cropping and pastures, but also relevant for irrigation enterprises in terms of frequency and timing of water applications)*	• Plant available water capacity • Soil profile texture • Soil structure • Effective rooting depth • Depth to physico-chemical limitations to root growth • Root density in soil profile • Depth to a watertable

Code	Limitation	Land use requirement/s	Diagnostic attributes and indicators
N	*Nutrients*	*Favourable nutrient conditions*	
Nd	Nutrient deficiency	Adequate nutrient supply	• Nutrient levels in soil – laboratory analysis
Nl	Nutrient leaching	Adequate retention of added nutrients	• Soil colour and texture and mineralogy • Cation exchange capacity and exchangeable cations • Soil pH
Nf	Nutrient fixation	Absence of nutrient-fixing conditions	• Al or Fe oxide content • Humic/organic soils (coastal swampy soils) • Nutrient sorption measurements • Soil type
Nr	Nutrient balance – soil reaction trend (pH)	Soil pH is suitable for plant growth and does not cause nutrient toxicities or deficiencies	• Soil pH
Nt	Nutrient toxicity	Absence of toxic levels of elements	• Chemical analysis of elements • Soil pH
P	*Soil physical factors*	*Favourable soil physical conditions for both plant growth and/or machinery operations.*	
Pa	Soil adhesiveness	Ability to harvest underground crops	• Soil texture • Soil consistence • Clay percentage • Clay mineralogy (clay type)
Pc	Soil compaction	Minimum susceptibility to soil compaction	• Soil texture and particle size analysis • Rigid or shrink/swell soil • Clay mineralogy (clay type) • Soil physical tests (e.g. plastic limit in combination with crop lower limit) • Bulk density • Linear shrinkage
Pd	Soil depth to a physical root barrier. *Effective rooting depth (incorporating physico-chemical constraints to rooting depth) is considered in the soil water availability limitation*	Adequate soil depth for plant physical support, root crop harvesting and plant edaphic requirements	• Depth to impermeable horizon • Depth to hardpan or rock • Depth to continuous gravel layer • Depth to chemical barrier

Code	Limitation	Land use requirement/s	Diagnostic attributes and indicators
Pm	Narrow moisture range	Suitable timing for cultivation	• Surface soil texture • Clay mineralogy (clay type) • Soil type • Plastic limit, drained upper limit
Pp	Excessive permeability	The soil has a capacity to retain ponded water if required for certain crops (e.g. paddy rice)	• Infiltration rate • Soil profile permeability class or direct permeability measurement • Thickness and texture of A and B horizons • Depth to impermeable or slowly permeable layer • Site drainage conditions (e.g. soil colour, mottling) • Profile ESP
Ps	Surface soil condition	Ease of seedbed preparation, no restriction to germination Ease of fruit set (peanuts)	• Surface soil condition (e.g. hard setting, loose) • Surface soil structure, texture and consistence • ESP of surface soil (and plough zone if appropriate)
Pv	Vertic properties	Minimise shrink-swell effects for engineering purposes and for the establishment of certain plants	• Soil cracks open to the surface • Soil physical tests: plastic limit, linear shrinkage • Soil texture (or particle size analysis) • Clay type (measured or estimated by clay activity ratio)
R	Rockiness	Minimal impact from gravel, stone and rock at the soil surface	• Size, type and abundance of coarse fragments on the surface and in the A horizon • Percentage rock outcrop
Sa	Salinity	Low levels of soluble salts in the soil profile. This limitation relates to the physiological expression of salinity in the soil.	• Measurements of soil salinity (EC & Cl) • Indicators of restricted drainage (see wetness limitation) • For irrigation use, chemistry of applied water in relation to soil chemistry

Code	Limitation	Land use requirement/s	Diagnostic attributes and indicators
Si	Recharge potential	Minimum potential to cause secondary salinity	• Landscape position • Soil colour, texture and structure • Soil pH profile • Salinity profile • Field permeability measurement or assessment • Substrate properties • Vegetation type • Infiltration rate
Ss	Discharge potential	Minimum susceptibility to secondary salinity	• Landscape position • Soil colour, texture and structure • Soil pH profile • Soil profile salinity • Soil profile ESP • Substrate properties • Depth to watertable • Vegetation type
T	*Topography*	*Safe and efficient use of machinery, efficient installation and maintenance of infrastructure and/or irrigation requirements*	
Tg	Small gullies	Land surface free of small gullies	• Size, distribution and density of small gullies
Tm	Microrelief	Level land surface	• Occurrence and nature of microrelief • Size, distribution and density of microrelief features
Ts	Slope	Safe and efficient use of machinery	• Slope percentage
V	Vegetation	Free of a vegetation restriction to use, absence of undesirable vegetation	• Structural form (e.g. forest) • Density of woody stems • Species present – woody weeds • Presence and cover of specific weed species
Vr	Vegetation regrowth	Free of vegetation regrowth problems	• Vegetation type and density • Presence of specific species • Propensity of species to sucker • Growth rates

Code	Limitation	Land use requirement/s	Diagnostic attributes and indicators
W	Wetness	Adequate soil aeration	• Site drainage class • Profile permeability class or permeability measurement • Depth to and degree of soil mottling and/or segregations • Soil colour • Profile salinity and ESP • Vegetation present at site • Period of water saturation • Soil structure and texture
X	Landscape complexity	Adequate size of uniform production areas and ability to access them	• Size, shape and accessibility of minimum production areas and UMAs • Size and shape of managerially different land types
Xs	Soil complexity	Relatively consistent and uniform distribution of soil types and soil properties across the landscape. Minimal distribution of managerially different soils	• Variability between adjacent soil types • Complexity of soil distribution pattern
Xt	Topographic complexity	Minimal dissection of the landscape. Short range variation in land slopes	• Distribution and density of watercourses, large gullies or other dissections • Distribution of managerially different slopes
Z	Pests and diseases	Absence of soil-borne diseases and pathogens	• Presence/record of pest or disease organism/s • Average climate statistics during growing period

4.2 Description of limitations

Each limitation is described below in terms of its effects and application, attributes, assessment and subclass determination. The order of limitations is based on the limitation alphabetical code (as per Table 8) and not perceived importance.

4.2.1 Wind erosion (A)

Definition and application

Soil loss due to wind erosion can occur when bare soil is exposed during periods of dry, windy conditions. Wind erosion can also cause sandblasting damage to crops. Wind erosion is usually associated with areas of sparse vegetation and loose soils, such as in the arid zone, on salt pans and on coastal sand masses. Disturbance of the soil surface during dry, windy periods can accelerate this process. Some cropping systems, such as pineapple production on the central

Queensland coast, are prone to soil loss from wind erosion. Frequent tillage, particularly rotary hoeing of sandy surface soils used for vegetables and sugarcane, can increase the susceptibility of soils to wind erosion.

Wind erosion is influenced by both climatic and soil factors. Climatic factors affecting wind erosion include mean annual rainfall, potential evapotranspiration and the frequency of strong winds, especially when soils are unprotected by vegetation. Extended periods of dry weather combined with high temperatures and high wind velocity can contribute to increased wind erosion.

Soil factors include texture, structure (specifically aggregate size) and roughness of the soil surface. The consequences of wind erosion are especially severe where the subsoil of texture-contrast soil profiles (Sodosols, Chromosols and Kurosols) has been exposed due to the loss of thin surface horizons. Land use practices that minimise bare soil surfaces, especially at susceptible times of the year, decrease the potential for wind erosion.

Attribute assessment and subclass determination

Soils susceptible to wind erosion include fine-grained sands (usually on coastal beach ridges or inland levees and sand plains), silty soils and very fine self-mulching clays. Particle size distribution, clay type and soil structure are key attributes.

Subclass limits are based on the management inputs – such as maintenance of surface cover, provision of windbreaks – required to prevent soil loss in areas where there is a risk of wind erosion. Land would be considered marginal or unsuitable where the risk is considered unacceptable and the management inputs required to reduce that risk are not economic for the specified land use.

4.2.2 Climate (C)

Definition and application

Regional climate characteristics are used to select suitable land uses for an area. Variations in climate within a study area resulting from changes in aspect, elevation or maritime influence may also need to be considered.

Unfavourable climatic conditions influence a range of factors relating to plant growth, seed/fruit set and required management operations (such as weed/disease control). Where climate factors are significant enough to affect a land use in this way, they should be considered as limitations in a land evaluation study.

Climate is sometimes considered as a composite limitation where factors such as rainfall, temperature and frost incidence are combined to define climate zones that can be recognised and delineated for a particular area. However, it is recommended that the specific climate limitations that apply in a given area be applied separately, especially if they vary enough in a study area to cause differences in the suitability between UMAs. These are considered below.

Temperature (Ct) and climate stress (Cs)

Temperature affects the growth potential of plants. Some plants may have reduced yield potential due to suboptimal temperatures at critical crop cycle stages. For example, some varieties of maize will have reduced yields if the minimum temperatures are below a critical level at ‘silking’. On the other hand, crops such as chickpeas require cool temperatures for seed set.

Extremes of temperature are also important. Species adapted for temperate climates will be affected by periods of high temperatures, while the growth of tropical species will be limited during periods of cooler temperatures. Plants being grown outside the normal growth cycle in an area – for example by farmers extending their season in an effort to tap into higher early season prices – may be more susceptible to temperature stress.

Heat or cold stress will significantly reduce the yield and quality of small crops (e.g. lettuce) and horticultural crops such as pineapples and mangoes. Livestock may also be affected by periods of extreme heat or cold, and require shelter during these periods.

In some land suitability assessments it may not be possible to combine the various effects of temperature into a single limitation. In this case the Ct limitation should be used for potential reductions in yield due to the likelihood of suboptimal temperatures while the Cs limitation should be used for climate stress due to the likelihood of temperature extremes (e.g. occurrence of heatwaves). The effects of frost are normally considered as a separate limitation.

Frost (Cf)

Plants vary in their tolerance to frost. Some plants are damaged by periods of even a few hours of temperatures near 0ºC, while others do not suffer damage when subjected to longer periods and/or lower temperatures. Frost damages the flowers or fruits of moderately sensitive crops, will reduce vegetative growth and may kill tropically adapted plants. Many plants have increased susceptibility to frost damage at certain stages of their growth cycles, such as germination/ emergence and fruit set.

