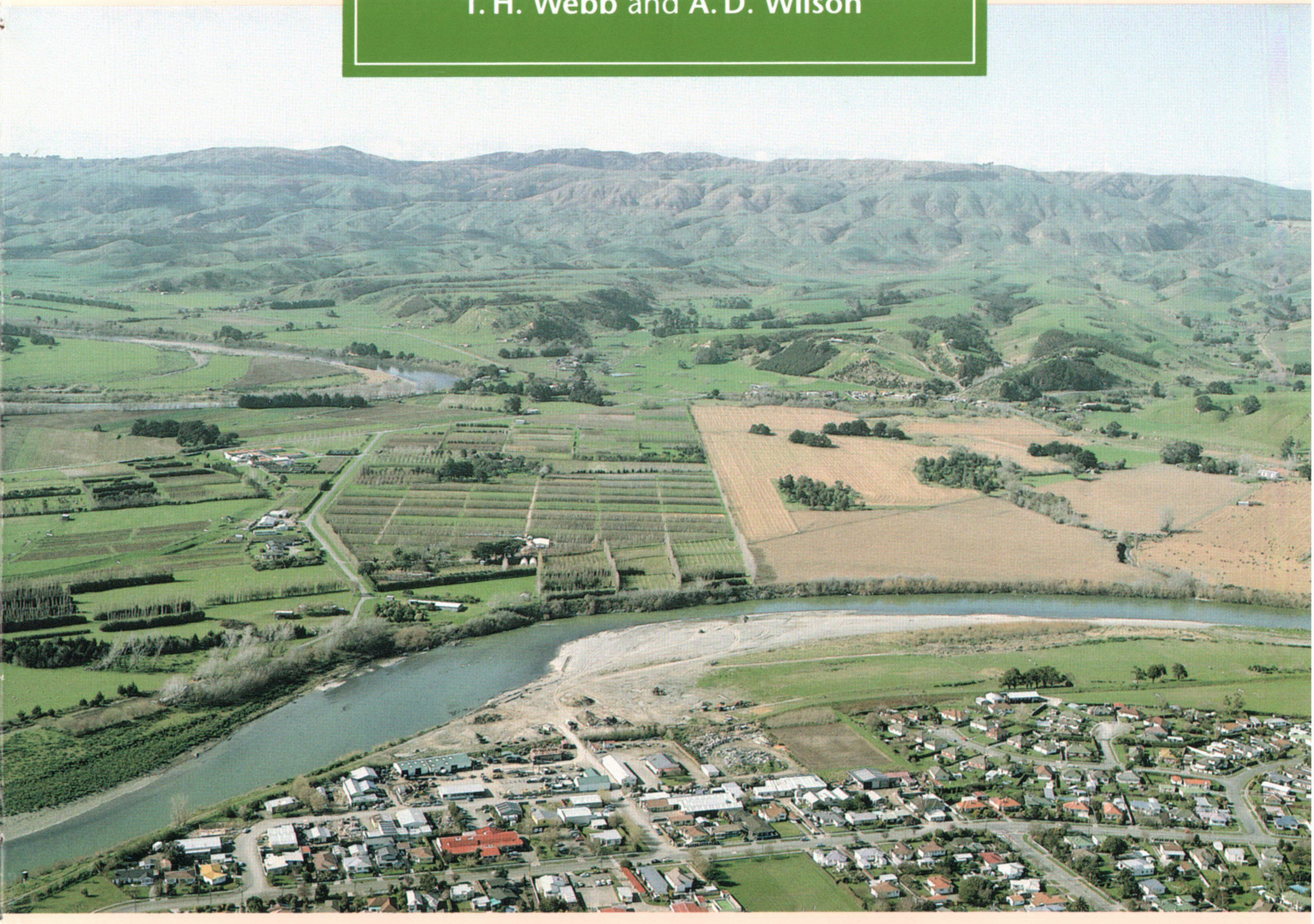
A Manual of Land Characteristics for Evaluation of Rural Land

T. H. Webb and A. D. Wilson



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A manual of land characteristics for evaluation of rural land

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Cover:
The Manawatu River floodplain, looking east from Palmerston North to the Tararua Range. The photo illustrates a range of land uses associated with land characteristics. Orcharding and cropping occur on deep, free-draining, alluvial soils on the low terraces. Pasture and forestry occur on the high loess-blanketed terraces containing soils with dense, slowly permeable subsoils. Pasture is the predominant cover on the steep mountain lands.

