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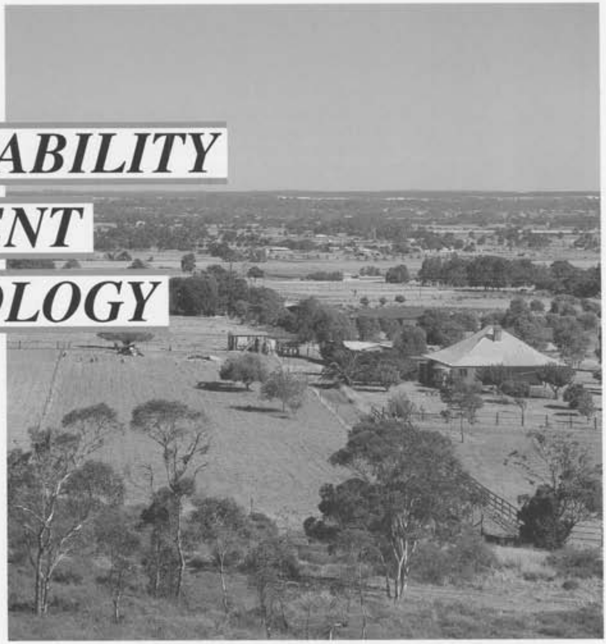

LAND CAPABILITY ASSESSMENT METHODOLOGY

for rural-residential development and associated agricultural land uses

M.R. Wells and P.D. King
WESTERN AUSTRALIAN DEPARTMENT OF AGRICULTURE

A NATIONAL SOIL CONSERVATION PROGRAM FUNDED PROJECT

LAND CAPABILITY ASSESSMENT METHODOLOGY

for rural-residential development and associated agricultural land uses

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Summary

This report describes the general principles used for land capability assessment by the Western Australian Department of Agriculture. Specifically, it presents a methodology for assessing the capability of land to support rural-residential development and associated agricultural land uses. The methodology was developed and tested using data from land resource mapping of portions of the Darling Range, east of Perth, and of the Swan Coastal Plain to the south.

The methodology closely follows principles of land evaluation developed by the Food and Agriculture Organization (FAO) of the United Nations. The land uses involved are complex, and have been divided into a number of component land use activities. Land use rating tables, based on a simple, 'single worst factor' approach, have been developed to determine the capability of land for each activity. The rating tables employ land qualities rather than land characteristics. Examples of assessment methods for most land qualities are provided.

The report is intended for use by practitioners and students of land resource survey and evaluation, and for those involved with rural land use planning. In areas other than the 'test surveys', the techniques described in the examples may require change as dictated by the availability of data and the nature of the country. Assessment techniques will continue to evolve as our understanding of the effects of soil/land use/management interactions on different land types improves. Nevertheless, the central core of the methodology provides guidelines which will be useful to any future land capability studies for rural-residential and associated agricultural land uses.

Financial assistance to the Darling Range Rural Land Capability Study by the National Soil Conservation Program enabled this methodology to be developed, and is gratefully acknowledged.

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1. Introduction

Land capability is defined as the ability of land to support a particular type of use without causing permanent damage (Austin and Cocks 1978). Land capability assessment has become an important prerequisite for rural land use planning in Western Australia. Land use planning involves preparing for changes in land use. In rural areas, significant changes can occur as a result of urban expansion. Most commonly, these include rural-residential development and an intensification of agricultural activities to smaller holdings or hobby farms. The aim of this report is to provide an objective system for assessing the capability of land to support these changes.

Rural-residential development involves the subdivision of rural land into small holdings to be used primarily for residential purposes. These holdings, generally varying in size from 1 to 20 ha, may also be used for a variety of agricultural purposes. When agriculture is undertaken as a secondary enterprise to the owner's main line of business the term 'hobby farming' is used. Small, independently viable, agricultural holdings also occur on the urban fringe. These are commonly used for annual or perennial horticultural production.

If poorly planned, rural-residential and hobby farming developments have the potential to strain the ability of State and local government bodies to provide services such as power, water supplies and transport facilities. Adjacent farming communities may be adversely affected by speculative land values and introduced mangement problems such as soil erosion, weed and pest infestation, fire control and stock control (Adams 1984). Small horticultural holdings can also provide problems for planners because of the large volumes of water required for irrigation and, in sandy soils, because of the risk of nutrient contamination of surface and underground water bodies. A knowledge of the land's capability can be used to address some of these problems and can assist planners to select environmentally appropriate areas for these land uses.

Land which is capable of supporting a particular use may not, however, always be deemed suitable or most appropriate for that use since capability assessment does not take into account socio-economic and political factors. Consideration of these factors, in conjunction with the land's capability, is a land use planner's role.

Ideally, land capability should be measured: for agricultural uses, crop and stock trials would form the basis for such measurement; for residential uses, engineering tests and free market economic evaluation of sites might be used. In the ideal situation, it would be possible to investigate the economics of several different land uses on each of the many soil or land types in a study area. Frequently however, the rate of urban expansion and the associated demand for rural-residential developments, hobby farms and small agricultural lots, necessitates a more pragmatic approach to assist land use planning. It is usually necessary to use assessment, rather than measurement, of land capability. That assessment should, however, be as objective as possible.

An objective method for the assessment of land capability for rural-residential development, hobby farming and associated agricultural land uses is presented. The method is broadly based on land evaluation guidelines developed by the Food and Agriculture Organization of the United Nations (FAO 1976, 1983). The interpretative systems used by the United States Department of Agriculture (USDA) (cited in Olson 1973) and the Land Protection Service in Victoria (Rowe *et al.* 1981) also influenced this method.

The methodology has been developed to use land resource survey data. These surveys involve the systematic examination, description, classification and mapping of one or more attributes (soils, landforms) to provide an inventory of data about areas of land referred to as land units. The inventory data are used to determine capability results which apply to all mapped occurrences of a subject land unit. The methodology needs to be somewhat general and, if it is used for site-specific assessment, care must be taken to ensure the subject land is as described on the land resource maps. In developing the methodology it has been applied to two regional land resource studies that cover portions of the Swan Coastal Plain and Darling Range (Figure 1). The methodology should, however, provide a suitable framework for land capability studies in other parts of the State.

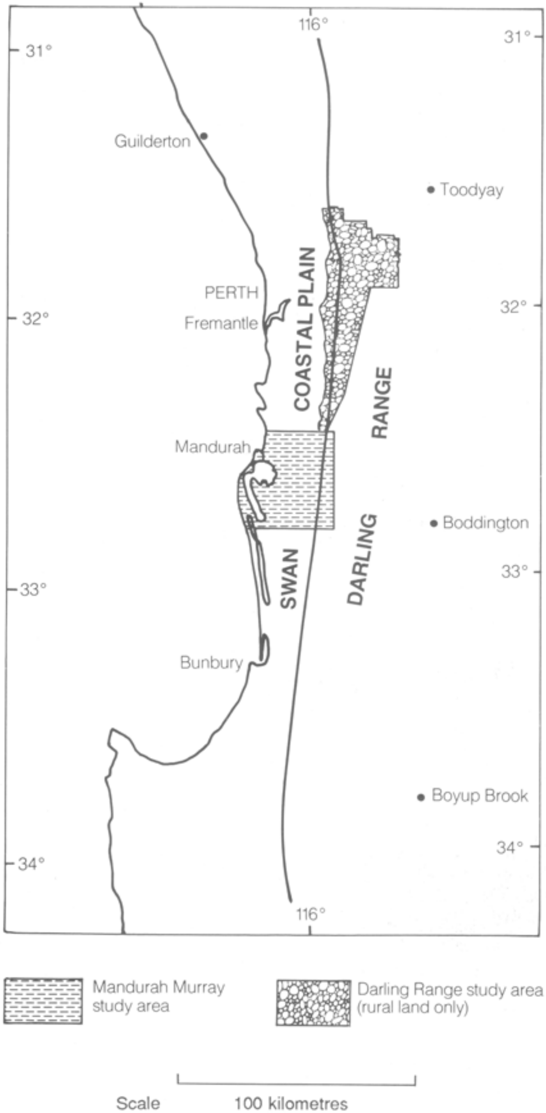


Figure 1. Location of study areas.

2. General Principles

Land capability was first defined by Klingebiel and Montgomery (1961) of the United States Department of Agriculture (USDA) and used to classify soil mapping units for agricultural purposes. In Australia, as elsewhere, land capability classification schemes are largely based on the USDA method, but their application has been expanded to include non-agricultural land uses.

The essence of land capability assessment is a comparison of the physical requirements for a particular land use with the qualities of land. Land qualities are those attributes of land which influence its capability for a specified use. 'Water erosion risk' and 'ease of excavation' are examples relevant to residential land use. Land qualities are determined by attributes such as slope and topsoil texture (among others) which are usually recorded for each mapping or land unit during a land resource survey. Attributes which are employed as a means of describing land qualities, are called soil or land characteristics.

The requirements of a particular land use can be expressed in terms of essential and desirable land qualities. To determine these qualities, the type of land use must first be carefully defined. Consideration must then be given to the effect the use will have on the land and, in turn, to the effect attributes of the land will have on that use.

Land capability assessment aims to achieve sustained land use without environmental degradation. Land qualities which relate primarily to the effect of use on the land can be grouped under the heading 'conservation factors'. Those qualities relating primarily to the effect of land on its use can be grouped under 'productivity or management factors'. The degree to which land conditions meet the requirements of the conservation, management, and productivity factors, determines the land capability class assigned to a particular area of land.

A five class land capability system is used by the Western Australian Department of Agriculture (Tables 1a, 1b). The classes indicate the degree of limitation that land qualities impose on a particular use together with levels of management needed to contain any subsequent land degradation. Class I land will have qualities which generally meet the requirements of a proposed use without any resultant land degradation effects. Class II to IV land is progressively less able to meet the land use requirements and the risk of land degradation increases accordingly. Use of Class V land is usually regarded as prohibitive in terms of the risk of land degradation, or in terms of development or land management costs. Capability subclasses, shown as letter no-

Table 1a. Land capability classes

Capability class	General description
I	Very high capability for the proposed activity or use. Very few physical limitations present which are easily overcome. Risk of land degradation is negligible.
II	High capability. Some physical limitations affecting either productive land use or risk of land degradation. Limitations overcome by careful planning.
III	Fair capability. Moderate physical limitations significantly affecting productive land use or risk of land degradation. Careful planning and conservation measures required.
IV	Low capability. High degree of physical limitations not easily overcome by standard development techniques and/or resulting in a high risk of land degradation. Extensive conservation requirements.
V	Very low capability. Severity of physical limitations is such that its use is usually prohibitive in terms of either development costs or the associated risk of land degradation.

Table 1b. Land capability subclasses

Capability subclass	Land quality limiting proposed land use	Capability subclass	Land quality limiting proposed land use
a	Soil absorption ability	m	Moisture availability
b	Foundation soundness	n	Nutrient retention ability
c	Slope instability risk	o	Water pollution risk by overland flow
d	Subsoil water retention ability	p	Microbial purification ability
e	Water erosion risk	q	Groundwater quality
f	Flood risk	r	Rooting conditions
g	Groundwater availability	s	Water pollution risk by subsurface drainage
h	Dam site construction suitability	t	Topsoil nutrient retention ability
i	Waterlogging/inundation risk	v	Wave erosion risk
j	Surface water availability	w	Wind erosion risk
k	Soil workability	x	Ease of excavation
l	Nutrient availability	y	Salinity risk

tations, indicate the particular land qualities which may limit the proposed land use and determine its capability class (Table 1b).

The physical conditions under which a particular land use may occur include those which are best for its operation, those which are less favourable but still acceptable, and those which are unsatisfactory. This range of conditions, from optimal to unsatisfactory, is shown in a land use rating table (examples in section 3.4) and, as such, is an expression of the requirements of the particular land use.

Within a land use rating table, values for relevant land qualities are segmented over a range from very good (rating 1) to very poor (rating 5) according to their effect on the specified land use. Land with qualities described under ratings 1 or 2 would be considered optimal for the particular use, while land with qualities described under ratings 4 or 5 would be considered poor.

Land quality ratings for a map unit (land unit) are determined by matching land quality values, assessed from field survey data, with those in the relevant land use rating table. For a particular land use, the capability class is derived from the least favourable rating. If, for example, there are six land qualities rated respectively as 1, 1, 3, 2, 1 and 2, the capability class is III. Roman numerals are used to clearly separate capability classes for a land use from ratings for individual land qualities. The quality or qualities of land responsible for the capability result are indicated by letter notations, termed subclasses, which follow the capability class. Thus, an area of land with a capability class of III, due primarily to water erosion risk, would be shown as capability IIIe for the defined land use.

Where a complex form of land use involving a number of component land use activities is assessed, each activity will be considered using separate rating tables. The overall capability of the complex use will be derived from the result for the most limiting land use activity.

The general method for the assessment of land capability from land resource survey data is as follows:

- define the land use
- determine the land use requirements (expressed as a range of land quality values within a land use rating table)
- assess land quality values for each map unit (land unit) using land characteristics data
- compare land quality values with the land use requirements as shown in the appropriate rating table
- determine land capability class and subclass from the most limiting land quality.

The procedure is illustrated in Figure 2.

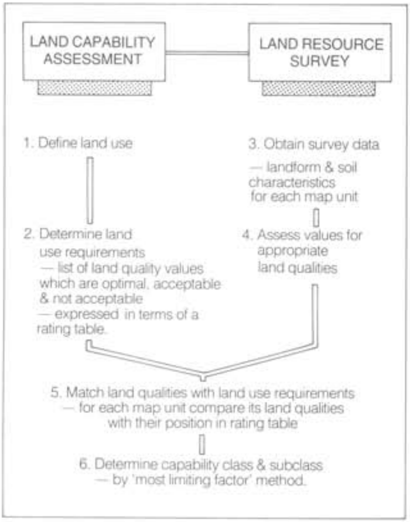


Figure 2. Flow diagram illustrating land capability assessment procedure.

3. Land Capability Assessment Method

3.1 Defining Land Use

The term 'rural-residential and associated agricultural land uses' covers a broad spectrum of land use activities. Rural-residential development refers to the use of small allotments of rural land, typically between 1 and 20 ha, primarily for residential purposes, although often some form of agricultural use may be undertaken. The smaller lots are generally used only for housing, possibly with the retention of some areas of native vegetation for solitude. These are called 'rural retreats' or bush blocks. Sewerage is usually not provided. The larger lot sizes enable agricultural use to be made of the land. When this is secondary to its residential purpose, and to the owner's primary source of income, the term 'hobby farm' is used. Small rural lots on the urban fringe may, however, be used entirely for agriculture without a residential component. Most commonly, this involves grazing or some form of annual or perennial horticulture.

The spectrum of land use activities is considered under three headings. These are:

- house and road construction
- on-site effluent disposal
- agricultural activities.