Local or regional temperature variations can influence the frequency of frosts within a study area. Landform can influence the frequency and severity of frost on a local scale as cold air will tend to settle in low lying positions and cause more severe frosts on calm nights. Aspect may also influence the severity of frost incidence in some localities.

Reliable data on short-range frost differences may be difficult to obtain. Landholders may have direct recordings of frost incidence, or anecdotal evidence of areas that are prone to frosting.

Precipitation (Cp)

Adequate rainfall is required for dryland cropping and pasture growth. A large regional study may encompass several distinct rainfall zones and these are used to determine subclass limits. Rainfall also interacts with soil water storage, so rainfall attributes may also be combined with the soil water availability limitation (M). If distinct rainfall zones are present, different soil water availability subclass limits may apply in the different zones. For irrigated cropping, the amount of rain that falls during the growing period is still a relevant attribute to consider as it will influence the frequency of required irrigation applications. It can also impact on timing of harvest, which can affect the quality and quantity of the crop. In irrigation areas the amount, rate and frequency of rainfall/runoff may influence the availability of irrigation water.

Solar radiation (Cr)

Low solar radiation may reduce net photosynthesis and thus limit crop yields. In North Queensland, crop growth over the wet season may be reduced by lack of sunlight, depending on the severity and extent of wet season cloud cover and rainfall. In southern Queensland, differences in aspect, slope position and elevation may affect the amount of incident sunlight and hence crop growth at a particular site. Similar differences in incident solar radiation are likely along or adjacent to the Whitsunday and wet tropical coasts of Queensland.

Humidity (Ch)

High humidity may inhibit ripening of crops or increase the incidence of disease or pathogens. These may lead to crop or fruit loss or blemishes on produce causing large losses in the quality and value of the crop. High humidity combined with drizzly or misty weather may reduce spray options and exacerbate disease or insect problems.

In some study areas there are significant variations in humidity within a region (e.g. between the wet tropical coast and tablelands). Elevation, aspect and slope position may all affect humidity as well as incidence of misty days.

Wind (Cw)

Horticultural tree crops are particularly susceptible to wind damage and can suffer direct losses from fruit being removed by the wind, trees being uprooted, or branches being damaged, resulting in disease and pathogen attack and fruit bruising. For example, macadamias are particularly susceptible when the nuts are maturing.

Crops can be damaged by extreme weather events such as cyclones in the wet season, intense winter lows or summer thunderstorms. Strong south-east trade winds along the Queensland coast can also cause crop damage. Farmers often use windbreaks along the edges of paddocks or growing areas if there is a frequent occurrence of strong winds.

Wind is used as a limitation only where the effects of wind can be related to land attributes. Damage to a crop by wind will be increased in more exposed areas and these may be indicated by aspect, slope and elevation. These attributes may be derived from the land resource survey or detailed topographic information where available.

Attribute assessment and subclass determination

Values for climatic attributes for different locations are available from the Bureau of Meteorology and similar sources, although the level of detail varies with location. Climate attributes during the growing season of the crop are most relevant and may include:

- mean monthly temperature
- mean monthly maximum and minimum temperatures
- frequency and severity of heat waves
- number of days outside a critical range
- relative humidity
- average rain days
- percentage of cloud cover, hours of sunshine
- net radiation
- mean daily and monthly wind speed and direction
- frequency of damaging frosts
- daily rainfall and monthly/annual/seasonal statistics.

The sparse distribution of meteorological recording stations may mean that differences in climatic attributes can be identified from this data only for broadly defined zones within a study area. However, climate models accounting for topographic and location factors increase the precision with which some attributes can be estimated. Derived climate data are available for many climate attributes, for example in SILO (Jeffrey, 2006).

Digital elevation models (DEMs) can be useful to determine aspect, elevation and slope attributes. However, only very high resolution DEMs (pixel size less than about 30 metres) are suitable to be used at the scale appropriate for small land parcels. These derived landscape features can then be used to supplement local knowledge, site data and meteorology data to determine microclimate characteristics that can in turn be used to define the climate limitations (Kidd et al. 2015).

For broadscale studies, climate zones within the study area are often constructed to delineate broad areas of climatic difference. Where differences in climatic attributes between zones are sufficient to affect suitability ratings, UMAs within each zone are given the limitation category relevant to that zone. Further refinement of climatic limitations may be possible if the level of limitation can be correlated with particular landforms.

Subclasses for climate limitations are derived by matching the published data on the climatic requirements of crops with the available climate data for a zone. For frost, wind and solar radiation, landscape attributes may be factored in to the assessment.

For certain land uses, the effects of some climate limitations may be reduced by using management techniques such as adjusting planting times or varieties, more frequent fungicide or pesticide applications to reduce disease incidence from high humidity, or constructing windbreaks to shelter crops from wind damage. The local acceptance of the required inputs to overcome these limitations should be used as a guide for determining subclasses.

4.2.3 Acid drainage water hazard (D)

Definition and application

The acid drainage water hazard applies particularly to acid sulfate soils (ASS) and the hazard that these soils pose to adjacent waterways. ASS are soils, sediments or other materials containing iron sulfides and/or acidity generated by their breakdown. These materials are environmentally benign when left undisturbed in an aqueous, anoxic environment but when exposed to oxygen the iron sulfides break down, releasing large quantities of sulfuric acid and soluble iron. Both substances have considerable ability to degrade the natural and built environment and the acid can mobilise other pollutants (e.g. aluminium, lead, zinc).

ASS are usually found at elevations of less than 5 metres Australian Height Datum within poorly drained horizons of coastal alluvial plains, marine plains and swamps, although they can be found at higher elevations. They can also develop in inland locations, usually in association with areas of salinised/waterlogged land. Unoxidised material is commonly referred to as potential ASS (PASS) due to its potential to produce acid if disturbed. Some PASS can have inherent self-neutralising capacity. Partially or fully oxidised ASS with low pH (<4) is commonly referred to as actual ASS (AASS).

The focus of this limitation is on the potential for acid drainage to enter surface water or groundwater and cause both on-site and off-site impacts. This limitation does not deal directly with the chemical attributes of AASS. Actual acidity present in the soil should be assessed using the soil pH limitation (Nr) and related metal toxicity should be assessed using the element toxicity limitation (Nt). Similarly, aspects of the presence of PASS will have a bearing on the wetness limitation (W).

Attribute assessment and subclass determination

The acid drainage water hazard is assessed according to the presence of and depth from the ground surface to the PASS layer. The assessment of AASS and PASS is described in the

Queensland acid sulfate soil technical manual (e.g. Ahern et al. 1998; Ahern et al. 2004; Dear et al. 2014). The assessment includes field texture categories or laboratory determined particle size content as this provides a guide to the natural pH buffering capacity of the soil. Landscape attributes such as surface gradient, fluctuating groundwater tables, incised stream channels as well as the presence, density and depth of drains within an area contribute to the movement of acid from an oxidising zone into a water body.

The subclass rating effectively describes the level of management required to control and manage acid drainage water when ASS are cultivated and drained for agricultural production. Cultivation and drainage works typically cause acid drainage when PASS is present at depths shallower than the depth of the proposed soil disturbance. For example, an acid drainage hazard would exist where:

- PASS is present 0.5–1.0 metres below the land surface and drains are >0.5 metres deep
- AASS is present 0–0.5 metres below the land surface and deep cultivation and shallow surface drains are present.

In general, drainage works should be shallower than the depth to PASS if acid drainage water hazard is to be avoided. For example, moderately deep drains (about 1 metre) are generally adequate for crops with rooting depths ≤1 metre. However, where sulfidic sediments are present at depths >1 metre, a reasonable buffer (e.g. >0.5 metre) should exist between the depth of disturbance and the depth to PASS.

Crop-specific comments

Acid and waterlogging tolerant crops and native vegetation may play a role in the formation of acid drainage water through their ability to dry the root zone. Consequently, root zone depth is an important factor in determining the likelihood of development of acid drainage water. Shallow-rooted crops such as turf will create less risk than deeper-rooted crops such as sugarcane.

4.2.4 Water erosion (E)

Definition and application

The water erosion limitation considers the potential impact of accelerated erosion of the land surface caused by various human activities. Most agricultural land uses increase the potential for soil loss from water erosion due to an increased volume of runoff, increased velocity of water flow, and decreased protection of the soil surface when devoid of surface cover. The rate of soil loss will increase above natural levels in many localities where surface water is concentrated, such as at water outlets and cross drains, particularly where these are located in flood-prone areas.

Some soils have a low surface erodibility, but high subsoil erodibility – for example Sodosols with hard setting surfaces. Therefore, it is recommended that subsoil erodibility be considered as a separate limitation (subsoil erosion, Es) or included as a distinct diagnostic attribute within the water erosion limitation.

Attribute assessment and subclass determination

Soil loss due to water is determined by climatic factors (e.g. amount, distribution and intensity of rainfall), landform (e.g. gradient and slope shape), soil factors (e.g. infiltration rate, soil dispersibility and erodibility), surface cover and management practices.

Rainfall erosivity is the main climate risk factor associated with soil erosion. It is defined as a function of rainfall energy in tonne-metres per hectare (E) and the maximum 30-minute intensity of each storm (I30) summed over time (Rosenthal & White, 1980). The higher the rainfall erosivity (EI30), the greater is the risk of soil erosion. Seasonal erosivity for Queensland may be obtained from Rosenthal and White (1980) and Rosewell (1993). If the study area includes zones of different rainfall erosivity, water erosion hazard should be assessed independently in each zone.

The surface erodibility of various soils can be ranked using a soil erodibility factor known as the USLE K-factor (Loch et al. 1998). Soil attributes used in the derivation of K-factor include soil permeability, surface soil structure, organic carbon and laboratory particle size analysis (which may be approximated from field texture). Where actual research data is not available, the K-factor may be estimated using the equations of Rosewell and Loch (2002) or Lu et al. (2003). Rosewell and Loch (2002) also provided a chart for ranking erodibility classes. Soil types, or some Australian Soil Classification (ASC) soil classes, may be used to help convey information on soil erosion potential.