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Introduction

In the New Zealand landscape, topography, climate, geology, soil and hydrology all show marked spatial variability. Land evaluation is the process of interpreting the opportunities and limitations presented by these relatively permanent biophysical factors in relation to the requirements of specified land uses. The evaluations are intended to assist land managers and planners to optimise the use of their resources and to promote land use that is economically viable and environmentally sustainable.

Since the 1960s the rural landscape in New Zealand has become increasingly diversified and land evaluation has become more important. Over this period, changes in land use (such as conversion of dairy farms to kiwifruit orchards) have become more common and horticultural and cropping enterprises have varied their mix of crops in response to market changes and new opportunities. Furthermore, with the introduction of the Resource Management Act (1991), more emphasis is placed on minimising environmental effects of land use. Clearly defined, objective classifications are needed to evaluate land for different uses and to assess their socio-economic and environmental impacts.

Past classifications lack objective definitions of class limits and generally have no clear relationship between the factors used in classification and crop production or management. This has resulted in a lack of precision and poor predictive capability (Wilson 1984). Land-evaluation classifications based on biophysical characteristics described in this manual will enable different units of land to be ranked objectively using factors related to crop growth or management requirements.

The wide range of land characteristics presented will enable interpretation for a range of land uses including suitability of land for specific uses, assessment of vulnerability of land to degradation or contamination, and land suitability for effluent disposal.

The objective of the manual is to attain consistent land evaluation classifications within and between regions by the development of a common methodology and by adoption of a common set of land characteristics and ratings. The provision of a common base will assist users to become familiar with different classifications. It will also allow experience gained from one classification to be more reliably transferred in the development of related classifications. The list of relevant land characteristics is considered to be the minimum dataset required in the development of land resource databases for evaluation of a wide range of land uses.

The approach taken is an adaptation of the 'Framework for Land Evaluation' (FAO 1976) which provides guidelines for the construction of land evaluation classifications to support rural land use planning (van Diepen et al. 1991). The central concepts of the FAO Framework adopted in this manual are:

- Classification of land suitability is related to well-defined land uses.
- Suitability ratings are based on land qualities (complex attributes of land that have direct effects on crop growth or management).
- High suitability ratings imply that productive capacity can be maintained.

Like the FAO Framework, this manual does not by itself constitute a classification. Rather, it presents principles of land evaluation and describes the land characteristics (together with methods of their measurement or estimation) from which classifications are to be derived. Guidelines on how to apply the principles in the manual to derive classifications from the land characteristics are provided. The manual also indicates the potential applications of land evaluation classifications in New Zealand and reviews past classifications

Applications of land evaluation

Land evaluation aims to rate the quality of land for a particular use relative to other land in an area. It provides an objective foundation upon which to base decisions on land management, land purchase, and land use planning. It should precede planning and development so that alternative uses can be assessed in terms of economic benefits and social and environmental effects (Cutler 1977). It should be recognised, however, that land evaluation does not prescribe best land uses but only indicates options.

Major areas where land evaluation has direct application are:

Land resource planning

Wherever planners need to evaluate land for alternative uses, an objective classification to rank the relative suitability of land for these purposes is needed. Land evaluation can identify regional constraints to land use and food production, and guide regional policy making. Brklacich and MacDonald (1992) give examples from Canada of the use of land evaluation to appraise the degree to which agriculture currently utilises production potential within regions and to demonstrate market opportunities bylocating regions suitable for production increases. They also demonstrate how land evaluation can indicate the degree to which changes in socio-economic conditions might alter these opportunities.

Under the Resource Management Act (1991), local authorities (and with litigation, Planning Tribunals) are to develop policies *'to achieve integrated management of natural and physical resources'* and have statutory responsibility to *'protect land of regional significance.'*

To achieve these objectives, authorities need to know the quality of land for which they are responsible and the extent of land of different qualities. For example, land use conflicts commonly occur on the urban fringe, and planners are required to balance the demands of land for urban uses against loss of land from agricultural production. A well-defined classification of land quality is needed to evaluate options for urban expansion and provide a basis to assess the economic, social and environmental impacts of loss of land from rural to urban uses.