The first two relate primarily to residential land use and the third to hobby farming, small grazing or horticultural blocks. Implicit in the definitions of the land use activities, which follow, is the requirement for clearing and land preparation, including firebreaks.

3.1.1 House and road construction

This activity is defined as the construction of residential dwellings of one or two storeys under the general standards set by the Western Australia Uniform Building By-laws 1974*, *Local Government Act 1960-1987*, and the construction of roads with sealed surfaces for light vehicles, under the general standards adopted by local government authorities (Lay 1985). It does not include residential/canal developments nor those which require massive engineering works.

For housing foundations, the capability assessment applies to house construction using either 'raft' or 'strip' foundations. The cheapest and most common form of house construction involves brick walls with a reinforced concrete raft foundation over a compacted sandpad of a minimum depth between 45 and 60 cm. In other situations, strip foundations are used beneath external walls and, in some cases, beneath internal walls. Strip foundations consist of concrete or limestone filled trenches which have been previously excavated to a minimum depth of 25-30 cm below the finished ground level.

*Note: Western Australia Uniform Building By-laws will be replaced by the Building Code of Australia (1988) during 1989.

House construction using a concrete slab foundation. The amount of excavation required to provide a level site is determined by the slope gradient.

In Western Australia, State Planning Commission (SPC) policy requires that scheme water be provided to each residence on lots smaller than 2 ha. On larger lots, rain-water or groundwater may be needed for domestic purposes. The average in-house domestic use of water has been estimated at about 173 kL per year (Metropolitan Water Authority 1975). Of this, a small proportion is used for human consumption, the remainder being used as a solvent or transport medium. To provide for estimated usage, the State Planning Commission of Western Australia usually stipulate a 96 000 L tank storage for rural-residential dwellings. This requirement is designed to cater only for in-house water use.

3.1.2 On-site effluent disposal

This activity is defined as the use of land for the on-site absorption of septic tank effluent and sullage from a single family dwelling on a block 1 ha or larger. Deep sewerage is generally not provided to houses in rural-residential developments or hobby farms. For the purpose of this assessment, it is assumed that the most common system for on-site disposal and treatment of domestic liquid waste will be used. This involves use of one or more septic tank units connected to a subsurface soil absorption system. The septic tanks act as a settling chamber for heavier material and contain anaerobic bacteria which digest or break down waste solids. After the solids have settled, the remaining liquid or effluent passes from the tanks into the soil absorption system.

The soil absorption system may consist of one of more leach drains or, in deep sandy soils, two soak wells. The operation of both absorption systems is the same. Effluent soaks into the ground and is purified by the processes of filtration, adsorption and oxidation which occur as effluent moves through soil pores.

A more detailed description of on-site effluent disposal and the assessment of land capability for this use is given by Wells (1987).

3.1.3 Agricultural activities

The range of agricultural uses considered includes grazing, annual horticulture and perennial horticulture. These land use activities are broadly defined since the methodology relies on land resource survey data and is to be used to assist planning at a regional level where only a qualitative ranking of land capability is required. More specific definitions would be required for site-specific agricultural land capability assessments. For example, root crops could be assessed separately from other vegetables currently under the broad term 'general annual horticulture'.

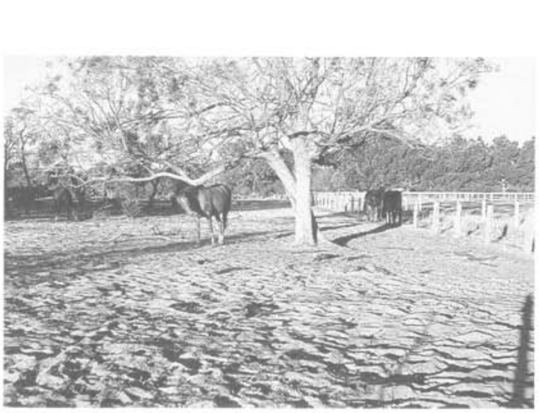
For grazing, suggested carrying capacity figures are not provided for each capability class because of variation within map units according to soil type, type of pasture and the level of fertilizer use. In addition, supplementary hand feeding of animals is common on hobby farms or grazing agistment blocks and this will allow greater stock numbers to be carried.

For hobby farms the scale of agricultural operations is less than that for commercial farming operations. It is assumed that most development inputs, particularly in relation to fertilizer application, will be at least proportionately similar.

Definitions of the agricultural land use activities are as follows:

- Grazing—defined as the grazing of cattle or horses on non-irrigated volunteer and improved pastures with occasional topdressings of superphosphate and within an average annual rainfall zone of 750-1250 mm. Stocking rates should be sufficiently low to maintain a permanent ground cover and to prevent wind or water erosion.
- General annual horticulture—defined as the use of land for vegetable growing or market gardening. The soil is cultivated at least once a year, regularly watered and fertilized, and generally only shallow rooted species are grown.
- General perennial horticulture—defined as the use of land for orchards, vineyards or tree crops. The soil is cultivated only at the initial planting and generally only deep rooting species are grown. The soils are irrigated, regularly fertilized and weeds are controlled by herbicides.

Whether horticulture is undertaken in either a hobby farm or commercial situation will be deter-



Grazing horses on either agistment blocks, hobby farms or equestrian stud properties is an important land use near many urban areas.

Orchards are often a competing form of land use to rural-residential developments near urban areas.

mined by the availability of water suitable for irrigation. However, water availability may be strongly influenced by competing urban and industrial needs. For land resource or land capability surveys, it is usually possible to make only general statements about water availability and its quality for groups of map units. More detailed evaluation of water supply is beyond the scope of most of these surveys. Because of the lack of precision, it is desirable to clearly separate the capability of land for horticulture from the capability of the water supply to support the same use.

Within this methodology, the term 'irrigation water supply' has been used as a land use activity quite separate from the horticultural activities. The assessment of irrigation water supply is made for broadscale planning purposes. Only an initial assessment of horticultural capability can be determined by considering a combination of the land use activities, 'irrigation water supply' and one of either 'general annual horticulture' or 'general perennial horticulture'. For specific sites, this assessment should always be fine-tuned by reference to the Water Authority of Western Australia (in this publication subsequently referred to as the Water Authority).

Where a farm dam supply is to be used, site-specific assessment will be required to determine the sufficiency of catchment area and the expected yield or spillway requirements. The nature of the topography will determine the type of dam used. For example, gully dams are used in drainage channels and narrow valley floors, excavated earth dams on hillslopes, and turkey nest or soak dams on flat terrain.

3.2 Determining land use requirements

Having defined rural-residential development, hobby farming, and their component activities, the next step is to define the land use requirements. For each activity it is necessary to establish the range of conditions from those which are essential for its operation to those which are undesirable. These can be determined by considering:

- the effect of the activity on the land; and
- the effect of the land on that activity.

The first consideration relates to conservation of land, whilst the second relates to its development, management or productive potential (Figure 3).

3.2.1 Effects of land use activities on land

Before land use activities are discussed, the effects of the preparatory clearing of vegetation must be considered. Clearing removes the protective cover from the soil, disrupts the soil surface and removes transpiring plants. The results of clearing are complex and will depend on factors including its extent, the nature of the soil, the slope of the land and its position in the landscape. On soils which disperse easily, increased exposure to rain may result in surface compaction. This, in turn, could lead to decreased infiltration, increased run-off and then to erosion. In other soils, removal of vegetation may cause the soil surface to be broken up leading to increased infiltration and a rising water table. This, in turn, could lead to problems of waterlogging, seepage, secondary salting or slope failure.

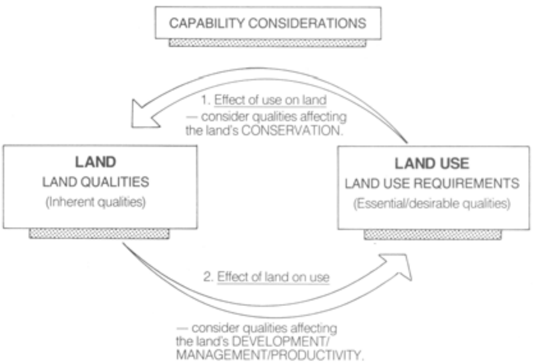


Figure 3. The interaction between land and land use.

- House and road construction

Houses, sheds, sealed pathways and roads increase the proportion of the land surface covered by impervious materials. Unless there are well designed drainage systems, an increase in surface water run-off may occur. On sloping land this can lead to increased soil erosion and, on flatter areas, to an increased susceptibility to waterlogging or site inundation.

Groundwater recharge below an established urban-residential block is generally greater than that under rural or rural-residential uses. When drainage is properly planned, most run-off is channelled into point source intakes allowing passage to the groundwater systems. In rural-residential areas, lower numbers of ratepayers mean that local government authorities can rarely afford to fund drainage works to the same standards as in urban areas and therefore erosion or waterlogging problems are more likely.

Land disturbance associated with excavation, levelling, and cut and fill for housing or road developments generally occurs over a relatively short time. Provided development is timed so that soils are not exposed to extended periods of high rainfall, and the soil is suitably revegetated after construction, erosion need not be a long term problem.

- On-site effluent disposal

The addition of water to land generally increases infiltration and leaching. However, for domestic effluent disposal on relatively large rural-residential blocks the volumes concerned are unlikely to cause any significant effects to these processes.

Nutrients applied to the soil as sewage effluent may pollute ground or surface water resources if soils are highly permeable or leach drains occur close to water. Rapid leaching of sewage effluent through

The effects of preparatory clearing of vegetation are an integral consideration for residential land capability assessment.

soils may also pose a public health risk if pathogenic micro-organisms remain in the leachate.

• Agricultural activities

On hobby farms, agricultural activities may be practised at far higher intensities than under commercial farming. This is often because of the landholder's unfamiliarity with the capability of his land or to a reduced need to be cost effective. Animals may be grazed in numbers exceeding the land's natural carrying capacity because supplementary feed and water are more easily afforded. Depending on the nature of the soil, trampling by animals may cause either surface compaction or breakdown and subsequently increase the susceptibility of the land to erosion.

Soil degradation may also occur under horticultural uses. If land is cultivated too frequently, soil structure and infiltration may decline. Poor management techniques such as cultivation up and down slopes, rather than along the contour, may cause soil erosion.

Excessive watering and fertilizer application to lawns, pastures, market gardens and orchards may cause nutrient addition to groundwater. The major nutrients applied are phosphorus and nitrogen. With the exception of the bleached grey siliceous sands such as those on the Swan Coastal Plain, phosphorus is quickly adsorbed in most soil types and is not lost from the plant root zone by leaching. However, nitrogenous compounds are more mobile and are easily leached during irrigation on most soils.

Market gardening on sandy soils requires large amounts of water and fertilizers. Nutrient enrichment of nearby water bodies may be an off-site effect.

3.2.2 Effects of the land on land use activities

The effects of land qualities on each of the land use activities are discussed below. Preparatory clearing of vegetation again needs to be considered. Clearing may be hindered by factors such as vegetation density, extensive rock outcrops, or by steep slopes.

• House and road construction

Although site characteristics are rarely prohibitive for house or road construction, they can have a significant effect on the design of engineering services and associated structures. Neil and Scales (1976) provide data to show that the cost of services are also directly influenced by slope, topography, drainage and soil type. Gordon (1983) estimates, for example, that within the Darling Scarp east of Perth, the cost of providing satisfactory foundations for a house site on poor subsoil conditions could be as much as $8000* over that expected for a normal block on the Swan Coastal Plain sands. Poor subsoil conditions can relate to soils with a high shrink-swell potential which cause cracking or distortion of walls, to areas of slope instability, and to areas where excavation is hindered by either rock outcrops, slope or poor drainage.

The soil requirements for road foundations are similar to those for housing. These are defined by Lay (1985) as: the ability to be compacted and formed to the required condition and shape, the ability to resist load without deformation, and the ability to resist moisture penetration.

• On-site effluent disposal

Successful functioning of septic tanks is achieved if soil surrounding the absorption system absorbs the volume of effluent produced and allows it to be purified by the processes of filtration, adsorption and oxidation. Soils surrounding effluent leach drains must be sufficiently permeable, and drains sited well above seasonal water table levels. Sites on steep slopes should be avoided because of the risk of seepage by lateral flow. Parker (1983) has demonstrated that effective bacterial purification can occur even in sands, provided some minor clay or organic matter is present and sufficient travel time is available before effluent reaches either an impermeable layer or the water table.

• Agricultural activities

Soil fertility might be considered the most obvious land quality to affect agricultural activities. Soil fertility is a combination of desirable soil chemical and physical features. Because it is relatively simple to modify soil chemical features (by the addition of fertilizer), more emphasis needs to be placed on the physical aspects of soil fertility. Soil chemical fertility is a relatively minor consideration for both hobby farming and commercial horticulture on small rural blocks. On hobby farms, heavy use of fertilizers to boost soil productivity is possible because land holders are usually supported by off-farm income. On horticultural blocks, heavy use of fertilizers is also common because of the relatively low price compared with other production costs, and compared with the economic losses which might be incurred through under fertilizing.

For house and road construction, soil chemical fertility is a minor consideration relevant to garden or lawn establishment and to revegation programmes following development. Excessively acidic or alkaline soils, saline soils, and non wetting sands are most likely to cause problems.

Land qualities related to soil physical fertility have a significant affect on agricultural land uses. For horticulture, the risk of waterlogging or inundation is important. Annual horticultural species in particular, require soils which are either naturally well drained or occur in locations which can be readily drained by artificial means. In free draining soils, there is a low incidence of root diseases and soil borne pathogens. The ability to retain water which is available to plants is generally of little importance for irrigated land uses unless water is limited. For grazing however, water retention ability will determine the amount of supplementary feed stock require. Where soils are cultivated at least once a year, good soil workability is needed. Plants require room and suitable soil rooting conditions for effective growth.

For irrigated horticulture, the amount and quality of available water will be of principal concern. Luke (1988) uses data which indicate that, for commercial horticultural production on the Swan Coastal Plain, up to 15 ML of water can be required per ha.

For grazing stock, drinking requirements can be determined using the formula,

$DR = 0.19T - 2.88$ (Luke 1987)

where DR = drinking rate in litres per day for one dry sheep equivalent, and

T = average maximum daily temperature (°C).

This formula assumes green feed is available in winter. If handfeeding is required, an additional 2L per day is needed per head of stock. Water quality requirements for plants and various stock are given by Luke (1987) and Hart (1974).

The ability to meet irrigation or stock watering requirements in any given situation is relatively site-specific. Groundwater or surface water supplies may be used. If dams are to be used to harvest rain water run-off, access to an adequate catchment is required. To determine catchment area (and assist water supply design) the Department of Agriculture produced a computer software package, Damcat II (Denby and Hauck 1988). For other information about required storage capacities for dams, refer Middlemas (1981).

*$8 000 in 1983 is roughly equivalent to $11 800 in 1989 (Australian Bureau of Statistics 1989).