Subclasses are based on the added management operations required to control erosion. Interpretation of erosion potential and specification of the required management inputs is most readily done through consultation with local experts. Accepted practices in terms of soil conservation measures required to control erosion (e.g. contour banks) will vary between land uses and regions and should be described clearly in any suitability framework. Subclasses may then be described in terms of the slope ranges permitted for each land use and soil type.

4.2.5 Subsoil erosion (Es)

Definition and application

The potential for subsoil erosion due to dispersible (and/or slaking) subsoils is a hazard for certain soil types and land management operations. Dispersion of subsoils may result in gully, tunnel or stream bank erosion. There is increasing demand for assessments of subsoil erosion risk for non-agricultural operations such as trenching for pipeline installation.

Attribute assessment and subclass determination

The major soil profile properties assessed for this limitation are the dispersibility of the subsoil and the depth at which dispersible subsoil occurs. A potential for subsoil erosion does not necessarily correlate with increased erosion risk at the soil surface. Dispersion is easy to detect using a field dispersion test. Other indicators related to dispersion are the exchangeable sodium percentage (ESP) of the soil, the sodium adsorption ratio (SAR) and the electrical conductivity (EC) of water extracted from the soil. Soils with a high ESP (or SAR) and low EC have a tendency to disperse. Soils with a low ratio of exchangeable calcium to exchangeable magnesium (Ca/Mg) also show an increased tendency to disperse. Subsoil erodibility may also be influenced by the hydraulic gradient within the soil profile, clay mineralogy and particle size distribution. Cation exchange capacity (CEC) and clay percentage are required for the correct interpretation of ESP data – the lower the clay content and/or CEC, the less significant the role of the ESP. For the correct methods to use when determining CEC and exchangeable cations, readers should consult Soil Science Australia (2013).

Subclasses are typically based on soil data and slope classes. Soil types, or some ASC soil classes, may help in the allocation of subclasses.

4.2.6 Flooding (F)

Definition and application

Crop or pasture damage due to flooding may result from moving water, submersion by standing water, erosive flooding or the deposition of sediment. Periods of inundation cause damage by depriving the plant of oxygen (i.e. creating anaerobic conditions). Damage due to the prolonged waterlogged conditions after floodwaters have receded is not covered by this limitation, but is dealt with in the wetness limitation (W).

Flowing water can flatten the crop (lodging) or expose roots. Erosive flooding due to high-velocity flows is more likely to occur on particular landforms on the floodplain, such as channel benches and scroll plains, resulting in crop losses and damage to infrastructure.

Plants vary in their capacity to withstand submersion or moving water. Short periods of inundation may benefit growth through increased water availability or addition of nutrients. The level of acceptable flooding will vary with land use and region. A degree of flooding is almost certain in every wet season for low-lying areas in the tropics, whereas it is less common in the south of the state.

Management operations and land use choice may mean that the flooding limitation can be ignored (or significantly downgraded) even in areas prone to flooding. Examples of this include seasonal crops grown in the winter (or dry season) in central and northern Queensland.

Attribute assessment and subclass determination

The flooding limitation is assessed by considering the period and depth of inundation, and/or frequency and velocity of flooding. Detailed quantitative data may be available from flood maps, satellite imagery of flood events, ground observations and local knowledge. In the absence of such data, it may be interpreted from elevation data (DEM), landform, hydrology, climate and vegetation.

Subclasses are based on the frequency, duration, depth and season of flooding and the likely loss of production owing to: (a) crops or livestock losses, (b) loss of access to crops and livestock, (c) damage to infrastructure, or (d) soil loss. Subclasses may also be based on the added inputs required for flood protection measures such as levees or drains. A ranking process may be used to determine subclasses for particular land or soil types, using local knowledge of the flooding hazard.

4.2.7 Water infiltration – irrigation (I)

Definition and application

This limitation applies only to irrigated land uses. The amount of water applied and the rate of application must match the infiltration characteristics of the soil in order to wet up the soil profile completely, but at the same time minimise deep drainage and runoff. Additional management requirements for spray and furrow irrigation are associated with surface sealing, slow permeability and runoff.

Infiltration – furrow irrigation, deep drainage (If)

This limitation assesses the suitability of land for furrow irrigation in terms of infiltration and the minimisation of deep drainage. It does not apply to other irrigation methods nor does it consider the water availability or infrastructure requirements necessary for successful furrow irrigation. Crop type is also not considered as this limitation refers to this specific irrigation method only. Areas considered unsuitable for furrow irrigation (e.g. excessively drained, deep sandy soils) may be suited to other forms of irrigation.

Additional management requirements for furrow irrigation are associated with short furrows or waterlogging in the upper end of furrows, if furrow lengths are too long or if upper end gradients are too low. Gradients and lengths of furrows should be designed to meet the water application rate, the infiltration characteristics of the soil and the sensitivity of the crop to waterlogging (Loveday, 1981). The potential for soil erosion in the furrow must also be considered, and this increases with furrow gradient (Shaw & Yule, 1978). These requirements illustrate why laser levelling is very important, especially on low slopes. Muchow and Yule (1985) suggested slopes should exceed 0.1% (1:1000). Jobling (1976) also provided guidance on slope requirements for furrow irrigation. Waterlogging problems associated with furrow irrigation on slopes less than 0.1% will be reduced if furrow lengths are shortened. On more steeply sloping land (greater than 1%) the furrow gradient can be reduced by aligning furrows across the slope.

Infiltration – soil profile recharge (Ir)

This limitation assesses the suitability of land for various forms of irrigation in terms of the capacity for irrigation to recharge the soil water deficit completely. Profile infiltration is affected by both surface infiltration and soil permeability. Local experience in some areas indicates that fine loamy or silty surface soils may slake and seal under irrigation, particularly spray irrigation. A slow rate of infiltration can result in incomplete recharge of the rooting zone, increased runoff and more frequent irrigation. Soils with a high sodicity in the upper profile have low soil permeability and therefore reduced ability to recharge the soil profile. Surface soil conditions that affect irrigation applications may also be considered as a soil physical factor (Ps) limitation.

Attribute assessment and subclass determination

Surface soil physical factors (see the ‘P’ limitations, Section 4.2.10), surface infiltration and soil permeability are assessed. Attributes indicative of surface condition, surface infiltration and permeability include soil texture and soil structure (grade, type and size), sodicity and the presence of a salt bulge. Soil permeability may also be inferred from the ASC class (e.g. Ferrosols, Kandosols and Tenosols generally have moderate to high permeability). Surface infiltration and soil permeability are considered in relation to slow soil profile recharge, excessive water loss (deep drainage) or additional management requirements. Surface infiltration rate measured with a disc permeameter and hydraulic conductivity measurements are required. Slope limits need further substantiation for each soil and crop management system.

Furrow irrigation – deep drainage: Slowly and very slowly permeable soils are given a suitability subclass rating of 1 to 3 (i.e. suitable for furrow irrigation). Moderately and highly permeable soils to at least 1 metre depth (e.g. those with sandy textures) are unsuitable.

Subclasses relating to furrow gradient can be defined by slope limits for each soil type or soil group. The range of gradients at which runoff, erosion and waterlogging effects are minimal for the soil groups determines subclass 1. The slopes at which these effects are unacceptable either in terms of excessive soil losses, yield reduction from waterlogging, excess water loss or additional management requirements establishes subclass 4. The maximum and minimum slopes for subclasses 2 and 3 must be established between the extremes of subclasses 1 and 4. In establishing the upper limits of subclass 3, consideration must be given to the gradient at which a furrow can be positioned across the slope before overtopping occurs. Risk of overtopping is also dependent on depth and shape of furrow, and rainfall/runoff rates. Consider the maximum permissible runoff velocity for the grade/soil type combination that minimises erosion risk.

Soil profile recharge: Soils with slow surface infiltration (e.g. those with massive hard setting surfaces) and/or slow to very slow soil permeability (to 0.5 metre depth) are given a higher subclass rating (i.e. less suitable).

4.2.8 Soil water availability (M)

Definition and application

All plants require adequate moisture to achieve optimum production. Soil water availability is assessed in terms of the capacity of the soil to retain and supply water for plant use, while recognising that different species will differ in their ability to extract soil water. Plant available water capacity (PAWC) provides the best estimate of a soil's moisture storage capacity. PAWC is the difference in volumetric water content between the drained upper storage limit and the lower limit after extraction of moisture by a crop. Historically the upper limit was referred to as field capacity and the lower limit was referred to as permanent wilting point. The terms currently in use are drained upper limit (DUL) and crop lower limit (CLL).

The effective rooting depth (ERD) of a soil is integral to assessments of soil water availability. If no chemically or physically restrictive layer occurs, ERD is taken as the depth to which approximately 90% of plant roots will extract water. Root restricting layers may be indicated by morphological features such as the presence of mottles, hard rock, hardpan or gravel layers or by certain chemical attributes, including very high or very low pH, element toxicity, high electrical conductivity (EC), high chloride (Cl) content, low Ca/Mg ratio and/or high ESP. PAWC for a soil profile is calculated by summing the PAWC for each layer within the ERD.

In dryland cropping and pastures, soils with restricted soil water availability are downgraded because of the effect on production. Estimates of seasonal soil water availability are based on the water storage capacity of soils, rainfall and evaporation, or by methods that model the seasonal fluctuations in the soil water store. For irrigated land uses, a low soil water storage capacity means more frequent and/or larger irrigation applications are required to attain optimum yields.

Attribute assessment and subclass determination

Baker and Ahern (1989) found that the assessment of soil Cl, EC and pH changes in the soil profile provided satisfactory estimates of effective rooting depth for Vertosols, sodic texture-contrast soils and miscellaneous free draining soils. Dang et al. (2010) found that Cl concentration was a more effective indicator of reduced water extraction and reduced grain yields than either EC or ESP. In addition, depth to soil mottling could also estimate rooting depth in Vertosols and sodic texture-contrast soils. Depth to a carbonate or gypsum layer in the subsoil may also indicate the depth of the regular wetting front, and therefore the regular rooting depth in some soils.