Guiding land purchase

Where the value of land is related to its productive capacity, land evaluation helps determine a suitable purchase price or rental value of land by providing an objective description of land quality and potential and the likely management inputs required under particular land uses. Land evaluation is particularly useful when comparing the relative value of different areas of land.

Determining suitability of land for a change in use

Land evaluation can help to protect investment and to increase profits wherever land improvement or a change in management is being considered. Examples of such changes are the development of community irrigation or drainage schemes or the change from agricultural to horticultural production. For example, a number of 'Landuser Guides' have been published to indicate the potential areas of land available for horticultural development in Otago and Southland (McIntosh 1992). Where major land use changes are contemplated, current land practices may not provide an adequate basis upon which to judge the suitability of proposed uses. The application of land evaluation classifications by qualified land resource specialists can prevent costly mistakes. Wilde and Hughes (1987) report on substantial losses in kiwifruit production that could have been avoided if information on land suitability had been sought before development.

Assessment of sustainability and environmental impacts of land use

Land evaluation can form a basis for assessment of the environmental impacts or social consequences of land use practices. Where sustainability conflicts with profitability, there is a need to assess sustainability separately from production potential (profit). Under the Resource Management Act (1991), local authorities have a statutory responsibility to *'sustain the potential of natural and physical resources to meet the foreseeable* *needs of future generations'* and to mitigate *'adverse effects of land uses on physical resources.'* A classification based on well-defined land characteristics can be used as a basis to determine sensitivity-vulnerability of land to impacts of land use practices such as:

- contamination of ground and surface waters through agricultural and effluent disposal uses,
- land degradation (physical, chemical, biological, erosion degradation),
- inundation by flooding.

Brklacich and MacDonald (1992) applied land evaluation classifications to determine the impact of estimated rates of soil loss from erosion for South Western Ontario. Their study suggested that, while long-term soil erosion was not likely to cause region-wide deterioration in land quality, there were isolated areas where significant degradation would occur. The analysis provided a rationale for targeting public resources for soil conservation to the areas prone to erosion. They also indicated how land evaluation could be applied to estimate the likely effects of changes in land use patterns and agricultural production practices on soil erosion rates. De la Rosa et al. (1992) and Batjes and Bridges (1993) reported on plans to develop classifications to identify the vulnerability of soil to chemical and organic contaminants.

Assessment of land suitability for effluent disposal

Soils differ in their inherent ability to store and assimilate effluents. Land evaluation can assess the ability of land to assimilate effluents, and the risk of ponding, runoff or leaching of contaminants to groundwaters.

Economic assessment of land use

Land evaluation can include economic analyses to estimate the economic suitability (e.g. gross margin) of each land unit for different land uses. Economic evaluations require detailed data on costs of inputs and technical procedures, such as computer models simulating soil water flow, crop growth and nutrient uptake (van Lanen et al. 1992). Rossiter (1990) used the Automated Land Evaluation System (ALES) to compare gross margins of alternative land uses under different cropping rotations.

Review of land evaluation classifications

Land use interpretations based on soil surveys

Over the past few decades, the Department of Scientific and Industrial Research developed several generalised, largely qualitative, land use classifications based on the concept of soil limitations to use. Classifications have included suitability of land for pastoral use (after Gibbs 1963), cash cropping (after Cutler 1967), commercial forestry (after Cutler 1967 and Mew 1980) horticulture (after Cowie 1974) and assessment of the actual or potential value of land for food production (after Cowie 1974). The latter classification was developed in response to the Town and Country Planning Act (1960), which required land having a high actual or potential value for food production to be protected from urban encroachment wherever practicable. Most soil survey reports published by NZ Soil Bureau, DSIR, in the last 25 years have included ratings of soils for some, or all, of these land uses.

A limitation of these classifications has been their subjectivity, which is due to ill-defined class limits and the lack of any clear relationships between the factors used in the classification and crop production. In addition, the classifications applied to broad land-use groupings (such as cropping, forestry) that contain crops with widely differing requirements. These soil-based classifications, therefore, have poor predictive capability, a low level of precision in allocation of soils to classes, and a lack of sensitivity to specific crop requirements.

McIntosh and Hewitt (1992) classified land in Southland and Otago according to suitability for horticulture, forestry and urban use. Their classifications were created to fit the detail available within current regional databases and to be easily understood and applied by non-specialists.

They used matching tables to rate land suitability based on the relative ranking of land characteristics. The disadvantages of this approach are the large number of land characteristics used (16 to 20) and the lack of direct correspondence between land characteristics and crop production.