3.2.3 Summary of requirements

The major requirements for rural-residential and associated agricultural land uses can be summarized as a list of essential and desirable conditions. These conditions are expressed here in terms of land qualities grouped under the headings of conservation, development or management, and productivity requirements. The groupings are not mutually exclusive. For example, severe water erosion may cause undermining of house or road foundations affecting development and management, as well as land conservation. The qualities are grouped here, and also in Tables 2, 3a, 3b and 3c, according to their major area of effect.

• Conservation requirements

Essential:

—Land should not be susceptible to an erosion risk which will prohibit its sustained use or cause off-site effects detrimental to adjacent land users or the community.

—Septic effluent disposal areas need to be suitably drained and be above seasonal water table levels. Soils need to be sufficiently permeable and adsorptive to accept and purify effluent, thus preventing ground or surface water pollution.

—Leaching of nutrients from the use of fertilizers should not pollute ground or surface water resources.

• Development/management requirements

Essential:

—Areas used for residential dwellings should not be susceptible to severe flooding or slope instability.

Desirable:

—Soil and land surface conditions should permit cost-effective construction, excavation and site preparation for houses and roads, with minimal disturbance of vegetation.

—Areas should be sufficiently free of waterlogging or inundation to provide easy access and on-site trafficability.

—Where cultivation is required, the soils should be easily worked.

• Productivity requirements (for agricultural activities)

Essential:

—Areas used for irrigated agriculture should have a sufficient supply of suitable quality water from a groundwater, surface stream or farm dam supply, and the land should not be strongly susceptible to salinity.

Desirable:

—Areas used for grazing or horticultural activities should have favourable conditions with respect to:

• soil nutrient availability
• soil moisture availability
• plant rooting conditions

These land use requirements can be developed further by listing a range of optimal, acceptable, and unacceptable values for relevant land qualities in tabular form. This is done within the land use rating tables. For each land use activity, land quality values can be graded over a five part scale according to their effect on that activity. Land use rating tables developed for the methodology 'test areas', (covering portions of the Darling Range and Swan Coastal Plain near Perth) are shown as examples in section 3.4.

3.3 Assessment of land qualities

3.3.1 Introduction

Land qualities are attributes of land which act in a distinct manner to influence the ability of land to support a specific kind of use.

The land qualities chosen for the assessment of rural-residential and associated agricultural land uses are listed in Table 2 under each of the following six component activities:

- house and road construction
- on-site septic effluent disposal
- irrigation water supply
- grazing
- general annual horticulture
- general perennial horticulture

The measurement or estimation of land qualities uses soil or land characteristics described during land resource surveys. In some cases, a quality can be satisfactorily described by a single land characteristic, while in others, a combination of characteristics is required. To determine characteristics for the assessment of each quality, there are two considerations:

- which characteristics most truly represent the quality?
- for which is it practicable to obtain information?

The assessment of land qualities, where based on the interactive effects of a number of land characteristics, may often be intuitive. However, it is preferable to use land qualities, rather than individual land characteristics, within capability rating tables (section 3.4). Qualities have the advantage of being directly related to the specific requirements of land use and they take account of interactions between characteristics (van de Graaff 1988). Land characteristics which may be used to assess land qualities are listed in Tables 3a, 3b and 3c.

Table 2. Land qualities assessed for each land use activity*

1. Housing and roads	2. On-site septic effluent disposal	3. Irrigation water supply**	4. Grazing	5. General annual horticulture	6. General perennial horticulture
Conservation factors					
• Water erosion risk • Wind erosion risk • Wave erosion risk	• Microbial purification ability • Water pollution risk —by overland flow —by subsurface drainage	—	• Water erosion risk • Wind erosion risk • Wave erosion risk • Water pollution risk —by overland flow —by subsurface drainage	• Water erosion risk • Wind erosion risk • Wave erosion risk • Water pollution risk —by overland flow —by subsurface drainage	• Water erosion risk • Wind erosion risk • Wave erosion risk • Water pollution risk —by overland flow —by subsurface drainage
Development/management factors					
• Ease of excavation	• Ease of excavation	• Dam site construction suitability	• Flood risk	• Soil workability	• Soil workability
• Waterlogging/ inundation risk	• Soil absorption ability	• Subsoil water retention ability	• Waterlogging/ inundation risk	• Waterlogging/ inundation risk	• Waterlogging/ inundation risk
• Flood risk	• Flood or inundation risk	• Flood risk		• Flood risk	• Flood risk
• Foundation soundness • Slope instability risk • Salinity risk					
Productivity factors					
—	—	• Groundwater availability • Groundwater quality • Surface water availability	• Nutrient availability • Topsoil nutrient retention ability • Moisture availability • Rooting conditions • Salinity risk	• Nutrient availability • Topsoil nutrient retention ability • Moisture availability • Rooting conditions • Salinity risk	• Nutrient availability • Nutrient retention ability • Moisture availability • Rooting conditions • Salinity risk

* For small rural-residential lots consider activities 1 and 2 only. For larger hobby farm or agricultural lots, consider activities 3, 4, 5, or 6 as required.

** Land qualities considered as appropriate for chosen method of water supply. For dams filled by surface run-off, site-specific assessment of sufficiency of catchment will be required. For groundwater or stream supply, permits are required from the Water Authority.

Table 3a. Characteristics used to assess qualities mainly related to conservation

Quality (subclass notation)	Characteristics*
LQ1 Water erosion risk (e)	Surface texture Surface stone or gravel Surface condition Slope Site drainage Depth to impermeable layer Permeability above impermeable layer Subsoil dispersion[1] Extent of existing erosion[2]
LQ2 Wind erosion risk (w)	Proximity to coast Landform/topography Surface texture Site drainage Surface condition Surface stone or gravel Extent of existing erosion[2]
LQ3 Wave erosion risk (v)	Nature of beach/surf zone state Extent of existing erosion[2] Shoreline movement[12]
LQ4 Microbial purification ability (p)	Permeability Nature of soils; texture and coherence Depth to impermeable layer (clay, rock or water table) Slope Site drainage
LQ5 Water pollution risk[3] —by overland flow (o)	Soil absorption ability[4] Run-off Flood risk[4]
LQ6 Water pollution risk[3] —by subsurface drainage (s)	Subsoil texture Soil coherence and fabric P adsorption or retention data[1]

*Refer to bottom of Table 3c for superscript notations.

Table 3b. Characteristics used to assess qualities mainly related to development/management

Quality (subclass notation)	Characteristics*
LQ7 Ease of excavation (x)	Depth to rock Slope Stone within profile Rock outcrop Site drainage Geology or rock type[5] Inundation risk[4]
LQ8 Waterlogging/inundation risk (i)	Site drainage Depth to impermeable layer Degree of soil mottling[6] Duration and extent of inundation or flooding[2]
LQ9 Flood risk (f)	Landform/topographic position[7] Duration and extent of flooding[2]
LQ10 Foundation soundness (b)	Engineering properties (USC)[8] Subsoil shrink-swell potential Geology or rock type[5]
LQ11 Slope instability risk (c)	Slope Site drainage Geology or rock type[5] Profile permeability Depth of regolith Extent of existing landslips[2]
LQ12 Soil absorption ability (a)	Site drainage/depth to water table Permeability (texture/structure) Depth to impermeable layer Gravel and stone within profile
LQ13 Dam site construction suitability (h)	Slope Depth to clay (impermeable layer) Depth to rock Surface boulders Inundation risk[4]
LQ14 Subsoil water retention ability (d)	Depth to impermeable layer Topsoil and subsoil textures Subsoil dispersion[1] Soil structure[6] Soil strength[9]
LQ15 Soil workability (k)	Topsoil texture Surface boulders Surface condition of soil Stone within profile Slope

Refer bottom of Table 3c for superscript notations.

Table 3c. Characteristics used to assess qualities mainly related to productivity

Quality (subclass notation)	Characteristics
LQ16 Groundwater availability (g)	Volume available[10]
LQ17 Groundwater quality (q)	Salinity of supply[10]
LQ18 Surface water availability (j)	Duration and volume of flow[11]
LQ19 Nutrient availability (l)	pH
	Ferruginous gravel content
	Reactive iron[1]
	Cation exchange capacity[1]
	Organic matter content[1]
	Soil colour and texture trend
LQ20 Nutrient retention ability (n)	Soil texture trend
	Coherence and fabric (for sandy soils)
	Soil depth
	Gravel content
	P adsorption or retention data[1]
LQ21 Topsoil nutrient retention ability (t)	Topsoil texture and colour
	Topsoil coherence and fabric
	Gravel content
	P adsorption or retention data[1]
LQ22 Moisture availability (m)	Broad soil type (texture, profile trend)
	Position in landscape
	Proximity to seepage area or water table
LQ23 Rooting conditions (r)	Depth to impermeable layer
	Broad soil type
	Gravel and stone within profile
LQ24 Salinity risk (y)	Electrical conductivity[1]
	Total soluble salts[1]
	pH
	Extent of existing salinity[2]

1 From laboratory analysis data where available.

2 Assessed by field observation.

3 Assessed only for areas of land at margins of surface water bodies. Effect of man-made drains not considered.

4 Land quality determined elsewhere.

5 Consider ratings based on Geological Survey of Western Australia interpretations (Environmental Geology Map Series) where available.

6 Indicated by Principal Profile Form (PPF) classification (Northcote 1979).

7 Correlate with Water Authority flood study mapping where available.

8 Unified Soils Classification (USC) is based on engineering properties such as particle size distribution and plasticity.

9 Infer from USC data where available.

10 Estimates from published data or from personal communication with staff of the Geological Survey of W.A. and the Water Authority.

11 Estimates based on field observation or stream flow data where available.

12 Assessed from maps produced by the Department of Marine and Harbours.

3.3.2 Land qualities

We now define each land quality and its rating values and discuss the characteristics which should be considered in its assessment. Examples of assessments are drawn from the Mandurah-Murray and Darling Range 'methodology test' areas. For each land resource survey map unit (land unit), values for relevant soil or land characteristics are usually compared with those in a simple table, and the quality rating determined by the most limiting factor. The terms used to describe soil or land characteristics are defined in the *Australian Soil and Land Survey Field Handbook* (McDonald *et al.* 1984) unless otherwise stated.

LQ1 Water erosion risk (e)

Water erosion is a process in which soil is detached and transported from the land by the action of rainfall, run-off, seepage and/or ice (Houghton and Charman 1986). Sheet, rill, gully, streambank and tunnel erosion are terms used to describe the most common types of water erosion.

Water erosion can severely affect rural-residential land use if housing or road foundations are undermined. More commonly, siltation of roads and drains is the result of erosion from construction sites left bare during periods of high intensity rain. However, after construction is complete, the erosion risk can generally be reduced if only small areas are left bare of vegetation. Under agricultural land uses, larger areas are likely to be exposed to erosion and its effects on productivity and general degradation of the land resource will be more significant.

Water erosion risk is defined as the intrinsic susceptibility of a parcel of land to erosion caused by water. It is dependent on climate, landform and soil factors. Erosion risk ignores land use and land management factors thereby differing from erosion hazard. Erosion risk is an intrinsic quality of the land whereas erosion hazard is a combination of risk and land use/ management factors (Houghton and Charman 1986). For most land capability studies the terms 'erosion risk' and 'erosion hazard' can be regarded as synonymous. Technically, the land quality is erosion risk, and when that quality is considered a limiting factor for a specific land use, it is more appropriate to refer to erosion hazard.

The most satisfactory methods of erosion hazard assessment are based on predicted soil losses by modelling the determinants of climate, soil erodibility, slope and vegetation factors (FAO 1983). Alternative methods for assessment of erosion hazard are as follows:

- the universal soil loss equation (USLE - Wischmeier and Smith 1978)
- the FAO soil degradation assessment (FAOSDA) methodology (FAO 1979)
- observed present erosion
- local methods based mainly on slope.

The choice between these methods will be determined by the circumstances of each land capability study. However, for most studies, where a qualitative estimate of erosion risk is required for a number of land mapping units, local methods based mainly on slope, will be preferred.

Assessment example LQ1:

The method of assessment used in the methodology test areas is described by Wells (1988) and outlined in Figure 4. Water erosion risk is determined by combining a slope class and a soil erodibility rating. The latter is determined from soil resistance and rainfall acceptance factors which, in turn, are derived using the diagnostic soil or land characteristics listed.

In this example, the procedure is as follows:

- Determine a rainfall acceptance index using Table 4. This is a version of the method used by the United Kingdom, National Environmental Resource Council (NERC 1975) with slight modifications to the slope, depth, and permeability classes to permit ready correlation with standard terms of Australian soil and land resource surveys (McDonald *et al.* 1984).
- Determine a soil resistance rating using Table 5.

Severe soil erosion can result from over clearing of vegetation, particularly where subsoils are dispersive.

- Combine the rainfall acceptance index with the soil resistance rating to determine soil erodibility using Table 6. Note that erodible subsoils may modify ratings (see footnote to Table 6).

- Determine slope class and combine with the soil erodibility rating to determine water erosion risk using Table 7. Note that topographic position and length of slope may modify ratings at specific sites (see footnote to Table 7).

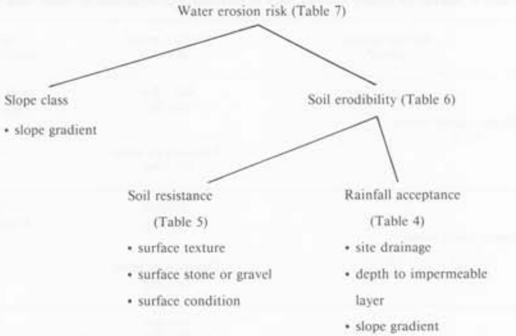


Figure 4. Schematic outline of erosion risk assessment example.

Table 4. Classification of winter rain acceptance rate used in LQ1 assessment example (after NERC 1975)

Site drainage	Depth to imperm-eable layer* (cm)	Slope classes								
		(0-5%)			(5-15%)			(> 15%)		
		Permeability above impermeable layer**								
		High	Moderate	Slow	High	Moderate	Slow	High	Moderate	Slow
Rapid to moderately well	>100	1	1	2	1	2	2	1	2	3
	50-100	1	1	2	2	2	3	3	3	4
	<50	—	—	—	—	—	—	—	—	—
Imperfect to poorly	>100	2	2	3	3	3	4	—	4	5
	50-100	2	3	3	3	4	4	4	4	5
	<50	3	4	4	4	4	4	4	4	5
Very poorly	>100	4	4	5	5	5	5	—	5	5
	50-100	4	5	5	5	5	5	—	5	5
	<50	5	5	5	5	5	5	5	5	5

Winter rain acceptance indices (in body of table):

1. very high; **2.** high; **3.** moderate; **4.** low; **5.** very low. —indicates combination of these conditions should not be possible.

*** Depth to 'impermeable' layers:**

- Clay subsoil generally considered impermeable unless it is well structured (except expansive soils) or stony.
- For shallow soils (< 50 cm) overlying rubbly laterite, depth class may effectively be 50-100 cm because preferred pathways through duricrust (Johnston *et al.* 1983) will assist downward percolation of water.
- For shallow soils overlying limestone in pinnacle rather than sheet form, depth class may also effectively be 50-100 cm because of variable true depth and the likelihood of preferred pathways.