Measurement of PAWC in the field has been undertaken by research workers for a limited number of soil profiles – mainly Vertosols used for dryland cropping, for example, Dalgliesh and Foale (1998), Dang et al. (2010), and Stuart Buck, Department of Agriculture and Fisheries (unpublished). Further information can be gained from texts such as Williams (1983), Williams et al. (1983), Gardner (1988), McKenzie et al. (2004) and the APSoil website (www.apsim.info/Products/APSoil.aspx). There are numerous pedotransfer functions that can be used to estimate PAWC. In Queensland the PAWCER program (Littleboy & Glanville, 1995) has been used. The equations used in PAWCER are those of Littleboy (2002) using particle size distribution, bulk density and –1500 kPa moisture content (–15 bar moisture content, which is assumed to approximate crop lower limit). The equations were developed from regression analysis of PAWC data reported by a number of authors and tested on an independent dataset containing a range of soils (Littleboy, 2002).

Because crops vary in their rooting depths and their capacity to extract water from soil, the PAWC of a given soil type may vary according to crop species. Well calibrated crop growth/water balance models such as APSIM (McCown et al. 1996) and HowLeaky (Freebairn et al. 2003) clearly relate the assessment of PAWC to crop yield.

It is essential to specify the soil depth that is associated with any PAWC value used in the assessment of the soil water availability (M) limitation. In fact, it is recommended that for the M limitation, different sublimitations be used for different soil depths, depending on the crop type being considered. For example:

- M1 (PAWC to 0.5 metres) for small crops such as cucurbits, tomatoes and pineapple
- M2 (PAWC to 1.0 metre) for cereal crops such as wheat, maize and sorghum and small tree crops such as bananas and carambola
- M3 (PAWC to 1.5 metres) for deep-rooted tree crops such as avocado, coffee and plantation timbers.

Dryland cropping

It is desirable to decide on a minimum long-term economic yield as a basis for determining the suitability class 3/4 boundary. It is therefore necessary to relate attribute levels (e.g. PAWC) to crop yields. When estimates of soil water storage capacity are the only information available, soils are ranked on this basis, and any historical yields for each soil obtained. If complete data is available, the class 3/4 boundary is more readily established. When yield data is incomplete, interpolation from available data, or extrapolation from similar situations, may suffice

Where little data is available, it is advisable to carry out some form of water balance modelling. Crop water balance models use actual rainfall data to provide reliability data for achieving a prescribed soil water supply to the plant at any point in the crop cycle. This can be expressed as a moisture index, that is, the ratio of supply to potential plant usage. Some models express this in terms of yield, and hence a relationship between hydrologic parameters such as PAWC and yield can be obtained. Modelling therefore provides the most realistic means of establishing the subclass 3/4 boundary.

Irrigated cropping

Less frequent irrigation is required for soils with a higher PAWC. Water balance modelling may be used to calculate the relationship between frequency of irrigation and PAWC. Soils with a lower PAWC may be downgraded if the cost of more frequent irrigation is significant.

4.2.9 Nutrients (N)

Definition and application

Plants and animals require adequate but not excessive levels of nutrients to maintain growth. Periods of inadequate supply may cause reductions in plant yield, particularly during critical periods such as flowering or fruiting. Livestock production may be limited by a reduction in either pasture growth or nutritive value caused by low soil nutrients.

Soil properties such as low nutrient-fixing capacity or high leachability will increase the management inputs required to overcome nutrient deficiencies. Excessive concentrations of some elements can reduce plant yields or be toxic to grazing animals.

Rather than a general nutrient limitation (N) it is recommended that specific sublimitations be used as required. The sublimitations of nutrient deficiency (Nd), nutrient leaching (Nl), nutrient fixation (Nf) element toxicity (Nt) and soil pH (Nr) are considered below.

The addition of fertilisers is an accepted practice for many land uses and therefore limitations relating to nutrient status are generally not regarded as being severe, especially for irrigated cropping. However, returns may be too low or unreliable to justify the application of fertilisers in more extensive land uses such as grazing or broadacre dryland cropping in marginal rainfall areas. The nutrient deficiency limitation (Nd) may then be used to downgrade suitability. This limitation is also used where nutrient levels are inherently low and amelioration requires a large initial fertiliser application to overcome the inherent deficiency and maintenance applications to replace nutrients used by the crop or pasture with time.

Additional management such as split fertiliser applications or slow release fertilisers may be necessary to overcome nutrient deficiencies in: (a) well drained soils with a low CEC due to the leaching of added nutrients out of the root zone, or (b) soils where nutrients are bonded or fixed to soil minerals (e.g. phosphorus bonding to sesquioxides in soils such as Ferrosols and Kandosols). The nutrient leaching (Nl) or nutrient fixation (Nf) limitations can be used to downgrade such soils.

Plant growth may also be inhibited either by high levels or a high proportion of specific ions in solution. These effects may be evidenced at levels below those that would affect plant growth from a high total soluble salt concentration. Examples of ions that display this effect on certain crops include chloride, aluminium, manganese, sodium and boron.

The solubility of some common elements may be pH-dependent (e.g. aluminium and manganese). Toxic levels of these elements may be associated with low soil pH (i.e. pH <5.5) and are common in actual acid sulfate soils. This limitation may be overcome in surface soils by pH adjustment (e.g. liming). In some cases, high levels of elements do not affect plant growth, but can cause problems with grazing animals (e.g. selenium) or off-site environmental impacts.

The element toxicity limitation (Nt) may be used where toxic levels of elements are identified, particularly aluminium, but may also include sodium where the total concentration of soluble salts does not constitute a salinity limitation. This limitation should not be used where yield reduction is associated only with poor soil physical conditions associated with high exchangeable sodium or magnesium percentages. Alternatively, a nutrient balance limitation (Nr) based on soil pH may be used as a surrogate for either nutrient toxicity (common in strongly acid soils) or nutrient deficiency (common in strongly alkaline soils).

Attribute assessment and subclass determination

Nutrient levels to determine deficiencies or toxicities are estimated from the results of a standard range of laboratory tests done on representative profiles of major soil types. Applicable nutrient assessment tests are described by Rayment and Lyons (2011). Interpretation of laboratory tests is provided by such texts as Peverill et al. (1999), Baker and Eldershaw (1993) and Hazelton and Murphy (2007).

Nutrient leaching can be implied by the presence of pale soil colours and coarse soil textures, as well as low cation exchange capacity, base saturation and organic matter contents. Nutrient fixing is generally associated with certain soil types and may be estimated from sesquioxide levels, organic matter and soil colour. Subclasses are based on the inputs required to overcome the nutrient limitation (e.g. fertiliser requirements, pH adjustment, soil amendments) or crop yield decrease. The level of inputs required to overcome the limitation can be inferred from research on fertiliser application rates required for problem soils. Land that requires additional management to maintain production can be downgraded accordingly. Subclass boundaries are derived from the local acceptance of inputs and/or economics.

Class 4 land (for any nutrient limitation) would be identified only for extensive land uses (low returns per hectare) where further studies would be required to determine whether the limitations could be reduced to achieve sustained economic production. For many land uses where the application of fertilisers is accepted as a standard management practice, land might only be downgraded to class 2 by this limitation.

4.2.10 Soil physical factors (P)

Definition, application and subclass determination

A number of soil physical properties affect land use. Soil physical limitations may be considered as a generic single limitation (P), or as a specific sublimitation as detailed below.

Suitability subclasses are based on the extra management required on soils that have physical limitations. For all physical factor limitations, except Pd soil depth, management inputs include the addition of soil amendments or increased/modified tillage operations. Where these inputs are not practical, classes are based on the expected effects on crop yield as a result of these limitations. Table 8 includes a full list of the soil attributes that are assessed when considering each of the sublimitations. Typically, local experience within a particular district provides a useful guide to problem soils and their characteristics.

Soil adhesiveness (Pa)

Harvesting of crops where the harvested material is below the ground surface (roots, tubers, underground fruit), is more difficult in soils that adhere to the harvested product or harvesting machinery, compared to those soils that do not. Further problems are encountered when cleaning is needed to remove soil in preparation for marketing, as this added process can be costly or damaging to the produce. Adhesive soils are prone to significant levels of soil disturbance during harvesting and may be subject to increased compaction and declining structural stability. This limitation applies only to crops that have underground harvest material and is more severe for crops that are easily damaged during handling.

Attributes used to indicate potential problems include soil texture, structure, consistence and clay mineralogy.

Susceptibility to compaction (Pc)

Frequent trafficking and cultivation of soils susceptible to compaction may cause compacted layers to develop directly below the soil surface or below the plough layer. Such compacted layers may restrict seedling establishment and root penetration into the underlying soil material, limiting the availability of water and nutrients. Occasional deep ripping, use of tracked machinery or permanent track cultivation is required to prevent adverse effects on crop growth in susceptible soils. Crop rotations incorporating deeper rooted crops and the introduction of a pasture phase may be used to ameliorate the effects of compaction.

If crops cannot dry a clay soil to a non-plastic (rigid) state, i.e. where the moisture content at the plastic limit is drier than at the wilting point (as estimated by crop lower limit), then these soils are highly susceptible to compaction. Shrink-swell clays have a natural ability to crack and self-repair if compacted; non-cracking soils (which can be inferred from a linear shrinkage test) are slow to repair, and would therefore benefit from mechanical remediation.

Compaction vulnerability will rarely render a soil unsuitable for cultivation. However, land may be downgraded in suitability due to the added management costs required to overcome this limitation. Attributes used to indicate potential problems include soil texture, structure and consistence, clay mineralogy and the results of soil physical tests.

Soil depth (Pd)

All crops require an adequate depth of soil to provide physical support for the aerial portion of the plant. Requirements for physical support increase with crops that have large canopies such as tree crops. Adequate soil depth is required to facilitate the harvesting of root crops and meet the edaphic requirements of certain crops (e.g. avocado).

Soil depth here refers only to the depth of a physical root barrier (hard rock, continuous cemented hardpan or continuous gravel layer). Effective rooting depth (incorporating physico-chemical limitations to root growth) is considered primarily in the soil water availability limitation. Physico-chemical constraints to root growth (such as very strong acidity, high soil salinity and very strong sodicity) may also overlap with other limitations such as nutrient toxicity, salinity and wetness. Where the underlying hard material is highly weathered or fractured, plants may have a rooting depth that is greater than the depth of soil.