Land use capability (LUC)

LUC is a grouping of land types to show, in a general way, their suitability for most kinds of farming. It attempts to provide a single-scale grading of land for all land uses, but has a particular bias towards suitability for arable cropping and soil conservation (Dent and Young 1981). The Ministry of Works and Development has classified all land in New Zealand according to the LUC system (National Water and Soil Conservation Organisation 1979). LUC as practised in New Zealand assesses the general capability of land (for cropping, pastoral farming, forestry and soil/water conservation) rather than its suitability for particular land uses and crops. The purpose for which the system was devised, and for which it is best suited, is farm planning (Dent and Young 1981). On a farm scale, the capability map shows the relative capability of land within a single system and enables land holders to decide where to locate particular activities to optimise farming systems.

LUC suffers from the following limitations:

- The general rating of land capability provided by LUC can be inappropriate for specific land uses. Two examples of inappropriate LUC ratings in relation to the suitability of land for intensive food production are:
  - Sandy soils that possess excellent drainage, aeration and root growth conditions have high value for horticulture under irrigation. However, within the LUC system, sandy soils are downgraded because of the risk of erosion and low soil-water storage under dryland conditions. Neither limitation is significant under intensive irrigation management.
  - On the other hand, land areas with drainage limitations which present a major risk for orchard and berryfruit production are sometimes given high LUC ratings because of their relatively favourable productivity for pasture and for some crops under dryland conditions.
- Criteria used in the classification of soils are poorly defined, and classifications are

frequently made on subjective assessments of defining criteria.

- There are a limited number of attributes used to determine the classification of flat land. Soil attributes are limited to drainage, depth, texture and stoniness. Other attributes of importance to crop growth or management, such as root penetrability within the root zone, aeration and compactability of soil materials under wheeled traffic, are not considered.

Thus, while the LUC system provides a generalised assessment of land versatility it has limited precision when assessing specialist or intensive land uses.

Development of concepts of versatility of land for intensive agricultural development

Molloy (1980) proposed a soil versatility classification for arable land. Soil versatility classes were defined by the physical characteristics of the root zone, and were applied within climatic zones.

Wilson (1984) and Wilson and Giltrap (1984) developed classifications for land according to its versatility for arable crop and orchard crop production respectively. They defined versatility as the ability of land to support sustainable production and management of a range of crops according to well-defined land attributes. The soil versatility class indicated the relative range in crops and land use systems that were feasible within the bounds circumscribed by climatic factors, and was applied within agro-climatic zones. The classification recognised that the physical nature of the land (physical soil characteristics, topography, climate) ultimately determines the range of plants that can be grown successfully, and the productivity of such plants and the versatility classifications were therefore assessed mainly in terms of soil physical characteristics. This manual provides a basis to update these versatility classifications and to extend them to other land uses.

Basic principles underlying the manual

Choice of land characteristics

Land characteristics were selected for their influence on productivity, crop quality, sustainability or land management. Emphasis is given to physical attributes because it is the physical nature of the land (physical soil characteristics, topography, climate) that primarily determines the range of crops that can be grown successfully, the potential productivity, and land management requirements associated with crop production, effluent disposal, etc. The few chemical attributes chosen are confined to those that determine buffering capacity and long-term nutrient-supplying power.

Some land characteristics apply to most forms of land use; others apply to a restricted range of uses. For example, effective rooting depth is of importance to almost all uses whereas 'days with water content less than the plastic limit' is important for arable farming but has little relevance for orcharding. Nutrient-supplying power is very important for all plant growth but is of lesser importance in horticultural production where soil nutrients are supplied through the addition of fertilisers. However, nutrient-supplying power can be of major importance to low-input forms of land use, such as 'organic' farming.

Derivation of land qualities

The effect of land characteristics on land use and management is seldom direct and uncomplicated. For example, a plant is not directly affected by rainfall or by soil texture, but it is affected by the availability of water and of chemical nutrients and by the incidence of poor aeration due to waterlogging.

Land qualities are attributes of land that directly influence its suitability for use, and are derived from land characteristics. Land qualities may be a single land characteristic (e.g. salinity), or a function of several land characteristics (water availability) and they may be related to soil properties (root penetrability), agronomic factors (e.g. chilling requirement), a combination of climate and soil factors (e.g. water availability) or to hazards (e.g. erosion hazards).