**** Permeability of soil above 'impermeable' layer (or to 100 cm):**

Classes are those used by McDonald *et al.* (1984) and correlate with terms used in Department of Agriculture land resource surveys (see Appendix 2) as follows: High (Rapid-very rapid); Moderate (Mod. rapid—mod. slow); Slow (Slow)

Table 5. Ratings for surface soil resistance to detachment or breakdown by water, used in LQ1 assessment example

Surface texture group*	Surface gravel or stone	Surface condition (dry)	Soil resistance
Sands—sandy loams (1-2)	Nil—few (0-10%)	Soft or loose	Low
		Firm or hard	Moderate
	Common or more (> 10%)	—	Moderate
Sandy loams-loams (2-3)	Nil-few (0-10%)	Soft	Low
		Firm or hard	Moderate
	Common or more (> 10%)	—	Moderate
Loams-clay loams (3-4)	Nil-few (0-10%)	—	Moderate
	Common or more (> 10%)	—	High
Clay loams-medium heavy clays (4-6)	—	Firm or hard	High
		Self mulching	Low

* Note: A range of soil texture groups is given to cover possible variations within a mapping unit. If, however, surface textures fall entirely within one texture group, soil resistance is determined from the uppermost row in which the texture group appears.

Table 6. Soil erodibility ratings for water erosion, used in LQ1 assessment example

Winter rainfall acceptance index (from Table 4)	Soil resistance to detachment or breakdown (from Table 5)	Soil erodibility rating*
1 Very high	High	Low
	Moderate	Low
	Low	Low
2 High	High	Low
	Moderate	Low
	Low	Moderate
3 Moderate	High	Low
	Moderate	Moderate
	Low	Moderate
4 Low	High	Low
	Moderate	Moderate
	Low	High
5 Very low	High	Low
	Moderate	Moderate
	Low	High

* Increase rating from low to moderate, or moderate to high if necessary following observation of existing erosion or non-wetting surfaces. Also, increase if laboratory data such as exchangeable sodium percentage, aggregate stability class or very fine sand and silt content, indicate erodible subsoils. These factors have not been directly considered within the main body of the table because primary consideration has been given to the risk of initiating soil erosion following surface disturbance, and to determine that risk through easily obtainable field characteristics.

Table 7. Assessment example LQ1: Water erosion risk

Slope class	Soil erodibility rating (from Table 6)	Water erosion risk*
(0-3%) Level-very gentle	Low Moderate High	Very low Very low Low
(3-10%) Gentle	Low Moderate High	Low Moderate Moderate
(10-20%) Moderately inclined	Low Moderate High	Low Moderate High
(20-30%) Moderately steep	Low Moderate High	Moderate High Very high
(> 30%) Steep-very steep	Low Moderate High	Moderate Very high Very high

* Increase risk to the next grade where land unit receives or concentrates excessive run-off water rendering it particularly susceptible to erosion.

LQ2 Wind erosion risk (w)

Wind erosion is a process in which soil is detached and transported from the land surface by wind. Transport of wind-blown particles occurs by surface creep, saltation, or suspension (Houghton and Charman 1986). Strong winds generally remove organic matter, silt, and clay fractions, leaving behind the sand and gravel fractions in a sorting action which, with time, renders a soil less productive and coarser in texture than originally. The processes of wind erosion are described in more detail by Bagnold (1941).

For residential land use, wind erosion may be no more than a nuisance factor, because generally, only small areas of land are left bare after development. In extreme cases however, usually in coastal areas, wind erosion can seriously affect development and cause undermining of houses or damage to roads. For agricultural land uses, larger areas are likely to be involved and effects on productivity and general degradation of the land resource are likely to be significant.

Wind erosion risk is defined as the intrinsic susceptibility of a parcel of land to erosion caused by wind. The risk factor is dependent on a combination of climatic, landform and soil factors, and ignores land management. Existing vegetative cover is not relevant since the risk is to 'bare' soil. In Western Australia there is no universally applicable model for assessing relative wind erosion risk from land resource survey data. Severe wind erosion problems are generally limited to exposed coastal areas or to land which has been heavily overstocked or overgrazed.

As with water erosion risk, most land capability studies are likely to employ a locally derived assessment method. An example of such in Victoria by Lorimer (1985) indicates that a simple assessment of relative wind erosion risk can be derived from two factors:

- exposure; and
- soil erodibility (by wind).

Assessment example LQ2:

For the methodology test areas, exposure and soil erodibility factors were assessed as shown in Tables 8 and 9, and then combined to determine an erosion risk value, as shown in Table 10.

- Exposure

There is a lack of data on the probability of erosive winds for much of the Swan Coastal Plain and the Darling Range. Land resource survey mapping units are rarely separated on the basis of aspect so only a relatively crude exposure factor can be included. In addition, prevailing winds may vary with time of day and the season. Over much of the Darling Range and Swan Coastal Plain there appears to be no overall prevailing wind direction except for areas near the coast. Here, the dominant effect of a south-westerly wind direction is indicated by wind eroded landforms, wind pruning effects on vegetation, and by the alignment of the coastal dunes. Further inland the exposure factor is less significant because wind directions and strengths appear to be more seasonally variable.

In general, exposure may also be affected by topography and relief. Moderate to steep slopes with relatively high relief will be more exposed than lower, more gentle slopes or undulating areas. These in turn will be more exposed than flat plains or depressions. Table 8 relates proximity to the coast and topography to determine a crude wind exposure factor.

• Soil erodibility to wind

A soil erodibility factor is based on the relative surface soil resistance to detachment by wind. This is determined by considering soil texture, surface condition and site drainage.

Particle size distribution or soil texture is the principal factor affecting soil resistance to detachment. The percentage of particles in the 0.1 to 0.15 mm or fine sand range is important since they are most easily moved by saltation (Bagnold 1941). Soils composed of finer particle sizes (heavier soil texture groups) are relatively resistant to erosive detachment because of strong cohesive forces between particles with relatively large surface area to volume ratios. Soils composed of coarser particle sizes are also relatively resistant to wind detachment because of their weight. Four surface soil texture groupings have been formed to indicate relative ease of detachability. These are modified by surface features and combined with a site drainage factor in Table 9 to determine a soil erodibility factor. Surface features including gravel cover, crusts or a hard setting condition, and the moisture content of surface soil as affected by site drainage, will increase the resistance of soil to detachment by wind.

Table 8. Wind exposure factor ratings used in LQ2 assessment example

Proximity to coast	Topographic group*	Exposure factor
Very close (foredunes and existing eroded areas within most recent coastal dunes-Holocene age)	H, L, F, D	Very high
Close (other areas of most recent coastal dunes)	H, L F, D	High Moderate
Moderate (areas of older dunes within the coastal belt-mid to late Pleistocene age)	H L F D	High Moderate Low Very low
Distant (all other areas)	H L, F D	Moderate Low Very low

* Topographic groups

H Higher relief, moderate to steep slopes and crests

L Lower relief, more gentle slopes or undulating rises

F Flat plains

D Depressions and swamps

Table 9. Soil erodibility ratings for wind erosion used in LQ2 assessment example

Surface texture groups	Site drainage*	Soil erodibility rating**
1 Sands—with a relatively high fine sand component	Well—rapid Moderately well —imperfect Poor—very poor	Very high High High
1 Sands—with a relatively high coarse sand component	Well—rapid Moderately well —imperfect Poor—very poor	High Moderate Moderate
2-4 Sandy loams, loams or clay loams	Well—rapid Moderately well —imperfect Poor—very poor	Moderate Low Low
5-6 Clays	Moderately well —imperfect Poor—very poor	Low Low

*See Appendix 2 for class definitions.

** If surface condition is crusted or hard set, or if surface gravels or stones are common or more abundant (> 10%) ratings are modified by decreasing to one lower grade (unless the rating is already 'low').

In this assessment example, Table 10 relates exposure ratings from Table 8 with the soil erodibility factor from Table 9 to determine a wind erosion risk.

Table 10. Assessment example LQ2: Wind erosion risk

Exposure factor (from Table 8)	Erodibility rating (from Table 9)	Wind erosion risk[1]
Very low	Low-high	Very low
	Very high	Low
Low	Low-moderate	Low
	High	Moderate
	Very high	High
Moderate	Low	Low
	Moderate	Moderate
	High	Moderate
	Very high	High
High	Low	Moderate
	Moderate	Moderate
	High	High
	Very high	High
Very high	Low	High
	Moderate	High
	High-very high	Very high

[1] In coastal dune systems, mobile sand sheets or active blowouts are automatically assigned a 'very high' risk.

LQ3 Wave erosion risk (v)

Wave erosion risk refers to the potential for waves to remove sand or soil material from coastal areas. Susceptibility to wave erosion is usually confined to beaches and primary foredunes unless the coast is in a state of net erosion. If it is in a state of net erosion, landforms other than the beach and foredunes may be affected in time. This land quality does not encompass the risk of tidal inundation in inlets. The latter is dealt with as 'waterlogging/ inundation risk' (refer LQ8).

Only two categories of wave erosion risk are suggested, susceptible and not susceptible. Susceptibility to wave erosion is determined by observation of the nature of the beach/surf zone state, dissipative or reflective, the absence of foredunes, wave scarping, distribution of seagrass wrack and by using shoreline movement plans, where available from the Department of Marine and Harbours.

LQ4 Microbial purification ability (p)

Purification ability relates to the ability of soil used for septic effluent disposal to remove microbes which may be detrimental to public health. It also relates to the soil's ability to provide suitable conditions for oxidation or breakdown of organic and some inorganic materials within the effluent. This ability is largely determined by the time of travel available until effluent reaches either the water table or an impermeable layer. This, in turn, will be largely determined by soil permeability, but is also influenced by the clay or organic matter content of the soil material.

Assessment example LQ4:

The method used in the methodology test studies for the assessment of purification ability, and for other land qualities relevant to on-site septic effluent disposal, is described by Wells (1987). Table 11 presents a modified version of the purification ability assessment table from his report. The modification relates to the inclusion of calcareous sands within the first soil grouping on the basis of results of studies into microbial removal within sands reported by Parker (1983). Parker's results showed, for limited data, that removal of microbes within coastal calcareous sands was not as great as might be expected from their high calcium content.

Table 11. Assessment example LQ4: Microbial purification ability

Permeability[1]	Nature of soil	Depth to impermeable layer[2]	Rating[3]
Moderately rapid —very rapid	Sands: (i) Grey or very pale leached sands with little coherence, and calcareous sands	> 5 m < 5 m	Low Very low
	(ii) Coloured sands (usually yellowish brown to red) and earthy sands with slight to moderate coherence	< 2 m 1-2 m < 1 m	High Moderate Low
Moderate—slow	Soils with loamy textures or heavier [4]	> 1 m 0.5-1 m < 0.5 m	High Moderate Low

[1] See Appendix 2 for class definitions.

[2] Depth to rock, impermeable poorly structured clay, or seasonal water table if known.

[3] If site drainage is very poor, soils will be insufficienty aerated for bacterial breakdown of effluent components. Rating is automatically very low.

[4] When these soils occur on steep slopes, lateral seepage may intercept the surface and result in ineffective purification. Where the slope is 20-30%, the rating is automatically low, and if slope is > 30%, the rating is very low.

LQ5 and 6 Water pollution risk

Water pollution risk refers to the potential for excessive nutrient loading or eutrophication of surface water bodies. In relation to the land uses considered in this methodology, the source of nutrients may be from septic tank wastes or from agricultural fertilizers. Although both phosphorus and nitrogen may be present in large amounts in both sources, phosphorus is of primary concern. Research by the Department of Conservation and Environment (1981) into the Peel-Harvey estuarine system near Mandurah, has shown that it is lack of phosphorus, rather than lack of nitrogen, which limits growth of the major algal species arising under eutrophic conditions.

The movement of nutrients from the soil to surface water bodies can occur through three mechanisms: overland flow; subsurface flow along the top of the clay layer of duplex soils; and by deep drainage into superficial groundwaters which are directly linked to surface wetlands. Within this methodology two subdivisions of water pollution risk have been created:

- the risk from surface or overland flow; and
- the risk from subsurface drainage.

Ideally, assessment of these land qualities should be made on a catchment basis and detailed consideration should be given to the effects of any man-made drainage infrastructure and to local and seasonal variations in the depth to the groundwater. This can rarely be done when the land capability assessment methodology uses the results of land resource mapping. When assessing water pollution risk, problems occur because factors such as the presence or absence of drainage infrastructure, location with respect to water catchments, and depths to groundwater are not used to define the map units and so cannot be consistent for all occurrences of any one map unit. Hence, for this methodology these factors are not considered and the assessment of water pollution risk is only made for map units which are usually adjacent to surface water bodies.

'Water pollution risk by overland flow' will be largely determined by the ability of the soil to absorb water, site run-off characteristics, and the likelihood of flooding or severe inundation. 'Water pollution risk by subsurface drainage' will, however, be largely determined by the ability of the soil, specifically the subsoil, to retain added nutrients against losses caused by leaching. Most of these determining factors are land qualities in their own right and are described in this methodology.

Assessment examples LQ5, LQ6:

Tables 12 and 13 illustrate the methods used in the methodology test areas for the assessment of water pollution risk. In relation to septic tank effluent disposal, these qualities are also discussed by Wells (1987).

Table 12. Assessment example LQ5: Water pollution risk by overland flow

Absorption ability[1]	Run-off	Risk rating[2]
High	—	Very low
Moderate	Nil-slow	Low
	Moderately rapid-very rapid	Moderate
Low or very low	Nil-slow	Moderate
	Moderately rapid-very rapid	High

[1] Refer to assessment of LQ12

[2] If the map unit is subject to high flood risk, the pollution risk rating is automatically very high. For a moderate flood risk, it is high. For a low flood risk, it is moderate. Refer to LQ9 for the assessment of flood risk.

Table 13. Assessment example LQ6: Water pollution risk by subsurface drainage

Soil description	Nutrient retention rating*	Pollution risk rating
Deep (> 1 m) grey leached siliceous sands where iron-organic pans or coloured subsoils, if present, occur at depths greater than 1 m	Very low	Very high
Grey leached sands or sandy loams with an iron-organic hardpan within 1m of the soil surface Duplex soils with moderately deep (50-100cm) sandy leached topsoils, or leached sands of similar depth overlying unrelated clays or a hardpan Shallow (< 50 cm) gravelly sands over rock	Low	High
Sands and earthy sands, either whole coloured or with coloured subsoils within 1 m of the soil surface Deep gravelly sands Calcareous sands Duplex soils with shallow sandy topsoils	Moderate	Moderate
Uniform loamy soils Gravelly duplex soils	Moderately high	Low
Uniform clay loams or clays Gradational earths with loamy topsoils Duplex soils with loamy topsoils	High	Low

* Approximate ranges of P adsorption (Ozanne and Shaw 1967) corresponding to ratings are as follows: very low < 2ppm, low 2-5ppm, moderate 5-10ppm, moderately high 10-20ppm and high > 20ppm (J. S. Yeates, personal communication).
Arbitrary ranges of P retention index are: very low 0-2, low 2-10, moderate 10-20, moderately high 20-100 and high > 100 (D. E. Allen, Chemistry Centre of Western Australia, personal communication).