The soil depth limitation is only applied in cases where a crop requires a depth of soil in excess of what is required for water or nutrient supply. Subclasses are based on the effect of the rooting depth on crop persistence or yield, or the management inputs required to increase the rooting depth (e.g. mounding). Published data on rooting requirements of the crop, for example Hackett et al. (1982), are matched to measured or estimated soil depth to give subclasses.

Narrow moisture range (Pm)

The moisture content of a soil can be an important factor in determining its capacity to be cultivated efficiently to achieve the desired result within the constraints of available machinery. Some soils may be cultivated at virtually any moisture content, while others can only be cultivated efficiently over a very narrow moisture range. Soils with moisture contents above that range are too wet to cultivate; and cultivation of the soil at moisture contents below that range gives a coarse seedbed. In some older soil suitability reports, this limitation may have been referred to as the 'workability' limitation.

Timing of cultivation may be critical for operations such as planting or cultivation to control weed growth. Such operations will be inhibited on soils with a narrow moisture range at which they may be cultivated. The effects are more pronounced for land uses where timing of operations is critical to achieve favourable market prices.

Narrow moisture range may be considered a limitation for any land uses where cultivation is required. However, accepted farming systems adopted within a region may mean that this limitation is not considered as important as it once was. For example, a large proportion of the irrigated and dryland broadacre cropping soils in inland Queensland are Vertosols. These soils generally have a narrow moisture range, yet this property has been accepted and incorporated within the adopted farming systems. However, soils with narrow moisture range may restrict the choice of new land uses such as annual irrigated small crops.

Excessive permeability (Pp)

Some crops, such as paddy rice, require ponded water for growth. Such crops have historically been grown in Queensland. Ponded water may also be a requirement for certain pasture species and in jute production. Excessive permeability to a significant depth increases the quantity of water required to maintain the ponding. In permeable soils, the required frequency of irrigation makes ponding water impractical.

This limitation is similar to the If limitation (infiltration – furrow irrigation). However, the furrow irrigation limitation incorporates extra attributes specifically related to furrow irrigation such as furrow length and furrow gradient.

Where soils have a thick, freely draining A horizon overlying an impermeable B horizon, further problems may be encountered when building banks to hold water. Impermeable material needs to be within 0.3 metres of the surface to enable construction of stable banks.

The water requirements needed to maintain ponded water are assessed from the soil permeability to a specified depth and site drainage conditions. Permeability can be measured directly for each soil horizon using field techniques, or inferred from soil profile attributes (e.g. thickness and texture of A and B horizons, soil structure and visible pore space. Indicators of site drainage are depth to an impermeable or slowly permeable layer, soil colour, degree of mottling or gleying, and the presence of ferromanganiferous nodules, see McDonald and Isbell (2009).

Subclasses are based on the management inputs required to maintain ponded water (including constructing and maintaining banks). Soils that are permeable to depth require increased irrigation frequencies, and these are obviously less suitable for these specialised land uses.

Surface soil condition (Ps)

Seedling emergence and establishment are affected by adverse physical conditions of the surface soil including hard setting, crusting, coarse self-mulching, hydrophobic or tough clay conditions.

Silty, hard setting surfaces that restrict water infiltration may be downgraded (i.e. have a higher subclass) for spray irrigation applications, as efficient water entry into the soil profile will be restricted. Furrow or trickle irrigation applications are less affected by this limitation. This situation can be managed by maintaining moist surface conditions to reduce the strength or consistence of the soil surface and increasing the frequency of irrigations.

Adverse surface soil conditions will also affect fruiting in crops that fruit underground, such as peanuts. Favourable surface soil conditions are more critical for these crops during fruiting than for seedling establishment.

This limitation is used to downgrade suitability where poor surface conditions affect production, or where increased management inputs are required to manage those soils.

Vertic properties (Pv)

Soils with shrink-swell characteristics (vertic properties) can significantly affect land use and the selection of crop type. These soils are typically cracking clays or Vertosols (Isbell, 2002). The shrink/swell behaviour of vertic soils can physically damage infrastructure and the root systems of plants. The establishment of certain tree crops (with large tap roots) is especially difficult in strongly cracking soils. In irrigated land uses, the effects of soil cracking can be addressed to a certain extent by maintaining moisture in the soil, thereby reducing soil shrinkage. The vertic properties limitation is used only where land use is affected by the shrink-swell behaviour of vertic soils. Other properties of cracking clay soils may relate to other soil physical factor sublimitations (e.g. soil adhesiveness, narrow moisture range), so care must be taken to avoid double accounting in limitations.

4.2.11 Rockiness (R)

Definition and application

Rockiness refers to rock outcrop and coarse fragments at the soil surface. For land uses requiring cultivation, coarse fragments in the surface soil (A1 horizon) or plough zone are also considered. Stony or rocky soils impede cultivation, damage tillage and harvesting machinery and deform underground plant components. The effects vary with the size, content and distribution of coarse fragments. The limitation is most severe in soils with a high percentage of large stones distributed throughout the plough layer. The presence of a high stone content in soils may also influence soil properties such as increasing infiltration rates while decreasing soil erosion, susceptibility to compaction, soil water storage and the surface area available for plant growth.

The expression of a rockiness limitation will vary with crop type. For instance, it affects both tillage and harvesting operations for root crops and peanuts, whereas it affects mowing/baling operations for hay crops such as lucerne. Tree crops are generally only affected during ground preparation and planting, however gravel can interfere with harvesting operations associated with macadamias.

Attribute assessment and subclass determination

Assessment of rockiness is based on the size, abundance and distribution of coarse fragments and stone on the surface and/or in the surface soil and on the abundance of rock outcrop using the categories outlined in McDonald et al. (2009). These attributes are recorded in the field at each survey site and are often described for each land type or UMA in the land resource inventory.

For land uses that require cultivation, subclasses are based on the added inputs required for cultivation and harvesting operations (e.g. machinery failures) or the inputs required to remove the limitation (e.g. stone picking).

Subclasses for grazing are based on the decreased productivity associated with large amounts of surface stones and rock outcrop and possibly the potential impacts on mustering and other operations.

4.2.12 Salinity (Sa)

Definition and application

The salinity (Sa) limitation refers to high levels of soluble salts in the soil profile. This may be a natural feature (primary salinity) or the result of hydrologic disturbance or the application of saline irrigation water (which are both forms of secondary salinity). Potential for the development of secondary salinity as a result of hydrologic disturbance is considered in Section 4.2.13 below.

Moderate salinity levels retard the growth of sensitive plants and reduce yield, while high salt levels may kill plants and lead to soil structural degradation. Plants are generally more susceptible to soil salinity during germination and seedling establishment phases. High soil salinity induces plant water stress by increasing the osmotic pressure plants must exert to extract soil moisture. The severity of this effect is related to the total concentration of salts in soil solution. High levels of soluble salts in the soil profile are also commonly associated with high ESP and may be associated with other subsoil constraints to plant growth such as acidity or alkalinity (see Section 4.2.9).

The toxic effects of specific ions can also reduce plant growth. For some species the effects are dependent on the ionic composition of the soil solution as well as the total ion concentration (e.g. the content of sodium, chloride, sulfate, magnesium, bicarbonate and boron in the soil solution). Occasionally, a high level of a specific soluble ion can be identified as limiting plant growth, even though the total salt content is not as limiting. In such a case, the effect is assessed as part of the nutrient toxicity (Nt) limitation.

Caution should be used in assessing salinity in soils, as it may be a transient feature (DERM, 2011). Under native vegetation, the concentration and position of salts in a soil profile is in equilibrium with a variety of influencing factors, such as clay content, clay mineralogy, rainfall and sodicity. After tree clearing, more water percolates through the soil and salts leach to deeper levels of the soil profile (DERM, 2011). Therefore, the severity of the salinity limitation may decline with time. Similarly, when additional water is applied to the soil (as in irrigation), salts may be leached to lower depths in the soil profile. However, irrigation water that is high in soluble salts can lead to increased soil salinity as well as toxic ion effects.

Attribute assessment and subclass determination

In Queensland, soil salinity is most commonly measured as the electrical conductivity of a 1:5 soil/water solution ($EC_{1:5}$) or the chloride concentration (Cl) of the same solution – both are determined in the laboratory. $EC_{1:5}$ may also be measured in the field as it provides soil salinity data that is easily and quickly collected. Field data is usually supplemented with data from a limited number of laboratory analysed representative sites or from samples from suspected or known salinity sites within a project area. Care must be taken with field EC measurements to consider the impacts of gypsum if present. Where gypsum is present in the profile, chloride concentration should be used as a salinity indicator in preference to $EC_{1:5}$.

As mentioned in Section 4.2.8, soil profile salinity is one of the factors assessed when determining the ERD for determination of the soil water availability (M) limitation. Irrespective of whether salinity is dealt with as a stand-alone limitation or incorporated into the M limitation, it is necessary to determine appropriate critical values and ascertain the degree of limitation with respect to different land uses. The *Salinity management handbook* (DERM, 2011) provides a compilation of available plant salt tolerance data for a wide range of crop, pasture and tree species from nine important research publications (see Tables 46 and 47 of the handbook). The data for salinity threshold and soil salinity values corresponding to 90% yield, 75% yield and 50% yield are listed for each plant species in these tables. Soil salinity data in these publications uses EC_{se} values to correlate to plant growth response. Conversions between EC_{se} and $EC_{1:5}$ units are therefore required – details regarding conversion factors (they depend on soil clay content) and issues surrounding plant salt tolerance data are documented in the handbook.

In locations where there is a permanent shallow groundwater table, salinity may not be a severe limitation, as plants can tolerate higher levels of salts when there is an unlimited supply of water compared to when they are moisture stressed. In such cases however, the location/UMA is likely to be downgraded on the basis of the wetness limitation (W).

4.2.13 Secondary salinity

Definition and application

Agricultural development, especially tree clearing and irrigation, disturbs the natural hydrologic equilibrium in the landscape and may cause secondary salinity. Increased deep drainage can lead to raised watertables which may be saline. Where watertables reach a critical depth below ground (which is influenced by particle size and other factors), evaporative concentration of salts may cause salinisation of the soil surface. Salt may also accumulate in places where saline groundwater is discharged lower in the landscape. Techniques for the identification of potential problem areas based on geology, geomorphology, soil and vegetation are provided in DERM (2011).