For every land quality there will be a set of critical values that is used to define class limits (suitability/versatility, etc.). The land qualities are generally ranked into an ordinal scale according to threshold values for each factor. Ratings generally range from 1 (very good) to 7 (very poor) or from 1 (good) to 5 (poor) depending upon the detail required. There are several methods that have been used to derive class limits from land qualities or land characteristics, including matching tables (FAO 1983), parametric methods (Riquier 1974), transfer functions based on process models (Bouma and van Lanen 1987) and decision trees (Rossiter 1990).

Objectivity

The classification of soils is based upon the best available information on land characteristics. Where measured values of land characteristics are available, precise classification is possible. Nevertheless, an element of subjectivity is inevitable in land evaluation as insufficient information is available for accurate determination of the relative effects that different land characteristics or qualities have on specific land uses.

Scientific procedures minimise, but do not eliminate, human judgments based on empirical appraisals. However, provided the basis of assessments is recorded, the user can trace the evaluation back to quantitative land characteristics and can assess the relevance of the ratings.

Most land evaluation classifications are based upon a maximum-limitation method in which the land qualities or characteristics with the most severe restrictions determine the suitability class, irrespective of the suitability of other land qualities or characteristics.

This method of rating land may appear to be of less value than a system which rates positive land qualities, but as Young (1975) points out, optimal conditions for a crop (which are often the same for many crops) may be less important than its tolerance to adverse factors, and many land use decisions are related to overcoming sub-optimal conditions.

Application to a wide range of land uses

The manual has been designed to cater for the wide range of potential demands of land evaluation for rural land. No single classification can have universal applicability for all rural uses, as specific land uses require specific classifications. However, the principles of land evaluation remain the same and a similar set of land characteristics is relevant for most evaluations. This manual collates the fundamental land characteristics and principles considered to underpin land evaluation for rural uses. It is intended that classifications derived from the manual will select the relevant land characteristics from those listed and will rate these according to the perceived need for different crop types, climate and management systems.

The manual has the capacity to accommodate interpretations relating to:

Land suitability

Classifications used to determine the ability of land to grow a particular crop (e.g. wheat, grapes) or a specific crop type (e.g. cereals) or for a particular land treatment (land suitability for irrigation or septic tank absorption fields).

Land versatility

In many instances land users are interested in growing a range of crops. A versatility classification rates land according to its ability to support production and management of a specified range of crops on a sustained yield basis (e.g. the arable-cropping versatility classification of Wilson 1984). It also provides a basis upon which to predict the relative quality and yield of these crops in relation to inputs required to obtain the yield.

Integrative classifications

Integrative classifications integrate non-biophysical factors, such as gross margins, with the biophysical factors to provide a solution to a problem or provide a dollar value for a land use. The evaluation may be expressed as a quantitative capability such as expected crop yield or effluent loading capability, or as an economic value such as gross margins.

Application to a range of data inputs and interpretation outputs

Provision is made for interpretations at various levels of detail depending on the purpose of the interpretation and the availability of information. Ratings for land characteristics may be assessed from several kinds of data, varying from direct measurements to estimates based on surrogate properties such as soil morphology. Where alternative sources of data exist, preference is to be given to the direct measurements. In some areas, qualitative estimates of land characteristics must be made. The method of determining land characteristics and the consequent reliability of assessments must always be clearly stated.

Suitability for quantitative applications

Where reliable data are available, interpretations based on the format of this manual allow for quantitative assessments suitable for economic analysis.

For example, van Lanen et al. (1992) used simulation modelling to estimate average yield and variability of yield for sugar-beet. Such land evaluation may quickly become out of date as relative costs and prices change. The economic analysis can be repeated when new economic conditions apply.

Provision for potential suitability ratings

Technically, it is possible to modify almost any site to produce a particular crop. However, in practice, the extent of modification depends on the land and climate characteristics, the cost of modifying them, the benefit gained, and the availability of capital.

Initially, land is rated according to suitability in its current condition (i.e. without major improvements); suitability is assessed in terms of crop growth potential in relation to the required recurrent and minor capital expenditure. The level of acceptable expenditure should be specified in the description of the land use being considered.

The classification includes a provision to rate land after major improvements have been effected. A major improvement is a substantial non-recurrent capital input that will effect a major and reasonably permanent change in the characteristics of the land. Major improvements include irrigation, reclamation of saline land, major drainage works and substantial soil alteration by deep subsoiling, land shaping or terracing.