LQ7 Ease of excavation (x)

This land quality is relevant to house or road construction, and to the installation of septic tank effluent disposal systems. For houses, cut and fill or bench excavation may be required to provide a level site on sloping terrain, and shallow excavations may be needed for strip foundations. Septic tank leach drains require trenches to be excavated 20-60 cm beneath the soil surface.

Soil and land characteristics influencing the amount and ease of excavation are depth to rock, slope, profile stone content, surface rock outcrop and site drainage conditions. Slope and site drainage also relate to the ease of machinery use associated with excavation and to the possible need to shore up sides of trenches against collapse.

Assessment example LQ7:

Table 14 illustrates how this land quality was assessed in the methodology test areas.

Table 14. Assessment example LQ7: Ease of excavation

Characteristic	Rating**			
	High	Moderate	Low	Very low
Depth to rock	Deep (> 100 cm)	Moderately deep (50-100 cm)	Shallow (25-50 cm)	Very shallow (< 25 cm)
Slope	< 15%	15-25%	> 25%	—
Stone within profile	Nil-common (< 20%)	Many-abundant (20-90%)	Very abundant (> 90%)	—
Rock outcrop	Nil-very few (< 2%)	Few (2-10%)	Common or many (10-50%)	Abundant or more (> 50%)
Site drainage*	Rapidly-imperfect	Poor	Very poor	—

* See Appendix 2 for class definitions.

** Note: 1. The rating will be determined by that of the most limiting characteristic.
2. Rating is automatically very low if site is subject to tidal inundation.

Extensive areas of rock outcrop can restrict excavation for house foundations or effluent disposal systems, and prevent cultivation for horticultural uses.

LQ8 Waterlogging/inundation risk (i)

Waterlogging is the condition of a soil which is saturated with water and in which most or all of the soil air has been displaced (Houghton and Charman 1986). Inundation occurs under severe waterlogging conditions when the land surface is covered by water. Waterlogging may be caused by excessive rainfall, seepage or tidal inundation, and is exacerbated by inadequate site and/or internal drainage (permeability).

Waterlogging is detrimental to the growth of most plants and will reduce trafficability for machinery. Waterlogged soils prevent the effective absorption and purification of septic tank effluent. They also prevent the absorption of storm water, thus increasing run-off and, in sloping areas, increase the possibility of erosion. The assessment of waterlogging risk assumes that no man-made drainage has been installed.

Assessment example LQ8:

Within the methodology test areas, waterlogging or inundation risk has been assessed by considering the depth to an impermeable layer, the degree of mottling within the soil profile, position in the landscape, and field observations of actual waterlogging or inundation. Classes of risk are correlated to the site drainage classes of McDonald *et al.* (1984) and are described in Table 15.

Table 15. Assessment example LQ8: Waterlogging/inundation risk

Waterlogging/ inundation risk*	Description
Nil	Very rarely waterlogged. Water is removed from the soil rapidly in relation to supply. Soils are usually coarse textured. No horizon is normally waterlogged/wet for more than several hours after addition of water. (Rapidly drained soils)
Low	Rarely waterlogged. Water is generally readily removed from the soil. Soils are often medium textured. Some horizons may remain waterlogged for several days to a week after addition of water. (Well or moderately well drained)
Moderate	Commonly waterlogged for several weeks during winter. Water is removed only slowly in relation to supply. Some horizons may be mottled and/or have orange or rusty linings of root channels. (Imperfectly drained)
Moderately high	Commonly waterlogged for several months during winter. Water is removed very slowly in relation to supply. A perched water table may be present and soil horizons are commonly gleyed, mottled or possess orange or rusty linings of root channels. (Poorly drained)
High	Usually waterlogged throughout winter and water is removed from the soil so slowly that the water table remains at or near the surface for most of the year. (Very poorly drained)
Very high	Inundated for most or all of the year either because of tidal action or topography (for example, a swamp)

The susceptibility of land to waterlogging or local flooding can incur additional development costs, with houses and effluent disposal systems being sited on large pads.

LQ9 Flood risk (f)

Flooding is the temporary covering of land by water from overflowing streams and run-off from adjacent slopes. Flooding differs from inundation in that it usually involves damage to land and property through overland water flow. By comparison, inundation usually involves little movement of water over the land surface. Flooding affects human safety, and may cause damage to property and general inconvenience by limiting access to land. Flood prone land should not be used for capital intensive uses such as residential development, but may be capable of supporting agricultural land uses such as grazing.

In some areas, the problem may be overcome by levee banks or retarding basins. Some changes in flooding characteristics may also be possible by special land management techniques aimed at delaying surface run-off. When dealing with large catchments, the problem can be regarded as a long term risk and a permanent limitation to land use.

The Water Authority does flood studies in many parts of the State. These delineate areas of land likely to be subject to an estimated 1-in-100 year flood. They also usually show that portion of the floodplain subject to more regular flooding as the active floodway. The Water Authority assigns a high hazard rating to active floodways and a lower hazard rating to areas between floodways and the 1:100 year flood boundary.

Within the Water Authority's high flood hazard areas, residential development is not recommended so as to prevent property damage and risk to human safety. This prevents any restriction being placed within the path of floodwaters which might otherwise back up and extend over larger areas further up the catchment. In the lower flood hazard areas, residential development can generally occur provided houses are located on sand pads above the 1:100 year flood height level. In such areas sand pads would need to accommodate both the house and its effluent disposal system.

To determine a flood risk rating for land capability studies, reference should be made to the Water Authority flood study maps. However, these might not have been completed over all portions of the study area. In such cases, an estimate of the extent of the active floodplain must be made from a geomorphic assessment. The subsequent risk rating will be made on a map unit basis and apply equally to all occurrences of a subject map unit.

Assessment example LQ9:

Within major portions of the methodology test areas, Water Authority flood study maps were not available. Hence three subjective ratings of high, moderate and low risk were used as described in Table 16.

LQ10 Foundation soundness (b)

Both soil and geological conditions influence the soundness of foundations for either house or road construction. Soil properties including soil density, drainage, plasticity, texture and linear shrinkage, affect the bearing capacity and settlement of the natural soil under load. Geological conditions such as caves and solution pipes in limestone (karst features) can indicate a risk of foundation subsidence. Geological and soil conditions resulting in slope failure are considered separately (refer LQ11).

At a particular site, the soil conditions which affect foundation soundness can be largely represented by two parameters, the Unified Soil Classification (USC) and the shrink-swell potential of the subsoil. Engineering interpretations based on these parameters can often be correlated with, or supplemented by, data from appropriately scaled geological maps. The Geological Survey of Western Australia produce a series of urban or environmental geology maps (Gozzard 1985) which contain interpretations of engineering properties. The map units employed are often easily correlated to soil or land resource survey map units (land units) since both map types relate to unconsolidated surface materials. However, because such interpretations apply to map units, the results, particularly in relation to foundation soundness, should be used only for preliminary planning studies and not as a substitute for detailed on-site investigations.

• Unified Soil Classification (USC)

The Unified Soil Classification System (Table 17) identifies soils according to their textural and plasticity qualities and groups them according to their performance as engineering construction materials. Both the United States Department of Agriculture and the Victorian Land Protection Service use USC data to rank soils in terms of their suitability for foundations. (Soil Survey Staff 1951 and Rowe *et al.* 1981.)

Table 16. Assessment example LQ9: Flood risk

Flood risk rating	Geomorphic description
High	• Immediate margins of major rivers.
Moderate	• Incised creeks and drainage pathways.
	• Upland valley floors where catchment areas are large.
	• Lower terraces of major rivers.
Low	• Higher terraces of major rivers (i.e. generally within 1:100 year flood limits).
	• Non incised, ill-defined drainage pathways associated with minor creeks and streams.
	• Upland valley floors where catchment areas are small.

Table 17. Unified Soil Classification System*

Material	Group symbols	Description
Gravels	GW	Well graded gravels, gravel-sand mixtures, little or no fines.
	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines.
	GM	Silty gravels, poorly graded gravel-sand-clay mixtures.
	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures.
Sands	SW	Well graded sands, gravelly sands, little or no fines.
	SP	Poorly graded sands, gravelly sands, little or no fines.
	SM	Silty sands, poorly graded sand-silt mixtures.
	SC	Clayey sands, poorly graded sand-clay mixtures.
Silt and clays	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity.
	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.
	OL	Organic silts and organic silt-clays of low plasticity.
	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.
	CH	Inorganic clays of high plasticity, fat clays.
Highly organic	OH	Organic clays of medium to high plasticity.
	PT	Peat and other highly organic soils.

* Cited in Olson (1973)

Unified soil classifications may be determined from laboratory analyses of representative soil types sampled during a land resource survey. Alternatively, the data may be obtained from reports and maps produced by the Geological Survey of Western Australia, where land resource survey map units and geological map units can be closely correlated.

• Subsoil shrink-swell potential

Shrinkage and swelling of subsoils in response to seasonal changes in moisture content is a common cause of differential settlement or movement in soils causing poor foundation conditions. The problem of structural cracking in houses along the Darling Scarp in Western Australia for example, is widely recognized (Hill *et al.* 1983, Gordon 1983).

Differential settlement can occur when a house foundation is seated on two different clay types or else partly on rock and partly on clay. The relative settlement can be as much as 4-5 cm and result in significant structural cracking (Airey, Ryan and Hill 1972).

Critical values, or class limits for linear shrinkage values for urban uses have been established by the New South Wales Department of Public Works (1977). These have subsequently been adopted by the New South Wales Soil Conservation Service (Charman 1978), and are used in this study (Table 18).

Table 18. Shrink-swell potential ratings

Subsoil linear shrinkage (%)	Shrink-swell potential
0-12	Low
12-17	Moderate
17-22	High
> 22	Very high

High linear shrinkage values are known to be associated with soils derived from the weathering of dolerite dykes. Although outcropping dykes are relatively easily identified in the field, the narrow width of some and the spreading of soils by colluviation or surface wash, will mean that mapping units which are uniquely subject to shrink-swell problems may be difficult to delineate.

Sands generally rate high on the scale of suitability for foundation soils because they drain easily and are not susceptible to shrinkage and swelling from moisture changes (Clegg 1962, 1970).

During a land resource survey, subsoil linear shrinkages may be determined by laboratory analysis of samples of representative soil types. Such data may sometimes be estimated from Geological Survey maps and reports by correlation of land resource map units with equivalent geological map units.

Assessment example LQ10:

For the methodology test areas Table 19 was used to relate USC, shrink-swell potential, and equivalent geological mapping units to a foundation soundness rating.

The siting of houses in areas with poor foundation conditions can have disastrous effects, in this case because of soils with changing moisture content. (Photo courtesy of Gordon Geological Consultants.)

Table 19. Assessment example LQ10: Foundation soundness

Characteristics	Rating*			
	Good	Fair	Poor	Very poor
USC (subsoil)	GW, GP, GM, GC, SW, SP, SM	ML,CL	CH, MH	OL, OH
Shrink-swell potential (subsoil)	Low	Moderate	High	Very high
Equivalent geological map unit**	Czl/Ql Qpr Qpb Qhs Qtl Qts Qt Qtr	Age, Anp, An, Am, Agv, Agp, Aes Qpa Qpc Qph Qha Qa Qc d Klb Alb	Qhw Qhsm	Qhg

* The rating will be determined by that of the most limiting characteristic.

** Refer to land resource survey reports of the Mandurah-Murray or Darling Range study areas for descriptions of geological units and their engineering properties.

LQ11 Slope instability risk (c)

This land quality relates to the risk of landslides or earth flows which might affect housing or road location. Pilgrim and Conacher (1974) consider that earth flows are generally not common in south-western Australia, but have some occurrence in areas such as the Darling Scarp.

Although the vast majority of landslides are believed to be triggered by prolonged heavy rainfall (Shirley and Francis 1977, Pilgrim and Conacher 1974) site factors are also important. Landslides are often associated with springs and swamps on hillslopes. Steep areas which are cleared and have deep regoliths are particularly susceptible. Movements of ground and surface waters also influence landsliding processes by causing a reduction in the strength of site materials and by increasing the disturbing forces.

The causal factors of slope failure in specific locations have been studied by Pilgrim and Conacher (1974) and Lilly (1979). Within the southern Chittering Valley near the confluence of the Darling and Dandaragan Scarps for example, Pilgrim and Conacher (1974) conclude that three factors are essential for the occurrence of earth flows. These are:

1. a threshold slope of 27%;
2. the presence of through-flow; and
3. particular soil characteristics.

The particular soil characteristics are:

- colluvial materials,

- the presence of subsoil clay horizons (zones of clay illuviation),
- factors increasing porosity such as rabbit burrows, root channels and the presence of stones,
- decreasing permeability down the profile,
- increasing moisture content down the profile,
- a marked increase in shear strength of the soil materials at the subsoil clay horizon.

Lilly (1979) concluded that weak weathering products of doleritic origin, which often have less shear strength than granitic soils, were a causal factor in a number of landslide events in the Wungong Dam area, also within the Darling Range.

Assessment of the relative risk of slope instability for land resource survey map units in any area, should consider the causal factors discussed above. Reference should also be made to the slope stability comments given for comparable geological map units if such mapping is available. In addition, field observations of existing landslips should be considered.

Table 20. Assessment example LQ11: Slope instability risk

Slope instability risk rating	Site description
Nil	All relatively flat to gently sloping areas (< 10%).
Very low	Gently to moderately sloping areas beneath the threshold slope value (27%) which either shed water readily or where it is unlikely that significant seepage or throughflow will occur.
Low	Moderate to steep slopes where soil cover is relatively shallow and basement rock outcrop is common; or steep sand dunes, where it is unlikely that significant seepage or throughflow will occur.
Moderate	Moderate to steeply sloping valley head-waters and sideslopes where significant seepage or throughflow is likely and/or colluvial material is deep.
High	Areas already subject to landslip or earthflows.

Assessment example LQ11:

For the methodology test areas, Table 20 was used to assign a relative slope instability risk.

LQ12 Soil absorption ability (a)

This quality relates to the ability of soils used for septic tank effluent disposal to accept sufficient volumes and rates of applied effluent. The ability of soils to accept storm water is generally included under the consideration of waterlogging/inundation risk.

Soil absorption ability is affected by characteristics such as soil permeability, site drainage, depth to an impermeable layer and the presence of stones within the soil profile. If the soil absorption ability at an effluent disposal site is inadequate there will be a high risk of surface ponding with water contaminated with microbes dangerous to public health.