The potential for land development to cause secondary salinity should normally be incorporated into a land suitability assessment. Refined methods for salinity risk assessment and stand-alone exercises such as Searle et al. (2007) and Chamberlain et al. (2007) provide flexibility to use salinity risk as an overlay to land suitability or within the suitability process. In either instance, the primary intent is to identify land that is at risk of being degraded by secondary salinisation processes, leading to a reduction in agricultural productivity and/or environmental impacts. The aim is to identify the areas that contribute to excess groundwater recharge (Si limitation) and/or areas of probable groundwater discharge (Ss limitation). Areas of actual groundwater discharge can be dealt with under the wetness limitation (W) and/or the salinity limitation (Sa).

Recharge potential (Si)

Deep drainage and groundwater recharge effectively occur in all parts of the landscape that are not actively discharging. The intent of the limitation is to identify areas in which the amount of recharge has increased considerably as a result of hydrologic disturbance – usually tree clearing and/or cropping, especially irrigated cropping. In particular, an aim is to identify recharge areas that are clearly linked to down-gradient discharge areas. In some instances, recharge areas may be linked to freshwater discharge zones rather than saline discharge areas.

Outflow or discharge potential (Ss)

The identification of potential outflow or discharge zones is important for both agriculture and land planning as many land uses cannot be undertaken in areas of saline or freshwater discharge. The limitation is concerned with areas of *potential* discharge only, not areas of *actual* discharge – the latter would be dealt with under the wetness limitation (W). Such areas are typically low in the landscape (e.g. footslopes and valley floors).

Attribute assessment and subclass determination

Landscape position, substrate properties, site drainage class and soil permeability (NCST, 2009) are attributes used to identify areas of potential recharge or discharge. Soil hydraulic conductivity, groundwater level and actual salinity measurements in the soil profile would also be commonly used. Site drainage and permeability combinations can be combined with landscape position to determine subclasses for identification of areas of potential discharge. For instance, lower slope positions and drainage depressions are given a higher subclass (less suitable). In addition, the distance to a drainage outlet may be incorporated into outflow potential.

Application of the recharge potential and discharge potential limitations is not always feasible in broadscale regional assessments, as the detailed information required may not be available. In these situations it is recommended that landscapes suspected to be vulnerable to secondary salinity be flagged (e.g. with the use of an overlay or with suitability subclass ‘0’). Any proposed agricultural development within these areas would therefore require further assessment and/or monitoring of the salinity risk.

4.2.14 Topography and microrelief (T)

Definition and application

This limitation includes the overall slope of the land surface as well as an uneven land surface due to microrelief or small gullies. Both types of topography are considered in terms of the way they affect machinery use as well as their impact on irrigation and other infrastructure applications.

The slope (Ts) limitation is applied to land uses that occur on sloping country where use of machinery is impeded or where access by grazing animals may be constrained (i.e. usually steep slopes). Another consideration is operator safety and machine manoeuvrability, which may be compounded by the need to implement necessary erosion control structures such as contour banks on steep slopes.

It has been a common practice to use slope factors contained in the water erosion (E) limitation to downgrade steep country with a higher suitability subclass (i.e. less suitable). However, it is far better to consider each of these limitations separately, as they are applied for different purposes.

The slope limitation may also be used where low slopes are required for land uses that use surface irrigation (e.g. furrow irrigation, ponded irrigation) and where runoff control measures are required, although care should be taken to avoid double accounting with the water infiltration (I) limitation.

An uneven land surface due to microrelief (including gilgai) or a high density of small gullies may also restrict the use of machinery or the ability to deliver water across the soil surface with furrow irrigation. The cost of earthworks to level such land sufficiently to facilitate cultivation or irrigated land use applications may make the proposed land use uneconomic. The limitations of microrelief (Tm) and small gullies (Tg) are used to identify these types of limitation more specifically.

Microrelief refers to relief of up to a few metres about the plane of the land surface; it includes gilgai, hummocky, biotic and other forms. Gilgai microrelief consisting of mounds and depressions associated with shrink-swell soils is the most common form of microrelief that impacts on land use in Queensland.

The size of land areas between any microtopographic discontinuities should be considered in relation to the size required for a viable production area – see Section 4.2.17, landscape complexity.

Attribute assessment and subclass determination

Slope (Ts)

Land slope should be recorded at each field site in the land resource survey. Broad slope categories may be determined remotely from digital elevation models (DEMs). Detailed on-ground topographic information is required to determine the low slopes required for surface irrigation land uses (furrow and ponded irrigation).

The maximum slope on which machinery can be used should be determined. Slopes greater than 25% are typically considered as unsafe for general machinery use and are therefore regarded as unsuitable, although the actual limit will vary with machinery type and other factors. Manoeuvrability is related to land features such as slope complexity/shape and machinery size.

The slope at which danger to the machinery operator is not likely, or where use of machinery of appropriate size is possible without any constraint, must also be identified. Slopes between these extremes are matched to the degree of danger or difficulty of machinery use to determine the remaining subclasses.

Microrelief (Tm)

The type, size, density and distribution of microrelief features should be described in the land resource assessment using the terminology of McDonald et al. (2009). The dimensions recorded are the vertical interval (i.e. the height of the microrelief feature) and the horizontal interval (i.e. distance between the microrelief crests). In gilgai microrelief, the vertical interval corresponds to the depth of the depressions and the horizontal interval is the distance between the mounds. The density of gilgai microrelief refers to the proportion of land surface occupied by the depressions.

Suitability subclasses are based on the amount of earthworks required to level the land or create a required slope to an extent sufficient for the proposed land use. The amount of levelling required for furrow irrigation is considerably greater than that required for cultivation alone. A ranking process is used to establish subclasses from the descriptions of microrelief in the resource inventory and the local perceptions of the problems associated with levelling the land.

Small gullies (Tg)

This limitation considers the occurrence of small gullies that are shallow enough to be levelled by commonly available machinery. Again, suitability subclasses are based on the amount of earthworks required to level the land or create the slope required for the proposed land use.

4.2.15 Vegetation (V)

Definition and application

Generally, clearing requirements and regrowth control are considered as part of the land use specifications and are not used to differentiate suitability. However, in some extensive land uses such as grazing of improved pastures, the cost of timber clearing and control of regrowth is considered significant in determining suitability. Following clearing, some native shrub or tree species may rapidly re-establish, sometimes to a density greater than before. This regrowth can be controlled with continued cultivation associated with cropping. For land uses where regular cultivation is not practised, other methods of regrowth control are necessary. The regrowth potential is determined by the species present before clearing.

Specific vegetation types can be considered to be a limitation, particularly in the context of grazing, when woody weeds or poisonous species are associated with certain land types.

Attribute assessment and subclass determination

Vegetation types including woody weed species are commonly identified and described during the land resource survey. Vegetation mapping is also widely available in Queensland.

Vegetation (V)

Vegetation types described during the resource survey may be assigned to each UMA and ranked according to their degree of limitation. It is rare for a vegetation type to completely preclude a specific land use.

Vegetation regrowth (Vr)

Subclasses are based on the management inputs required for initial timber clearing and subsequent control of regrowth or control of woody weeds. Local knowledge of the inputs required to clear and/or maintain clearings of different vegetation types is used to rank subclasses to vegetation types.

4.2.16 Wetness (W)

Definition and application

Waterlogged soils reduce plant growth and may prevent effective machinery operation. Some plants are tolerant of waterlogging, but most are affected by reduced oxygen supply to roots and are more susceptible to disease. Delayed machinery operation can result in reduced yields caused by various factors including delays in planting, harvesting and weed and disease control. Land is downgraded because of either potential yield reduction or the cost of drainage measures.

Attribute assessment and subclass determination

The wetness limitation is an assessment of site drainage – determined by considering both internal (soil profile permeability) and external (landscape) factors.

Soil permeability is the potential of the soil to transmit water internally. It is controlled by the saturated hydraulic conductivity of the least permeable layer in the soil. This can be inferred from soil attributes such as structure, the presence of hardpans, colour, texture and cracking. The supply and removal of water from the site is a function of slope, topographic position and depth to the watertable.

Indicators of poor drainage include soil colour and mottling. Mottles are clearly visible patches or streaks of colour that are different to the dominant colour of the soil layer. Soil mottling alone may be used to determine the site drainage rating. However, mottling may not always reflect the current drainage conditions – it may be a relict feature. Colour patterns due to biological or mechanical mixing are also not considered. Gley soil colours are key indicators of soil wetness and vegetation species are frequently a strong indicator of site drainage.

Both soil permeability and drainage (along with all other relevant soil attributes) are described in the field using the guidelines and terminology of McDonald and Isbell (2009). Commonly, an overall rating for each attribute is applied to the site. However, for land suitability purposes, it has been found useful to ascribe drainage and permeability class separately for various depths in the soil (e.g. to 0.5 metres, 1.0 metre and 1.5 metres). This provides a better match with the specific requirements of various crops.

As wetness can be highly seasonal, it may be important to assess drainage and permeability separately for summer (wet season) and winter (dry season) crops. Although a soil may show signs of wetness, a crop grown in the dry season will not often experience these conditions as the supply of water will be limited.

If artificial drainage measures are feasible for a particular land use, additional assessment is required. For example, two UMAs may have the same natural site drainage rating but one may be much easier to drain artificially. Soil permeability can determine the density of subsurface in-field drainage measures required, while landscape features may determine ease of surface drainage and water disposal.

Quantified assessment of site drainage can be attained by piezometer measuring of watertables, including an oxygen content assessment as reflected by redox potential or dissolved oxygen sensor. These need to be monitored over the long term to allow meaningful interpretation of data.

Subclasses are established by relating site drainage attribute levels to yield reduction caused by poor aeration and/or untimely machinery operation. Plant tolerance information in the literature is invariably given in qualitative terms, so that in the absence of local farmer experience, crop experts usually provide the best available information. If drainage measures are feasible, subclasses are based on their establishment and maintenance costs, as well as their effectiveness.