For some land uses, such as horticultural production in areas subject to drought, all prudent land users install irrigation systems; in this case, provision of irrigation is not an option and should be considered within actual rather than potential interpretations.

Land characteristics and methods for their estimation

The soil and land characteristics that are perceived to influence crop production and soil management, together with the criteria used to assess them, are given in Table 1, which is derived largely from Wilson (1984) and Wilson and Giltrap (1984). Land characteristics are grouped into topographic, soil physical, soil chemical, environmental and climatic characteristics.

Where possible, class boundaries and technical words conform with those used in the New Zealand Soil Classification (Hewitt 1992), the Glossary of Soil Physical Terms (McQueen 1993), the Soil Description Handbook (Milne et al. 1991) and Methods of Chemical Analysis of Soils (Blakemore et al. 1987).

Ratings

Most land characteristics are given numerical ratings in the right-hand columns of the tables. Permeability profiles and soil temperature regimes do not form a numerical sequence, and ratings are presented as letter codes. Ratings are ranked according to whether a characteristic is considered favourable or unfavourable, with a rating of '1' indicating most favourable conditions. This system works well for all attributes except pH and phosphorus retention. High pH is given a rating of '1' but is generally considered to be less favourable to plant growth than slightly lower pH values. High phosphorus-retention values are considered favourable in relation to topsoil structural stability but unfavourable in relation to fixation of phosphate.

It is intended that national consistency in the interpretation of numerical ratings will be achieved by the application of these ratings in Landcare Research databases and land evaluation reports.

Where data sources do not allow a rating to be subdivided as finely as presented here, adjacent classes can be joined. When classes are joined they should be designated within the database as the numerical midpoint between classes — e.g. where classes 3 and 4 are joined this should be designated as 3.5. As a general rule, where there are more than five classes, the two highest and two lowest classes can be grouped without much loss of interpretative ability.

Methods proposed for estimating land characteristics differ according to the type of data available from the soil inventory. The most precise methods, as indicated, should be used for evaluations based on modern survey data. For past surveys, or where required data are not available, other methods are given. Where possible, class limits have been derived from empirical relationships between measured and estimated values. This does not necessarily mean a one-to-one correspondence in all cases. Therefore, the method of determining land characteristics should be clearly stated.

Topographic characteristics

Slope angle

Topography affects management and production costs by influencing access, machinery performance, and susceptibility to erosion. The following slope thresholds are recognised:

- On slopes of less than 7°, the full range of mechanical harvesters and machines for topdressing, spraying, weeding and harvesting may be used.
- The upper limit to prevent excessive losses from combine harvesters is considered to be 11° (Spoor and Muckle 1974).
- The upper limit for safe use of harvesting machinery is considered to be 15° (Hunter 1992).
- The upper limit for cultivation of arable crops, in terms of safety of machinery and erosion hazard, is considered to be 20° (Hunter 1992).

Soil physical characteristics

Effective rooting depth (ERD)

Effective rooting depth (ERD) is the effective depth of soil that can be potentially exploited by the rooting systems of most common crops, and which can provide a medium for root development, water and nutrient uptake. The ability of crop root systems to utilise the ERD depends on crop type and development stage.

Effective rooting depth is derived from potential rooting depth (PRD) by subtraction of

Table 1. Land characteristics and related land qualities.

Land characteristics	Related land qualities
Topograhic characteristics:	
Slope angle	Trafficability, workability, erosion hazard, harvesting efficiency, iirrigability
Soil physical characteristics:	
Effective rooting depth	Water and nutrient availability, root penetrability
Penetrability (penetration resistance, packing density)	Root penetrability
Profile available water	Water availability, droughtiness
Soil wetness (or evidence of reduction, drainage class)	Supply of oxygen to the root zone, risk of waterlogging, water availability
Air-filled porosity	Supply of oxygen to the root zone, risk of waterlogging, ease of drainage
Stoniness	Workability, root penetrability
Rock outcrop	Hindrance to machinery and related management constraints
Permeability profile	Ease of drainage, risk of waterlogging, effluent absorption potential, leaching and water loss hazards
Penetration resistance in topsoils	Soil trafficability
Days with water content below plastic limit	Soil workability
Clay content and mineralogy of topsoils	Topsoil structural stability, arable sustainability, susceptibility to compaction and crusting
Soil chemical characteristics:	
Nutrients (P, K and S)	Nutrient supply
pH	Aluminium toxicity, nutrient availability
Salinity	Crop growth, slaking
Cation-exchange capacity	Buffering capacity, effluent absorption capacity
Organic matter	Structural stability, workability
Phosphorus retention	Structural stability, P fertiliser requirement
Environmental characteristics:	
Flood return interval	Flood hazard
Erosion severity	Erosion hazard
Climatic characteristics:	
Soil temperature	Crop suitability, yield
Frost severity	Frost damage
Frost-free period	Frost hazard, crop suitability, frost protection
Growing degree days	Crop suitability, yield, ripening
Chill period	Vernalisation, crop suitability, yield
Sunshine hours	Crop suitability, yield, ripening
Soil water balance	Water deficit, irrigation requirement, effluent absorption capacity