Assessment example LQ12:

The method used in the test study areas for the assessment of absorption ability, and for other land qualities relevant to on-site effluent disposal, is described by Wells (1987). His relevant assessment table is shown in Table 21.

Table 21. Assessment example LQ12: Soil absorption ability

Characteristics	Rating[1] High	Moderate	Low	Very low
Permeability class	Very rapid—rapid	Moderate—moderately rapid	Moderately slow	Slow
(Hydraulic conductivity)[2]	> 1 m/day	0.05—1.m/day	0.01-0.05 m /day	< 0.01 m /day
Drainage class[3]	Well—rapid	Moderately well—imperfect	Poor	Very poor
Depth to impermeable layer	Deep (> 100 cm)	Moderately deep (50-100 cm)	Shallow (25-50 cm)	Very shallow (< 25 cm)
Stones within profile	Nil—common (< 20%)	Many (20-50%)	Abundant (50-90%)	Very abundant (> 90%)

[1] The rating is determined by that of the most limiting characteristic.

[2] Permeability is a composite expression of soil properties and depends largely on soil texture, soil structure, the presence of pans and the size and distrubution of pores in the soil. Permeability categories are essentially ranges of hydraulic conductivities. Permeability categories are assigned during a soil survey, based on a consideration of the above factors. Where hydraulic condictivity measurements have been made, these can be used in lieu of the empirical assessments of permeability category.

[3] See Appendix 2 for class definitions.

LQ13 Dam site construction suitability (h)

This land quality is relevant to hobby farming or agricultural land uses where a dam is required to provide water storage for livestock or irrigation. It relates to the use of machinery for dam construction and the requirement for excavation to reach a sufficiently impermeable layer to seal the dam.

Depending on site topography, there are three types of dams which may be used. These are gully wall, excavated earth tanks or turkey nest dams. Other characteristics which influence this land quality are slope, depth to an impermeable layer and surface rock outcrop.

Guidelines for the assessment of potential dam sites using these characteristics are summarized in Table 22. These guidelines are applicable to the general farming situation. It is possible to successfully use sites outside the guidelines, but extra expense will be involved. For more information refer Pepper (1981).

Assessment example LQ13:

For the test survey areas the guidelines above were used to derive a land quality rating as shown in Table 23. The values for some characteristics have been modified slightly in order to fit standard descriptive terminology (McDonald *et al.* 1984).

Table 22. Guidelines for site assessment of potential dam locations

Characteristics	Guidelines*
Slope	0-10%—suitable for excavated tanks and gully wall dams.
Depth to clay	0-0.8 m—suitable for excavated tanks and gully wall dams.
	Greater than 0.8 m—generally unsuitable for excavated tanks. May be suitable for gully wall dams if potential borrow pits exist on valley sides adjacent to proposed dam wall.
Surface rock	Out-cropping rock often indicates a limitation to excavation depth and may hinder construction.

* G. Luke, and I.A.F. Laing, personal communication, Salinity and Hydrology Research Branch, Division of Resource Management, Department of Agriculture.

Table 23. Assessment example LQ13: Dam site construction suitability

Characteristics	Rating*			
	High	Moderate	Low	Very low
Slope %	< 10	10-20	20-30	> 30
Depth to clay (impermeable layer)	< 50 cm	50-100 cm	100-200 cm	> 200 cm
Depth to rock	> 100 cm	50-100 cm or variable	25-50 cm	< 25 cm
Surface boulders	Nil	Very few -few (1-10%)	Common (10-20%)	Many or more (> 20%)

* The rating is determined by that of the most limiting characteristic.

Rating is automatically very low for areas subject to a very high inundation risk.

LQ14 Subsoil water retention ability (d)

This land quality relates to hobby farming or agricultural land uses where a dam may be required to provide water storage for livestock or irrigation. Subsoil water retention ability will be determined by the texture, structure, strength and dispersion characteristics of the material used to form the base and batters of the dam. General guidelines used by the Salinity and Hydrology Branch (G. Luke, I.A.F. Laing, personal communications) for the assessment of soils for dam base material are summarized in Table 24.

Assessment example LQ14:

For the test survey areas, the guidelines above were used to derive ratings as shown in Table 25. Dispersion was not included in Table 25 because its effect depends on soil strength and such data are not readily related to recognized soil types. Soil strength data are also rarely collected during land resource surveys.

LQ15 Soil workability (k)

Soil workability is the ease with which the soil can be cultivated or tilled by machinery. This land quality also relates to machinery trafficability. The workability of a soil depends on a number of soil characteristics such as texture, depth, structure, consistence and the occurrence of gravels, stones or boulders within the surface layer. Slope angle, surface rock outcrop and the susceptibility of the soil to waterlogging may also act as limitations to machinery use. Waterlogging is treated as a separate land quality (refer LQ8).

Soft or loose sandy soils are generally easier to work than firm or hard setting clayey soils. Well structured soils are easier than massive soils. Moisture content is also important and can determine the optimum time to work the soil. Soils with sandy to sandy loam textures are easy to work at nearly any moisture content, while self mulching clays for example, have a very narrow moisture range within which they can be worked.

Assessment example LQ15:

For the methodology test surveys the rating table shown in Table 26 was used.

Table 24. Guidelines for soil assessment for dam base material

Characteristics	Guidelines
Subsoil texture	Should be sandy clay loam or heavier.
Subsoil structure	Should not be well structured (i.e. not rapidly permeable).
Subsoil strength	A high strength soil which is stiff and has a high resistance to deformation has the best water-holding characteristics. Low strength clays are very soft, easily deformed and are often associated with piping failure in dams. Low strength clays should be avoided.
Subsoil dispersion	• Dispersion* of soil fines (silt and clay sized particles, <0.02 mm) provides material that may fill porous channels thus limiting seepage from dams. • Soils which are highly dispersive and have a high strength are suitable for dams, whilst those which are highly dispersive and have a low strength are not. • Moderately dispersive soils with either a low or high strength rating generally provide suitable material for dams. • Soils which are non-dispersive will only be suitable if they are completely apedal or structureless. • Soils which readily slake are unsuitable.

* Dispersion may be assessed by laboratory analysis of aggregate stability (Emerson, 1967) or sodicity. (ESP > 6)

Table 25. Assessment example LQ14: Subsoil water retention ability[1]

Characteristics	Rating[2] High	Moderate	Low
Subsoil texture	Clay loams, light clays or medium to heavy clays (texture groups 4, 5, 6)	Loams (texture group 3)	Sands or sandy loams (texture groups 1, 2)
Permeability[3]	Slow, moderately slow	Moderate, moderately rapid	Rapid, very rapid

[1] 'Subsoil' may be an unrelated or buried soil layer if occurring within 1m of surface.

[2] The rating is determined by that of the most limiting characteristic.

[3] See Appendix 2 for class definitions.

Table 26. Assessment example LQ15: Soil workability

Characteristics	Rating[1] Good	Fair	Poor
Surface texture	Sands and sandy loams (texture groups 1,2)	Loams and clay loams (texture groups 3,4)	Light and medium to heavy clays (texture groups 5,6)
Surface condition	Soft-firm, self mulching[2]	Hard set	Periodic cracking or strongly undulating gilgai surface
Profile stone	Nil—few (0-10%)	Common (10-20%)	Many or more (> 20%)
Surface boulders	Nil—very few (0-2%)	Few (2-10%)	Common or more (> 10%)
Slope	0-5%	5-15%	> 15%

[1] The rating is determined by that of the most limiting characteristic.

[2] Favourable only over a narrow moisture range.

Rating modifier: Areas subject to a very high waterlogging/inundation risk automatically have a poor soil workability rating. Other drainage conditions can generally be countered by variation in the time of soil working.

LQ16 Groundwater availability (g)

Groundwater availability for stock watering or irrigation is a land quality relevant to hobby farming and irrigated horticulture. It is assumed that only the superficial aquifer would be generally considered for these uses because deeper aquifers are usually reserved by the Water Authority for urban or industrial uses.

Land resource survey reports should discuss the topic of groundwater resources or, at least, refer to relevant publications by the appropriate authority. However, the survey reports can make only a general statement about the potential for groundwater extraction and its likely quality because groundwater location may not be closely linked to mapping units.

These statements must, of necessity, apply to broad groupings of map units (usually geomorphic elements) rather than to individual map units and should be based on information from the Geological Survey of Western Australia or the Water Authority. Suggested categories which refer to the likelihood of obtaining a groundwater supply sufficient for stock watering or irrigation on small rural lots are as follows:

- low probability
- variable and site specific
- probable
- highly probable

The categories are very general. At specific sites actual availability of groundwater and permit requirements will need to be determined by contacting the Water Authority.

LQ17 Groundwater quality (q)

Groundwater quality is an important consideration for irrigation or stock watering. Total soluble salts (TSS) is the general criterion used, although sodium hazard, bicarbonate hazard, and specific ion imbalances, may be of concern. In general however, for Western Australian conditions, TSS is the factor most likely to restrict the use of groundwater for irrigation. Suggested categories are shown in Table 27.

Table 28 shows the general upper limits of total soluble salts in water for use by various plants and various animals. Even groundwater of relatively low salt content can give rise to unacceptable salt concentrations if it is stored in dams, particularly in late summer and autumn, because of concentration by evaporation. For irrigated cropping however, there are some management techniques available to alleviate or minimize the problems of using water of marginal quality. These include modifying the choice of crops, the irrigation method, irrigation timing and application rates.

Data from the Geological Survey of Western Australia or the Water Authority usually enables general statements to be made in land resource survey reports on the quality of water held in superficial aquifers. Statements on groundwater quality, like those on groundwater availability, will apply only to broad groupings of map units (usually geomorphic elements) rather than to individual map units.

Table 27. Salinity criteria

Category	TSS mg/L*	or	TSS mS/m
Fresh	< 500		< 91
Marginal	500-1 000		91-182
Brackish	1 000-3 000		182-545
Saline	> 3 000		> 545

* mg/L = mS/m x 5.5

Table 28. General upper limits of total salts in water for agricultural purposes*

Water use		Salinity**	
		mg/L TSS	mS/m TSS
Plants:	Oranges, apricots	500	91
	Peas, carrots, potatoes, lettuce	500	91
	Apples, pears	1,500	273
	Cauliflower, cabbage, tomatoes	1,500	273
	Figs, spinach, asparagus	3,500	636
Stock:	Poultry	3,000	545
	Dairy cattle (milk producing)	3,500	636
	Pigs	4,500	818
	Horses	6,500	1182
	Dairy cattle (dry)	7,000	1273
	Sheep (lambs, weaners, breeding ewes)	7,000	1273
	Beef cattle	10,000	1818
	Sheep (adult, dry)	10,500-14,000	1909-2545

* Adapted from Luke (1987) and Hart (1974) - Note that the figures for plants are very generalized and will vary with soil drainage, seasonal rainfall and irrigation technique.

** mg/L = mS/m x 5.5

LQ18 Surface water availability (j)

This land quality relates to land use activities where a surface water supply is required for stock watering or irrigation. Land resource survey reports should address the topic of surface water resources or at least refer to relevant publications by the appropriate authority. For some areas, only general statements can be made about the availability of surface water. These might be based solely on field observations of stream condition during the survey. For specific land use proposals, the Water Authority will need to be contacted for permit requirements and extraction conditions.

Assessment example LQ18:

For the methodology test studies, areas of land (map units) which contained, or were adjacent to, a river, stream, lake or swamp were ranked on a qualitative basis as shown in Table 29.

Table 29. Assessment example LQ18: Surface water availability

Rating	Description
Nil	Map unit does not contain a stream, river, lake or swamp
Rarely possible	Map unit contains a stream, river, lake or swamp which does not provide a perennial supply. (For example, minor valleys and drainage lines of small catchments.)
Sometimes possible	Map units containing perennial swamps.
Likely	Map unit contains a stream which is perennial, or nearly always so, or is adjacent to a major river. (For example upland valleys on the Darling Range or high terraces of major rivers.)
Highly likely	Map unit contains a stream, river or lake which definitely provides a perennial supply. (For example, low terraces and valley floors of major river systems.)

LQ19 Nutrient availability (l)

Assessments of soil chemical fertility usually involve a quantitative measure of the soil's ability to supply nutrients for plant growth.

Two land qualities are concerned:

- nutrient availability - the capacity of the soil to supply nutrients;
- nutrient retention - the capacity of the soil to retain added nutrients.

Nutrient availability is most important in farming systems where fertilizers cannot be readily applied, while nutrient retention becomes significant in farming systems which rely heavily on fertilizers. Assessment of nutrient retention is discussed under LQ20 and LQ21.

Nutrient availability involves two major aspects:

- the quantities of nutrients present in the soil;
- the forms in which they are present, and their tendency towards fixation making them unavailable to plants.

Measuring soil nutrient content in quantitative terms is a relatively simple and common method of assessing nutrient availability. However, under existing farming systems dependent on fertilizers, this method is generally unsatisfactory for two reasons. Firstly, nutrient deficiency can be overcome by addition of fertilizers although cost is often an important factor. Secondly, the nutrient content of the soils being sampled may be considerably influenced by the preceding use and management.

To quantitatively rank areas of land in terms of nutrient availability it is desirable to concentrate on characteristics which influence the tendency towards fixation. These include soil reaction and the presence of free iron oxides. Nutrient availability is generally highest in the pH range 6.0-7.5 and is reduced for higher values (more alkaline) or lower values (more acid).

A high content of free ferric oxide (Fe_2O_3) leads to strong P fixation and hence reduced availability to plants.

In addition to these characteristics, other commonly used indicators of chemical fertility status are cation exchange capacity (CEC) and organic matter content. In general terms, soils with low CEC values and low levels of organic matter have a low fertility status.

Assessment example LQ19:

For the methodology test surveys a rating for nutrient availability was determined using Table 30.

Table 30. Assessment example LQ19: Nutrient availability

Characteristics	Rating*		
	High	Moderate	Low
Soil reaction (pH)	Neutral (6.0-7.5)	Mildly acid or mildly alkaline (5.0-6.0 or 7.5-8.5)	Strongly acid or alkaline (< 5.0 or > 8.5).
Ferric oxide Fe_2O_3 content[1]	Nil Fe gravels or Reactive Fe < 300	Very few-few (< 10%) Fe gravels, or Reactive Fe 3000-1 000	Common or more (> 10%) Fe gravels, or Reactive Fe > 1 000
Soil colour and texture trend (Broad soil types)	Dark coloured uniform loams, clays or gradational earths	Red, yellow and brown duplex soils or gradational earths	Highly leached, pale or bleached sands. Calcareous soils. Duplex soils with bleached subsurface A2 horizons
Cation exchange capacity[2] (me/100 g)	> 25	15-25	< 15
Organic matter[3]	% Organic C > 2.5 or very dark soil colour, value chroma (V/C) rating 1	% Organic C 1.5-2.5 or reddish brown soil colours, VC rating 5	% Organic C < 1.5 or yellowish grey soil colours, VC rating 2, 3, 4.