4.2.17 Landscape complexity (X)

Definition and application

Effective management of suitable land requires that an area of land is practical to utilise in terms of the minimum production area required for a particular land use.

The landscape complexity limitation (X) may be used where there are:

- small areas of suitable land located within a larger area of unsuitable land
- areas that may be suitable, but have an accessibility constraint
- small areas of land with significantly different managerial requirements occurring within an area of otherwise suitable land.

If the landscape complexity is due to soil differences, the Xs limitation may be used; or if due to differences in topography, the Xt limitation may be used. Either case may result in areas that are too small to be delineated as individual units at the scale of mapping used for the assessment. Complexity may exist within a UMA or across two or more UMAs and creates management difficulties. A farmer will use the management system that is optimal for the dominant land type in the production area. This may be suboptimal or unsuitable for different components of that production area.

Soil complexity (Xs)

Soil complexity may be due to any of the following:

- complex distribution of managerially different soils – for example those requiring different tillage practices, fertiliser rates, irrigation frequencies and requirements, pest spraying schedules and harvesting dates
- areas of otherwise suitable land too small, too narrow or too irregular in shape to be used or managed according to their suitability – examples are small areas of suitable land among larger areas of less suitable land, or narrow alluvial terraces adjacent to less suitable steep land
- areas of unsuitable land that cannot be avoided – for example a narrow, sandy prior stream channel meandering through a UMA being assessed for furrow irrigated crops.

Topographic complexity (Xt)

The topographic complexity limitation may be used to downgrade areas of suitable land to lower suitability classes due to management restrictions imposed. Examples of topographic complexity include the following:

- inadequate size or shape of land between large gullies, terraces or other dissections too difficult to be levelled in normal land preparation – gullies shallow enough to be levelled are considered part of the small gullies (Tg) limitation
- complex slopes with managerially significant slope changes, either down and/or across slope – these complex slopes make machinery operations more difficult or impracticable, either before or after conventional erosion control structures are implemented.

Attribute assessment and subclass determination

Land attributes are:

- land types with significantly different management requirements occurring within or among UMAs
- size and shape of areas of suitable land types
- size and shape of areas between watercourses, large gullies or other dissections
- slope changes over short distances, down and/or across slope.

Landscape complexity is assessed where the complexity occurs within a minimum production area. It is evaluated after mapping, which is an essential part of its assessment, and usually after other limitations have been determined.

Suitability subclasses are based on one or more of the following:

- the relative degree of management change between the different land types
- the additional management inputs required to manage small or variable parcels of land
- the size and shape of land in which a minimum production area can be contained
- the degree of short distance slope changes down and/or across a slope.

4.2.18 Pests and diseases (Z)

Definition and application

The effect on the production of crops or livestock by pests or diseases is well documented. Most pests and diseases are associated with a land use wherever that land use occurs, and cannot be used to differentiate suitability between areas of land. In a few cases, however, discrete areas of land may be identified where a pest or disease may be prevalent. This can be related to the inherent environmental conditions (e.g. wetness, high humidity), with the pathogen occurring wherever those conditions prevail. Alternatively, the occurrence of some pests and diseases may be limited to areas that have been infected, as would be the case for some soil-borne pathogens e.g. Panama disease in bananas.

The pests and diseases limitation is only used to identify areas contaminated by soil-borne pathogens from others that are similar in nature, but uncontaminated. Most pests and diseases are not site-specific, and should be considered as part of the land use specifications through their effect on yields and inputs. Pests and diseases that are site-specific, with their occurrence related to the environmental conditions that are conducive to the pathogen, are covered by other relevant limitations (e.g. wetness, temperature, humidity).

This limitation can be extremely time or crop specific, and the distribution of the pest or disease may change rapidly as previously uninfected areas become infected. Furthermore, research in techniques of control of pests and diseases is ongoing and the limitation may be removed as new control techniques become available. The time-specific nature of the assessment and interpretation of this limitation suggests that it may be more appropriate to just identify impacted areas (e.g. as an overlay). This allows the user to interpret suitability according to the effects of the limitation at the time.

Attribute assessment and subclass determination

Knowledge of the occurrence of pest or disease organisms is gathered from local experience in using particular areas of land for a specified land use.

Subclasses are based on the decrease in production associated with the presence of a pest or disease, or the inputs required to overcome its effects. The occurrence of a pest or disease should generally only be recorded as being present or absent, and the level of infection would not be recorded unless paddock-scale data was available. It is likely that only one suitability subclass would be used, corresponding to where the pathogen is present and by implication a subclass of ‘1’ (negligible limitation) where it is not present.

5 Land capability classification

In Queensland, a land capability classification system is generally only used for broadscale or reconnaissance assessment studies where information is required at a small scale of presentation (1:250,000 or smaller) – see Section 2.2. It is anticipated that the future use of the land capability classification scheme by government agencies for regional planning purposes will be minimal. Nevertheless, it remains valuable in understanding and interpreting historical work.

The land capability classification used in Queensland is based on that of Rosser et al. (1974), which is a modification of the Klingebiel and Montgomery (1961) scheme, used by the United States Department of Agriculture Soil Conservation Service. The system uses eight classes, with limitations and hazards to agricultural and pastoral use becoming progressively greater from class I to class VIII, accompanied by a decreasing adaptability and choice of use. The classes are described in detail below, in Section 5.1.

The system allows for assessment of land for general agricultural, pastoral and non-agricultural uses. Based on historical use by CSIRO and the Queensland Government, agricultural use implies cultivation for dryland cereal and oilseed cropping while pastoral use implies grazing of stock on improved pasture or native pasture. The system does not accommodate comparative assessment of specific land uses (e.g. dryland winter cereals, irrigated cotton). Where an assessment of a specific land use is required, the land suitability classification system described in Section 3 should be used.

5.1 Land capability classes

Class I Land suitable for all agricultural and pastoral uses:

- Suited to a wide range of crops and is highly productive.
- Presents no limitations to use of machinery or choice of implements.
- Wind and water erosion hazard are low even under intensive cultivation.

Class II Land suitable for all agricultural uses but with slight restrictions to use for cultivation in one or more of the following categories:

- Land has some minor limitation to the choice of crops, and/or slight restrictions to productivity.
- Land has some minor impediment to the use of cultivation machinery, which limits the choice of implements, or restricts the conditions for successful operation.
- Land is used for cultivated cropping that requires simple conservation practices to reduce soil loss to an acceptable level. These include agronomic practices such as contour working, strip cropping and stubble mulching.

Class III Land suitable for all agricultural uses but with moderate restrictions to use for cultivation in one or more of the following categories:

- Land has moderate limitations to the choice of crops and/or moderate restrictions to productivity.
- Land has moderate impediment to the use of cultivation machinery, which limits the choice of implements, or restricts the conditions for successful operation.
- Land is used for cultivated cropping that requires intensive conservation practices to reduce soil loss to an acceptable level. These include contour banking systems and intensive residue management involving specialised machinery.

Class IV **Land primarily suited to pastoral use but which may be safely used for occasional cultivation with careful management. Limitations arise from one of the following categories:**

- Land is such that the choice of crops is severely restricted, and/or existing conditions severely limit productivity under cropping.
- Land has severe impediment to the use of cultivation machinery, which limits the choice of implements, or severely restricts the conditions for successful operation.
- Land cannot be used safely for permanent cultivation. If cropped, a pasture phase must be the major component of the cropping program to limit soil loss to an acceptable level.

Class V **Land that in all other characteristics would be arable but has limitations that, unless removed, make cultivation impractical and/or economic – examples include swampy land that may be drained, or land that contains surface rock that could be removed at a cost**

Class VI **Land that is not suitable for cultivation but is well suited to pastoral use and on which pasture improvement involving the use of machinery is practicable**

Class VII **Land that is not suitable for cultivation but on which pastoral use is possible only with careful management; pasture improvement involving the use of machinery is not practicable**

Class VIII **Land that has such severe limitations that it is unsuited for either cultivation or grazing**

5.2 Method for land capability assessment

The general approach to land capability assessment is very similar to that used for land suitability assessment, but in the case of land capability, the land uses are predefined.

Limitations and capability subclass determination

The fourteen limiting factors used in Rosser et al. (1974) have been replaced by the limitations and diagnostic attributes used for land suitability classification – see Table 8. Where appropriate for broadscale studies, limitations can be combined to simplify the assessment. For example, nutrient deficiency (Nd), nutrient leaching (Nl), nutrient fixation (Nf) and element toxicity (Nt) could be grouped together as one nutrient limitation (N).

Similar to land suitability assessment, limitation categories and capability subclasses are established for each limitation and ranked according to severity. The capability subclasses will range from the least severe to the most severe, on a scale of 1 to 8 (matching the land capability classes I to VIII). Possible limitation categories and subclasses for the water erosion and rockiness limitations are shown in Table 9. Note that not all eight classes may apply for each limitation. See references such as Clarke and Wylie (1997) and Vandersee (1975) for discussion and examples of land capability.

Table 9: Example of limitation categories and capability subclasses

Limitation	Degree of limitation (limitation category)	Capability subclass
Water erosion (E)	Simple practices required to maintain soil losses under cultivation at an acceptable level	e2
	Pasture rotation, cover crops or minimum tillage operations required to reduce soil losses under cropping to an acceptable level	e4
	Special practices or grazing restrictions required to reduce soil loss to an acceptable level; cultivation not possible	e7
	Grazing will cause soil losses in excess of the acceptable level	e8
Rockiness (R)	No limitation from rockiness	r1
	Tillage restricted with some types of machinery	r2
	Tillage restricted with most types of machinery	r3
	Tillage difficult with all machinery; occasional use possible	r4
	Use of all machinery for cropping impractical	r5

For broadscale land system surveys, the limitation categories should be assessed for each land unit or component land type. The overall land capability class should then be assessed for the land system, ideally based on the class of the dominant land unit/s. At the land system level, land capability often incorporates a range of two or more classes (e.g. classes II and III, or classes III and V).

Notation and allocation of overall land capability class

The land capability classification is recorded as a series of characters indicating the limitations and capability subclasses present. For example, if rockiness is a limiting factor to the extent that all use of machinery for cropping is impracticable, the land unit would be recorded as class V(r5) – the ‘r5’ denoting that the land is assessed as class V on the basis of limitation R.