Table 2. Slope classes.

Slope angle (degrees)	Description	Rating
0–3	level to very gently sloping	1
4–7	gently sloping	2
8–11	moderately sloping	3
12–15	moderately sloping to strongly sloping	4
16–20	strongly sloping	5
21–25	moderately steep	6
26–35	steep	7
>35	very steep	8

the depth occupied by stones and other materials not available for root growth. PRD can be estimated according to the methods of Griffiths (1985). PRD is the depth to a layer that may physically impede root extension. The presence of toxic chemicals, such as high levels of aluminium, may also limit root depth, and chemical criteria can be used to determine PRD when the critical limits of the chemical species are known. Soil physical characteristics known to influence root development are penetration resistance, aeration, water retention (Table 3), sharp contrasts in soil properties including fragipans and other compact horizons, cemented layers, lithic and paralithic contacts (Hewitt 1992), gley horizons, stiff and slowly permeable clays, and stony horizons with few or no fines <2 mm. Defining criteria and critical limits for the assessment of PRD are given in Tables 3 and 4.

Root penetrability within the potential rooting depth

The quality of the potential rooting depth as a medium for root development is assessed from the summation of penetrability with depth. Penetrability is assessed by measurements of penetration resistance or by density estimates.

A penetration resistance of >3000 kPa defines

Table 3. Critical limits for assessment of potential rooting depth.

Physical limitation	Land characteristic	Method of assessment
Root penetration	Maximum penetration resistance or density	Penetration resistance <3000 kPa (< very stiff penetration resistance class) **or** <1.85 Mg/m^3 packing density (< very dense class).
Aeration	Depth to reducing conditions	Depth to mean spring water table and i) a positive reaction to free ferrous iron test in >60% soil mass, **or** ii) low chroma in >60% of soil mass.
Water retention	Minimum available water holding capacity (AWC)	i) Where RR/ET_{max}* is <0.5, AWC is <5% v/v.** ii) Where RR/ET_{max} is >0.5, AWC is <3% v/v.**

* RR is rainfall (mm), ET_{max} is maximum evapotranspiration.

** Do not apply where the summer water table is within 1 m of the soil surface.

Table 4. *Effective rooting depth (ERD) classes.*

ERD (m)	Description	Rating
>1.2	very deep	1
0.9–1.2	deep	2
0.6–0.9	moderately deep	3
0.45–0.6	slightly deep	4
0.25–0.45	shallow	5
<0.25	very shallow	6

the potential rooting depth (Taylor et al. 1966), and critical penetration resistance limits of 1500 and 2200 kPa (Table 5) are derived from Griffiths (1985). Penetration resistance and packing density values are weighted average values from the base of the Ap horizon to the lesser of the specified depth limits or potential rooting depth. The 3000 kPa limit corresponds to the very stiff penetration class in the Soil Description Handbook (Milne et al. 1991, p. 57). Density terms reflect packing in stony and non-cohesive soils

Table 5. *Class limits for penetrability using penetration resistance and density.*

Cohesive soils Maximum weighted average penetratio n resistance (kPa) over potential rooting depth or soil depth			*Non-cohesive and stony soils* Maximum weighted average density over potential rooting depth or soil depth			Profile penetrability class	Rating
0–0.45 m	0.45–0.9 m	0.9–1.2 m	0–0.45 m	0.45–0.9 m	0.9–1.2 m		
1500	1500	2200	loose	loose	compact	very high	1
1500	2200	2200	loose	compact	compact	high	2
1500	3000		loose	dense		moderate	3
2200	2200		compact	compact		moderate	3
2200	3000		compact	dense		low	4
3000	3000		dense	dense		very low	5