* The rating is determined by that of the most limiting characteristic.

[1] Estimated by field data on nature and content of gravels by laboratory analyses of reactive iron. (Class limits, J.S. Yeates, personal communication).

[2] Reference: Booker and tropical soil manual (1984).

[3] References: Bruce and Rayment (1982) and Charman (1978).

LQ20 Nutrient retention ability (n)

This land quality refers to the ability of the entire soil profile to retain added nutrients against losses caused by leaching. Assessment of nutrient retention ability is relevant to land uses requiring fertilizers and to disposal of septic tank effluent. This land quality is also used in the assessment of water pollution risk by subsurface drainage (LQ6).

Phosphorus is the major nutrient of concern since it is the element most commonly used in agricultural fertilizers to assist plant growth. While nitrogen is also applied extensively, it is taken up by plants mainly as nitrate, a form in which it is not adsorbed by the soil, but exists almost entirely in the soil solution. The ability of soil to retain added nitrogen will be largely dependent on soil permeability characteristics, whereas phosphorus retention will depend on characteristics relating to the adsorption process. In this methodology, nitrates are not considered further.

The nutrient adsorption process is influenced largely by the type and quantity of clay, and the presence of organic material and hydrous oxides. In addition, the presence of a high water table can reduce the soil's nutrient retention ability as it affects the distance over which the soil can react with the percolating nutrients.

To qualitatively rank land resource mapping units in terms of their nutrient retention ability, the relative amounts of clay, organic matter and hydrous oxides in both the topsoil and subsoil layers of the dominant soil types should be considered. In addition, the relative depths of these layers will be important. Soil texture adequately reflects clay content, and soil colour can reflect organic matter content and the presence of hydrous oxides. Where such laboratory data are available, P adsorption measurements, or PRI (phosphorus retention index) measurements, should be used to supplement assessments based on observed soil physical properties.

Assessment example LQ20:

Nutrient retention ability was assessed for the methodology test studies using Table 31.

LQ21 Topsoil nutrient retention ability (t)

This land quality relates specifically to the ability of the topsoil layer (nominally 0-30 cm) to adsorb nutrients against losses caused by leaching. As with LQ20, phosphorus is the major nutrient of concern and the same criteria can be used in its assessment. From a productivity viewpoint, assessment of this land quality is relevant to land uses, such as grazing and annual horticulture, which involve fertilizer application for shallow rooting species.

Assessment example LQ21:

Topsoil nutrient retention ability was assessed for the methodology test studies using the criteria shown in Table 32.

Table 31. Assessment example LQ20: Nutrient retention ability

Soil description	Rating*
Deep (> 1 m) grey leached siliceous sands where weak iron-organic pans or coloured subsoils, if present, occur at depths greater than 1 m	Very low
Grey leached sands or sandy loams with an iron-organic hardpan within 1 m of the soil surface	
Duplex soils with moderately deep (50-100 cm) sandy leached topsoils, or leached sands of similar depth overlying unrelated clays or a hardpan	Low
Shallow (< 50 cm) gravelly sands over rock	
Sands and earthy sands which are either whole coloured or have coloured subsoils within 1 m of the soil surface	
Deep gravelly sands	Moderate
Calcareous sands	
Duplex soils with shallow sandy topsoils	
Uniform loamy soils	Moderately high
Gravelly duplex soils	
Uniform clay loams or clays	
Gradational earths with loamy topsoils	High
Duplex soils with loamy topsoils	

* Approximate ranges of P adsorption, (Ozanne and Shaw 1967) corresponding to ratings are as follows: very low < 2 ppm, low 2-5ppm, moderate 5-10ppm, moderately high 10-20 ppm and high > 20 ppm (J.S. Yeates, personal communication).

Arbitrary ranges of P retention index are: very low 0-2, low 2-10, moderate 10-20, moderately high 20-100 and high > 100 (D. G. Allen, Chemistry Centre of Western Australia, personal communication).

Table 32. Assessment example LQ21: Topsoil nutrient retention ability

Topsoil texture group	Nature of soil	Rating
Sands	• Light grey siliceous sands	Very low
	• Dark grey or pale yellowish brown siliceous sands	Low
	• Red, brown or yellow siliceous or earthy sands • Sands with ferruginous gravels • Calcareous sands	Moderate
Sandy loam or loams	—	Moderately high
Clay loam or clays	—	High

* Approximate ranges of P adsorption (Ozanne and Shaw 1967) corresponding to ratings are as follows: very low < 2 ppm, low 2-5 ppm, moderate 5-10 ppm, moderately high 10-20 ppm and high > 20 ppm(J.S. Yeates, personal communication).

Arbitrary ranges of P retention index are: very low 0-2, low 2-10, moderate 10-20, moderately high 20-100 and high > 100 (D. G. Allen, Chemistry Centre of Western Australia, personal communication).

LQ22 Moisture availability (m)

This land quality is relevant to hobby farming or agricultural land uses because of the effects of moisture stress on crop or pasture growth. Moisture stress begins to occur when soil water within the root zone falls substantially below field capacity.

Moisture availability is affected by climate, soil, landforms and hydrology. The climatic determinants are rainfall and potential evapotranspiration. Climatically determined moisture deficiency is modified by soil moisture storage, topographic situations such as valley floors receiving run-off, seepage areas and the proximity of groundwater to the root zone.

Soil moisture storage is determined principally by texture and soil depth, and modified by local topographic or site drainage situations. Only a generalization can be made about actual water availability to plants as rooting depths vary between pasture and crop species. However, not all water held within a soil will be available for plant growth.

Plant-available water capacity is considered to be the difference between the amount of water that can be held in a soil after any excess has drained away following saturation (field capacity), and the moisture content at which plant growth ceases (wilting point) (Houghton and Charman 1986). Coarse sands have a low available water capacity (0.08 cm^3/cm^3), but other textures from sands to clays have values fluctuating around 0.15 cm^3/cm^3 (Salter and Williams 1967). For whole soil profiles, Northcote (1983) reports experimental results for a vineyard situation in South Australia where a duplex soil had a higher amount of plant-available water than similar volume of a uniform clay.

In most areas of Western Australia, pastures require irrigation to fully sustain grazing animals throughout the year. Except in areas around swamps, cropping or market gardening is restricted to the winter growth period unless crops are irrigated. Assessments of moisture availability can therefore ignore the climatic determinants and the term can be used interchangeably with soil moisture storage. Consideration needs to be given to the texture and texture trend characteristics which affect plant-available water capacity, and to depth, site drainage, and topographic factors which determine soil moisture storage.

Assessment example LQ22:

Moisture availability was assessed for the methodology test studies using the criteria shown in Table 33.

Table 33. Assessment example LQ22: Moisture availability

Soil type	Rating*
Uniform sands (with coarse sandy fabric or with gravels)	Very low
Uniform sands (with earthy fabric or minor clay content)	Low
Uniform clays	Moderately low
Duplex soils (with shallow topsoils)	Moderate
Duplex soils (with moderately deep topsoils)	Moderately high
Uniform loams or gradational soils	High

* Ratings are modified to account for the effect of local topographic or site drainage situations as follows:

—in seepage areas or where the water table occurs very close to surface the rating is automatically high.

—if the subject soil type occurs in a valley floor, incised or non-incised stream channel or drainage area, the rating should be increased one level.

LQ23 Rooting conditions (r)

This land quality relates primarily to agricultural activities involving pasture or crop growth. The development of an effective root system is vital to plant growth. Roots hold plants in place and have the further function of extracting moisture and nutrients. Rooting conditions are controlled by the effective soil depth and ease of root penetration.

Effective depth is the depth to a limiting horizon such as rock, a cemented hardpan, or a particularly dense massive clay subsoil. A perched or permanent water table can also act as a barrier to root development. Effective depth will usually equate to the depth to an impermeable layer within the profile.

Ease of root penetration may be determined by a combination of soil physical characteristics including bulk density, texture, structure, consistence and the percentage of stones and gravel within the profile. Except in detailed land resource studies, specific data are unlikely to be available on all these characteristics and an approximation based on broad soil types may be required.

Assessment example LQ23:

The land quality 'rooting conditions', was assessed for the methodology test areas using the criteria in Table 34.

Table 34. Assessment example LQ23: Rooting conditions

Characteristics	Rating*			
	Easy	Moderate	Difficult	Very difficult
Depth to rock	Deep (> 100 cm)	Moderately deep (50-100 cm)	Shallow (25-50 cm)	Very shallow (< 25 cm)
Soil type	Uniform sands, or loams	Gradational soils, Duplex soils	Uniform clays with strong structure	Uniform clays lacking structure (plastic-sticky when wet, hard when dry)
Stones in profile	Nil-few (< 10%)	Common (10-20%)	Many or more (> 20%)	
Gravels in profile	Nil-many (< 50%)	Abundant or more (> 50%)		

* The rating is determined by that of the most limiting characteristic.

LQ24 Salinity risk (y)

The risk of salinity is of primary importance for plant production. A soil is referred to as being saline when it contains a high concentration of soluble salts which can limit (or kill) plant growth. This occurs by the creation of an osmotic potential so high that it prevents plants from obtaining water and nutrients from the soil solution. Where plant cover has been reduced as a result of soil salinity, the land may be predisposed to an increased risk of erosion by wind or water.

Assessment of salinity risk for map units can be made from laboratory analyses of representative samples of soils. Criteria used may be either electrical conductivity of the soil water extract or the total soluble salt content of the soil. Approximate limits to generally recognized salinity classes (Northcote and Skene 1972) are shown in Table 35.

Table 35. Criteria for assessing soil salinity

Description	ECe (dS/m)*	TSS %	
		Surface	Subsoil
Not susceptible	0-4	< 0.05	< 0.10
Possibly or slightly susceptible	4-8		
Moderately susceptible	8-15	0.05-0.15	0.10-0.3
Strongly susceptible	> 15	≥ 0.15	≥ 0.3

* 1 dS/m = 1 mS/cm

Salinity can be a major limitation to agricultural land uses. In addition to restricting the growth of productive plants, bare saline areas are subject to erosion.

Where analytical data are not available, morphological features and vegetation indicator species such as samphire (*Halosarcia* spp) and barley grass (*Hordeum leporinum*), can be used to assess the susceptibility of areas of land to salinity. Northcote (1983) reports that the following morphological features can assist in the identification of saline soils.

1. Surface soils and subsurface soils
   - white salt encrustation on soil surface
   - thin crusted surface with vesicular underside and/or with 'sugary' (granular) soil below
   - soil pH 9 or higher
2. Subsoils
   - alkaline soil reaction trend with soil pH 9 or higher.
   - neutral soil reaction trend with high $CaCO_3$ content (usually visible).

In addition to these features, saline soils can be identified from the results of a diagnostic test using silver nitrate ($AgNO_3$) during field inspection (Morse *et al.* 1982). In this test, a small sample of soil is mixed with distilled water and a dilute (5%) solution of silver nitrate is added. In the presence of the chloride ion, a white precipitate of silver chloride forms.

3.4 Matching qualities with land use requirements

The capability results are determined by matching land qualities (section 3.3) with land use requirements (section 3.2), within land use rating tables. Results are expressed as a capability class, from I to V, and a capability subclass, shown as a letter notation. Capability classes (Table 1a) indicate the degree of severity of limitations to land use, and the subclass(es) (Table 1b) indicate the nature of those limitations (limiting land qualities).

Individual map units (land units) have separate capability results for each land use activity. In this methodology 'rural-residential development and associated agricultural land uses' has been divided into six component land use activities (Table 2). These are:

- house and road construction
- on-site septic effluent disposal
- irrigation water supply
- grazing
- general annual horticulture
- general perennial horticulture

Example rating tables, used in the methodology test studies, for each of these activities are shown in Tables 36 to 41.

Each rating table is an expression of the land use activities' requirements. Within the body of each table, the effective range over which land quality values are thought to influence the activity, is divided into a number of ratings. Each rating represents a particular degree of limitation. Land quality values for a given map unit (land unit) are compared with their positions in the land use rating table. The most limiting land quality then determines the overall capability class. The land quality, or qualities, responsible for that class, are shown by capability subclass notations. This is referred to as a 'single worst factor' scheme (van de Graaff 1988).

The 'single worst factor' scheme is also used to determine capability classes and subclasses for complex land uses which comprise more than one land use activity. For example, capability for 'rural retreats' can be determined by combining the result for 'house and road construction' with that for 'effluent disposal'. The combined, or overall capability, is determined by the most limiting land use activity. A land unit classed IIIe for housing for example, and IVa for effluent disposal, would have an overall capability of IVa. A unit classed IIIe and IIIa respectively for those land use activities would have an overall capability of IIIe,a; for 'rural retreats'.

On larger lots where hobby farming or commercial agriculture is practiced, the portion of land, if required, for houses, roads or effluent disposal will be relatively small. Given the natural variability of land conditions within large lots and the siting and design flexibility they allow, the capability for hobby farming is determined by the result for the dominant agricultural activity, or by a combination of agricultural activities as appropriate. The capability assessment result for either annual or perennial horticulture will need to be combined with that for 'irrigation water supply' to determine the overall result, unless only soil capability is required.

Table 36. Land use rating[1] table example: House and road construction

—areas capable of being used for the construction of residential dwellings of one or two storeys, for construction of roads with sealed surfaces for light vehicles, and for shallow excavations associated with these uses

Land qualities[2] (subclass)	Rating 1 (Nil	2	3 Degree of limitation	4	5 Severe)
Water erosion risk (e)	Very low-low	Moderate	High	Very high	—
Wind erosion risk (w)	Very low-low	Moderate	High	—	Very high
Wave erosion risk (v)	Not susceptible	—	—	—	Susceptible
Ease of excavation (x)	High	Moderate	Low	Very low	—
Waterlogging /inundation risk (i)	Nil	Low-moderate	Moderately high	High	Very high
Flood risk (f)	—	—	Low	Moderate	High
Foundation soundness (b)	Good	Fair	Poor	Very poor	—
Slope instability risk (c)	Nil	Very low	Low	Moderate	High
Salinity risk (y)	Not or possibly susceptible	Moderately susceptible	Strongly susceptible	—	—

[1] Capability class, expressed in Roman numerals, is determined by the most limiting land quality.

[2] Land quality values determined from land characteristics data (section 3.3).

Table 37. Land use rating[1] table example: On-site effluent disposal

—areas capable of being used for soil absorption and purification of septic tank effluent from a single family dwelling on a block 1 ha in size or larger.

Land qualities[2] (subclass)	Rating 1 (Nil	2	3 Degree of limitation	4	5 Severe)
Microbial purification ability (p)	High	Moderate	Low	Very low	—
Water pollution risk[3]					
—by overland flow (o)	Very low	Low	Moderate	—	High-very high
—by subsurface drainage (s)	—	Low	Moderate	—	High-very high
Ease of excavation (x)	High	Moderate	Low	Very low	—
Soil absorption ability (a)	High	Moderate	Low	Very low	—
Flood risk[4] (f)	—	—	Low	Moderate	High

[1] Capability class, expressed in Roman numerals, is determined by the most limiting land quality.