All limiting factors that apply are shown; those not mentioned can be assumed to be not limiting. For example, III(pd3e2) is interpreted as: (a) class III due to limiting soil depth ‘Pd’; (b) water erosion ‘E’ is also present and would place the land in class II if this was the only limitation present; and (c) other possible limitations – from Table 8 – are of no practical consequence.

6 Agricultural land classification for land planning in Queensland

Agriculture is a core component of the economic prosperity of Queensland. It is therefore important to protect agricultural land so that its productive capacity is maintained.

Threats to agricultural land include:

- inappropriate and irreversible land uses
- fragmentation due to inappropriate subdivision
- degradation due to on-site or off-site activities.

Various regulations and policies have been developed to protect agricultural land resources from incompatible activities that compromise its existing or potential productivity. The agricultural land classification system has been central to the majority of these mechanisms since the early 1990s.

6.1 Agricultural land classes (ALC)

Agricultural land classification in Queensland follows a simple hierarchical scheme that is applicable across the state. It allows the presentation of interpreted land evaluation data to indicate the location and extent of agricultural land that can be used sustainably for a wide range of land uses with minimal land degradation. Provision is also made to highlight areas that may be suitable for one specific crop considered important in a particular area. Three broad classes of agricultural land and one non-agricultural land class are identified:

Class A – Crop land
Class B – Limited crop land
Class C – Pasture land
Class D – Non-agricultural land.

The classes imply a decreasing range of land use choice and an increase in the severity of land use limitations and/or land degradation hazard. The classification is hierarchical, with class A land having the greatest potential for producing the widest array of crops and class D land being unsuitable for any agricultural land use. The four classes, including subclasses, are summarised in Table 10.

Class A (crop land) has two subclasses: A1 – land suitable for a wide range of broadacre crops and A2 – land suitable a wide range of horticultural crops only. This allows better discrimination of crop land at both local and state-wide levels.

Class B (limited crop land) is land that is not suitable for a wide range of crops (broadacre and/or horticultural) but is suitable for a narrow range of crops or crops with specialised requirements e.g. tea, pineapples, plantation forestry. Class B land may be suitable for a wider range of crops with changes to knowledge, economics or technology. It is also suitable for sown pastures and pasture phases may be an integral part of a cropping system on this type of land. The original definition of class B land (Land Resources Branch, 1990) resulted in inconsistent allocations of crop land because of the presence of a major 'and/or' statement in it. In some areas this resulted in the creation of subclasses B1 and B2, but this distinction is no longer required.

Class C (pasture land) is divided into three subclasses. C1 land is the higher fertility grazing land typically used for beef cattle fattening and includes the brigalow and gidgee lands that are not suitable for cropping. C2 land is more typically suited to sheep and cattle breeding, while C3 is restricted to grazing with low stocking rates.

Class D land is not suitable for agricultural use (including grazing); generally due to the presence of extreme limitations such as very steep slopes, rock outcrop, salinity, acidic drainage or severe degradation. Class D land also includes land alienated from agricultural use (e.g. urban areas) and land with high order conservation tenure (e.g. national parks).

Combined codes (e.g. A1/C1) may be used to clarify the agricultural land classification where the mapping scale is too small for further delineation. A code such as A/C may also be used where there is no reliable information to make a more accurate determination (but local knowledge suggests that a range of classes exists) or a land resource survey/land evaluation is incomplete.

6.2 Method of agricultural land class assessment

The method for assessment of ALCs will depend on the quality and extent of land evaluation information available for the particular area. ALCs are generally allocated or interpreted with reference to a land suitability study, a group of land suitability studies or from a broadscale land capability/land system study.

A. Where land suitability data are available

ALCs may be derived by simplifying or summarising land suitability information based on the number of crops that are suitable for any particular parcel of land.

The derivation of ALC from suitability data is relatively straightforward where the land suitability framework is comprehensive, since it is a hierarchical classification. For each UMA, the number of crop types for which the land is suitable – i.e. with a suitability class of 1, 2 or 3 – is calculated. If this number equals four or more, the UMA is class A crop land. Crops with very similar agronomic requirements, which are managed in the same way, are not regarded as different crops (e.g. maize and grain sorghum, peaches and nectarines, oranges and lemons). Different irrigation strategies for the same crop (e.g. spray irrigation, furrow irrigation) do no not increase the number of crops. Where an historic suitability framework that does not cover a comprehensive range of crops is being used to generate ALC, these rules may need to be relaxed. For example, land that was assessed as being only suitable for citrus may also be suitable for strawberries, peaches and mangoes, if the additional crops are added to the scheme.

Class A crop land is divided into subclasses A1 and A2 depending on the partitioning of suitability for broadacre and horticultural crops.

Lands that are suitable for three crops or less will predominantly be class B (limited crop land). Being categorised as limited crop land does not reduce the importance of these lands to agriculture. Instead, it simply states that these lands have the capacity to grow a more limited range of crops than class A land.

Class C land (pasture land) can be derived by an assessment of the pastoral potential of the various land types that are not suitable for cropping. Class D land (non-agricultural land) should be clearly evident because of the presence of extreme land use limitations or other land use/data that suggests the land is permanently alienated from agriculture.

Table 10: Definition of agricultural land classes.

Code	Description
A	**Crop land** **Land that is suitable for a wide range[1] of current and potential crops with nil to moderate limitations to production.**
A1	Suitable for a wide range of current and potential broadacre and horticultural[2] crops.
A2	Suitable for a wide range of current and potential horticultural crops only.
B	**Limited crop land** **Land that is suitable for a narrow range[3] of crops. The land is suitable for sown pastures and may be suitable for a wider range of crops with changes to knowledge, economics or technology.**
C	**Pasture land** **Land that is suitable only for improved or native pastures due to limitations that preclude continuous cultivation for crop production. Some areas may tolerate a short period of ground disturbance for pasture establishment.**
C1	Suitable for grazing sown pastures requiring ground disturbance for establishment; or native pastures on higher fertility soils.
C2	Suitable for grazing native pastures, with or without the introduction of pasture species, and with lower fertility soils than C1.
C3	Suitable for light grazing of native pastures in accessible areas, and includes steep land more suited to forestry or catchment protection.
D	**Non-agricultural land[4]** **Land not suitable for agricultural use, including land alienated from agricultural use.**
A/C A/D B/C C/D	Land that is a complex of class A, B, C or D land where it is not possible to delineate the land class at the map scale. The dominant class is the first code in the sequence and is assumed to be >50% of the area, but <70%[5].

Table 11 provides an example of the relationship between land suitability classes and agricultural land classes for various crops.

[1] A wide range of crops is four or more crop types of local commercial significance.

[2] Horticulture includes intensively grown small crops (e.g. vegetables) as well as tree crops (e.g. grown for nuts, seeds or fruit). Silviculture (plantation forestry) is not included.

[3] A narrow range of crops is three or fewer crop types (broadacre or horticulture) of local commercial significance. Silviculture (plantation forestry) may be included. Crops with similar agronomic requirements e.g. maize and grain sorghum, peaches and nectarines are not generally regarded as different crop types. Different management regimes (including irrigation strategies) for the same crop do not increase the number of crops.

[4] Non-agricultural land includes land that cannot be placed in any of the other land classes and includes land such as urban areas and stream channels.

[5] In cases where two or more land classes are equally dominant and none are greater than 50%, judgement is used to identify the most appropriate agricultural land class/es for the unit.

Table 11: Allocation of agricultural land classes from land suitability classes†

Land suitability classes for various land uses							Agricultural land class	
Sugar cane	**Sweet corn**	**Cucurbits**	**Tomatoes**	**Citrus**	**Mangoes**	**Sown pastures**	**Code**	**Class**
2	3	3	3	3	2	2	A1	Crop land
4	4	2	2	3	2	2	A2	
3	4	4	4	4	5	3	B	Limited crop land
4	4	3	3	5	5	3	B	
5	5	4	4	5	4	3	C1	Pasture land
5	5	5	5	5	4	4	C2	
5	5	5	5	5	4	5	C3	
5	5	5	5	5	5	5	D	Non-agricultural land

† Land suitability classes shown here are illustrative only and may not indicate real conditions in one area.

B. Where only a land capability study is available

The four basic ALC classes (A, B, C or D) may be derived from the eight land capability classes. For example, class A land is equivalent to capability classes I to III.

C. Where broadscale mapping (e.g. land system mapping) at scales of 1:250,000 to 1:500,000 is available

In some areas of Queensland, it is necessary to reinterpret broadscale land resource information to derive the agricultural land classes. This may be a difficult task, requiring considerable background research to understand and use the original information. The heterogeneity often present in broadscale mapping has consequently driven the need to create complex ALC codes to more clearly define the ALC for a particular land system. For example, a land system could be a mix of arable hill slopes (class A1) and stony outcrops (class C3) and would thus be indicated as A1/C3.

Practitioners creating ALC data from broadscale studies should be cognisant of the varying accuracy within them and the inherent limitations of the interpretation. A reliability scheme or statement should be produced to accompany the data. While the allocation of ALC to these broadscale studies may be qualitative, it is supported by many of the same formal and informal data sources and decisions that are used when creating a land suitability scheme.

6.3 Discussion on lands with limited cropping potential

In the past, it was common practice to allocate some lands with limited cropping potential as class A agricultural land, particularly where the crop was considered regionally important and supporting infrastructure was in place e.g. sugarcane and an associated sugar mill. This led to differences in the application of land classification criteria, based on the perceived importance of a crop to local industry and infrastructure. In order to minimise confusion, this version of the guidelines attempts to be explicit about what constitutes land classes A and B. Class B land is arable but is limited in the range of crops it can sustainably produce.

By refining the agricultural land class definitions, the perceived ability to preference one land use over another is removed. The previous use of infrastructure requirements to assist in determining important land uses also gave rise to an implied preference of one land use over other potential land uses. The favouring of a land use or the implied importance of one land use over another is against the resource and management focussed principles of this guideline.

How a land classification system or scheme is used or interpreted to fulfil local and regional planning requirements depends on the policy and planning frameworks operating at a particular time and place. For example, in some parts of Queensland class B land may be an important resource of the cropping industry.

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