[2] Land quality values determined from land characteristics data (section 3.3).

[3] Pollution risk considerations generally only apply to map units at margins of surface water bodies or which overlie superficial aquifers feeding directly into them. Effects of man-made drains not considered.

[4] Areas subject to a very high waterlogging/inundation risk are treated as equivalent to a high flood risk i.e. it is a severe limitation.

Table 38. Land use rating[1] table example: Irrigation water supply
—areas capable of obtaining a water supply of sufficient quantity and quality for irrigation of crops or pasture on small (1-20 ha) rural lots. It is assumed a potable water supply will be obtained from either a rooftop catchment or a reticulated off-site supply

Land qualities[2] (subclass)	Rating 1 (Nil	2	3 Degree of limitation	4	5 Severe)
Surface water harvesting (dams)[3]					
Dam site construction suitability(h)	High	—	Moderate	—	Low to very low
Subsoil water retention ability (d)	High	—	Moderate	—	Low
Flood risk (f)	Nil-low	Moderate	—	—	High
Groundwater extraction (bores)[4]					
Groundwater availability (g)	—	High probability	Probable	Variable and site specific	Low probability
Groundwater quality[5] (q)	Fresh	Generally fresh or thin layer	Marginal to brackish	Brackish	Saline
Stream extraction[4]					
Surface water availability (j)	Highly likely	Likely	Sometimes possible	Rarely possible	Nil

[1] Capability class, expressed in Roman numerals, is determined by the most limiting land quality for the chosen method of supply—either by dams, groundwater bores or direct stream extraction.

[2] Land quality values determined from land characteristics data (section 3.3).

[3] Assessment for dams does not consider catchment area, expected yield or spillway requirements. Nature of topography will determine type of dam. Site-specific assessment of dam site and catchment adequacy is recommended.

[4] Note that values for these land qualities are likely to be subjective. In most areas, government controls impose extraction limits on groundwater or stream supplies. All site-specific inquiries should be directed to the Water Authority.

[5] If shallow groundwater is brackish to saline, seepage may affect quality of water harvested and stored in dam.

Table 39. Land use rating[1] table example: Grazing
—areas capable of being used for grazing of cattle or horses on non-irrigated[2] volunteer and improved pastures with occasional topdressings of superphosphate (rainfall zone 750-1250 mm)

Land qualities[3] (subclass)	Rating 1 (Nil	2	3 Degree of limitation	4	5 Severe)
Water erosion risk (e)	Low-very low	Moderate	High	Very high	—
Wind erosion risk (w)	Low-very low	Moderate	—	High	Very high
Wave erosion risk (v)	Not susceptible	—	—	—	Susceptible
Water pollution risk[4]					
—by subsurface drainage (s)	Low-moderate	High	Very high	—	—
—by overland flow (o)	Low-moderate	High	Very high	—	—
Flood risk (f)	Nil-moderate	—	—	High	—
Waterlogging/inundation risk (i)	Low	Moderate	Moderately high-high	Very high	—
Topsoil nutrient retention ability (t)	High	Moderately high-moderate	Low-very low	—	—
Nutrient availability (l)	High	Low-moderate	—	—	—
Moisture availability (m)	High-moderately high	Moderate-low	Very low	—	—
Rooting conditions (r)	Easy-moderate	Difficult	Very difficult	—	—
Salinity risk (y)	Not susceptible	Possibly susceptible	Moderately susceptible	Strongly susceptible	—

[1] Capability class, expressed in Roman numerals, is determined by the most limiting land quality.

[2] The capability rating determined here for grazing could be combined with that for 'Irrigation water supply' to determine an overall capability for irrigated pasture if required.

[3] Land quality values determined from land characteristics data (section 3.3).

[4] Pollution risk considerations generally only apply to map units at margins of surface water bodies or which overlie superficial aquifiers feeding directly into them. Effect of man-made drains not considered.

Table 40. Land use rating[1] table example: General annual horticulture
—areas capable of being used for growing vegetables or for small market gardens of generally shallow rooted species; and where soil is cultivated at least once a year and regularly fertilized[2]

Land qualities[3] (subclass)	Rating 1 (Nil	2	3 Degree of limitation	4	5 Severe)
Water erosion risk (e)	Very low	Low	Moderate	High	Very high
Wind erosion risk (w)	Very low	Low-moderate	High	—	Very high
Wave erosion risk (v)	Not susceptible	—	—	—	Susceptible
Water pollution risk[4]					
—by subsurface drainage (s)	—	Low	Moderate-high	Very high	—
—by overland flow (o)	Low-very low	Moderate-high	Very high	—	—
Soil workability (k)	Good	—	Fair	Poor	—
Waterlogging/inundation risk (i)	Nil	Low	Moderate	Moderately high	High-very high
Flood risk (f)	Nil	Low	Moderate	—	High
Nutrient availability (l)	High	Moderate-low	—	—	—
Topsoil nutrient retention ability (t)	High	Moderately high-moderate	Low-very low	—	—
Moisture availability (m)	High-moderate	Moderately low-low	Very low	—	—
Rooting conditions (r)	Easy	Moderate	—	Difficult	Very difficult
Salinity risk (y)	Not susceptible	Possibly susceptible	—	Moderately susceptible	Strongly susceptible

[1] Capability class, expressed in Roman numerals, is determined by the most limiting land quality.

[2] Water supply considered separately (see rating table for 'Irrigation water supply').

[3] Land quality values determined from land characteristics data (section 3.3).

[4] Pollution risk considerations generally only apply to map units at margins of surface water bodies or which overlie superficial aquifers feeding directly into them. Effect of man-made drains not considered.

Table 41. Land use rating[1] table example: General perennial horticulture
—areas capable of being used for small orchards, vineyards or tree crops, of generally deep rooting species and where soil is cultivated only at initial planting, but regularly fertilized[2]

Land qualities[3] (subclass)	Rating 1 (Nil	2	3 Degree of limitation	4	5 Severe)
Water erosion risk (e)	Low-very low	Moderate	High	Very high	—
Wind erosion risk (w)	Very low-moderate	High	—	Very high	—
Wave erosion risk (v)	Not susceptible		—	—	Susceptible
Water pollution risk[4]					
—by subsurface drainage (s)	—	Low	Moderate-high	Very high	—
— by overland flow (o)	Low-moderate	High	Very high	—	—
Soil workability (k)	Good-fair	Poor	—	—	—
Waterlogging/ inundation risk (i)	Nil	Low	Moderate-moderately high	High	Very high
Flood risk (f)	Low	Moderate	—	—	High
Nutrient retention ability (n)	High	Moderately high-moderate	Low-very low	—	—
Nutrient availability (l)	High	Low-moderate	—	—	—
Moisture availability (m)	High-moderately low	Low	Very low	—	—
Rooting conditions (r)	Easy	Moderate	—	Difficult	Very difficult
Salinity risk (y)	Not susceptible	Possibly susceptible	—	Moderately susceptible	Strongly susceptible

[1] Capability class, expressed in Roman numerals, is determined by the most limiting land quality.

[2] Water supply considered separately (see rating table for 'Irrigation water supply').

[3] Land quality values determined from land characteristics data (section 3.3).

[4] Pollution risk considerations generally only apply to map units at margins of surface water bodies or which overlie superficial aquifers feeding directly into them. Effect of man-made drains not considered.

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Appendix 1. Land resource survey procedure

Guidelines for conducting land resource surveys and for the field description of land characteristics are given by Gunn *et al.* (1988) and McDonald *et al.* (1984). Procedures will vary somewhat between surveys as dictated by their purpose, mapping scale, and the available time and manpower resources. Nevertheless, a general outline of the procedure is as follows.

1. Preliminary

1.1 Collection of available background data:

- topographic and geological maps, previous reports on environmental factors (geomorphology, soils, climate, vegetation, land use)
- obtain aerial photographs of appropriate scale (usually 1:10,000-1:50,000) and appropriate quality.

1.2 Stereoscopic examination of aerial photographs:

- delineate tentative map unit boundaries according to topographic variation and soil conditions reflected by changes in pattern and tone of aerial photographs and by observable vegetation changes.
- devise sampling strategy and select representative photographic patterns for field examination (free survey technique - Steur 1961). The density of site observations will vary with the purpose of the survey and the extent, and detail, of any prior mapping of land resources or environmental attributes in the area.
- A site density of 0.5-1 observations/cm² of published map scale is recommended as a standard for Australian soil surveys using aerial photograph interpretation if no information on the variability of soils in the survey area is available (Reid 1988). For land resource surveys however, Gunn (1988) states that a minimum density of 0.25 observations/sq cm of published map scale is acceptable. Choice between the recommendations will be determinated by whether the survey is primarily orientated toward delineating soils or landforms.
- plan field traverses.

2. Field work

2.1 Preliminary reconnaissance to gain familiarity with area and any existing mapping of environmental factors.

2.2 Field traverse work:

- Soil profile and landform characteristics data are recorded within representatives of all map units (using descriptive techniques of McDonald *et al.* 1984). Soil profiles are hand augered to a depth of 1.5-2m, where possible, using a 10cm diameter auger and classified according to the Factual Key Notation of Northcote (1979). Maximum use is also made of exposed roadside cuttings, excavations and drainage channels for description and sampling.
- A complete list of the attributes likely to be recorded during land resource surveys in Western Australia, with the associated computer entry codes and terminology, is provided by King and Wells (1988). These data may be recorded onto standard site record cards and subsequently entered onto computer. Small portable microcomputers are now commonly used to provide direct input of data in the field.
- Limited sampling of major soil types for laboratory analysis - as required and determined by the purpose of the survey.
- Analyses of physical properties generally include particle size analysis, liquid and plastic limits, linear shrinkage and dispersion. Chemical analyses may include pH, electrical conductivity, total soluble salts,

organic C, total N, C/N, total P, available K, reactive Fe, P retention index, S buffering capacity and exchangeable cations.

3. Data analysis, mapping and reporting

3.1 Sorting and delivery of soil samples to laboratory for analysis.

3.2 Entry of data onto mainframe computer (PDP-11) to facilitate the sorting and analysis (if not done by direct computer entry in the field).

3.3 Data sorting and analysis using the Worldwide Applicable Resource Inventory System software (WARIS-Rosenthal *et al.* 1986).

3.4 Correlation of field survey data with tentative aerial photograph interpretations and any existing mapping of environmental factors.

3.5 Final mapping and coding onto aerial photographs.

3.6 Transfer of line work onto orthophoto maps, stereo mates, or similar (if mapping to be produced by computer methods).

3.7 Delivery of interpreted photographs or orthophoto maps to mapping agency where, depending on the production technique, line work will be either scanned, digitized or manually traced before map production.

3.8 Report production

This commonly involves the use of electronic spreadsheets such as Dynacalc (Dynasoft 1986) to present the salient soil and landform characteristics and the land qualities subsequently assessed for each map unit. In this format, survey results can be relatively easily included in a geographic information system data base for the survey area.

3.9 Checking of draft maps produced by mapping agency.

3.10 Final map production (by mapping agency).

4. Promotion and extension of results

4.1 Seminars/talks with direct clients.

4.2 Production of summary pamphlets/extension material.

Appendix 2.

Site drainage and permeability class definitions

Site drainage is a term used to summarize local soil wetness conditions and the descriptions of McDonald *et al.* (1984) are quoted here.

'Very poorly drained'	water is removed from the soil so slowly that the water table remains at or near the surface for most of the year. Surface flow, groundwater and subsurface flow are major sources of water, although precipitation may be important where there is a perched water table and precipitation exceeds evapotranspiration. Soils have a wide range in texture and depth, and often occur in depressed sites. Strong gleying and accumulation of surface organic matter are usually features of most soils.
'Poorly drained'	water is removed very slowly in relation to supply. Subsurface and/or groundwater flow, as well as precipitation, may be a significant water source. Seasonal ponding resulting from run-on and insufficient outfall also occurs. A perched water table may be present. Soils have a wide range in texture and depth; many have horizons that are gleyed, mottled, or possess orange or rusty linings of root channels. All horizons remain wet for periods of several months.
'Imperfectly drained'	water is removed only slowly in relation to supply. Precipitation is the main source if available water storage capacity is high, but subsurface flow and/or groundwater contribute as available water storage capacity decreases. Soils have a wide range in texture and depth. Some horizons may be mottled and/or have orange or rusty linings of root channels and are wet for periods of several weeks.
'Moderately well drained'	water is removed from the soil somewhat slowly in relation to supply, due to low permeability, shallow water table, lack of gradient, or some combination of these. Soils are usually medium to fine in texture. Significant additions of water by subsurface flow are necessary in coarse-textured soils. Some horizons may remain wet for as long as one week after water addition.
'Well drained'	water is removed from the soil readily, but not rapidly. Excess water flows downward readily into underlying moderately permeable material or laterally as subsurface flow. The soils are often medium in texture. Some horizons may remain wet for several days after water addition.
'Rapidly drained'	water is removed from the soil rapidly in relation to supply. Excess water flows downward rapidly if underlying material is highly permeable. There may be rapid subsurface lateral flow during heavy rainfall provided there is a steep gradient. Soils are usually coarse-textured, or shallow, or both. No horizon is normally wet for more than several hours after water addition.'

Permeability is the characteristic of a soil which governs the rate at which water moves through it. Three permeability classes are used by McDonald *et al.* (1984).

'Slowly permeable'	potential to transmit water vertically is so slow that the horizon or soil would remain wet (saturated) for periods of a week or more after thorough wetting, whether or not there were obstructions to water movement outside the soil body. The soil may vary in structure, but there are few pores that could conduct water when the soil is wet; cracks or spaces among peds that may be present when the soil is dry close on wetting.
'Moderately permeable'	capacity to transmit water vertically is such that the soil would remain wet for no more than a few days after thorough saturation if there were no obstructions to water transmission outside the soil body. Soil horizons may vary in structure, or they may be massive (but porous) if they contain continuous conducting pores or cracks that do not close with wetting.

'Highly permeable'	the capacity to transmit water vertically is so great that the soil would remain wet for no more than a few hours if there were no obstructions to water movement outside the soil body. The horizons have large and continuous or connecting pores and cracks that do not close with wetting. Many gravelly and sandy soils provide these conditions, as do some medium or fine textured soils that have strong granular structure and/or large connecting pores.'

Those authors give approximate saturated hydraulic conductivity limits for each class as follows: High (>1 m/day), Moderate (0.01-1m/day), Slow (< 0.01m/day). The classes are expanded in this methodology as: Very rapid (> 5.0m/day), Rapid (1-5m/day), Moderately rapid (0.5-1m/day), Moderate (0.05-0.5m/day), Moderately slow (0.01-0.05m/day), Slow (< 0.01m/day).

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