Table 6. *Class limits for penetrability using packing density.*

Maximum weighted average packing density (Mg/m^3) over potential rooting depth or soil depth			Penetrability class	Rating
0–0.45 m	0.45–0.9 m	0.9–1.2 m		
1.35	1.35	1.6	very high	1
1.35	1.6	1.6	high	2
1.35	1.85	1.85	moderate	3
1.6	1.6		moderate	3
1.6	1.85		low	4
1.85	1.85		very low	5

and are defined by Milne et al. (1991, p. 57).

Where penetration resistance data are not available, estimates of root penetration may be made from the packing density (Table 6). Dry bulk density neglects the contribution to soil strength of the generally water-filled pore volume. This component is correlated with clay content. Packing density corrects for the effects of clay and enables direct comparisons of density of soils with different clay contents (Wilson and Giltrap 1982a).

Packing density
= Dry bulk density + 0.009(clay%)

It is assumed that root growth is optimal at packing densities less than 1.35 Mg/m^3. The packing density critical limit of 1.85 Mg/m^3 is derived by application of the above formula to data from 10 studies given by Jones (1983).

Profile available water (PAW)

The amount of soil water available for plant growth is an important determinant in crop production in low-rainfall areas, or where rainfall is variable, and determines frequency of irrigation. PAW is also of importance in determining land suitability for effluent disposal and the potential of land to pollute groundwaters.

Patterns of soil water extraction vary with plant species and soil–climate characteristics. Where classifications are developed for specific crop types, precise values for available soil water may be derived. For general-purpose land evaluation, the amount of soil water available for growth is defined as the profile readily available soil water (PRAW) or profile available water (PAW) for the lesser of the potential rooting depth or 1.2 m soil depth. PRAW is estimated from the volumetric water content difference between –10 kPa and –1500 kPa in the 0–0.4 m layer, and between –10 kPa and –100 kPa in lower layers. PAW is estimated from the volumetric water content difference between –10 kPa and –1500 kPa for all depths.

Readily available water holding capacity is determined by water-release methods (Gradwell and Birrell 1979). Horizon or sample depth values are then integrated over the potential rooting depth or 1.2 m and expressed as millimetres of water to determine PRAW. Where laboratory data are not available, then the readily available water holding capacity may be estimated from the soil profile morphology, as described by Wilson and Giltrap (1982a). Where relevant, estimates of readily available water capacity may be made using mean values of soil groups, as described by Griffiths (1985).

Classes for PAW and PRAW are presented in Table 7.

Table 7. *Classes for profile available water (PAW) and profile readily available water (PRAW).*

PAW (mm)	PRAW (mm)	Class	Rating
>250	>150	very high	1
150–250	100–150	high	2
90–150	75–100	moderately high	3
60–90	50–75	moderate	4
30–60	25–50	low	5
<30	<25	very low	6

Soil wetness class

Wetness status may be used to indicate likely seasonal aeration constraints. The saturation of pores by water markedly reduces gas exchange rates and induces seasonal anaerobic or partially anaerobic conditions. Wetness classes may also be used to derive water availability, drainage requirements and trafficability constraints.

Soil wetness status may be determined with decreasing precision by:

- direct measurement,
- derivation from occurrence of reducing conditions,
- inference from soil mottle patterns indicative of reducing conditions.

The choice of method depends on the logistics of soil survey operations and the availability of data. The method used should be stated. Where wetness assessments are made from observations within one or a few years, then this should also be stated.

Direct measurement of soil wetness
Soil wetness is expressed as the duration of wetness within specified depths in most years (Table 8). 'Wet' soil is defined as soil containing water held at a tension of less than 1 kPa.

Wetness inferred from chemical reduction
Reducing conditions can be identified by a positive reaction to the free ferrous iron test (Milne et al. 1991, pp.128–129). The duration of reducing conditions may be estimated from seasonal observations on the same or similar soil classes. Wetness status is assessed from the duration of reducing and hence anaerobic conditions within the lesser of specified soil depths or the potential rooting depth (Table 9).

Soil wetness inferred from mottle pattern or drainage class
Wetness status has traditionally been inferred from morphological indicators of reduction and/or from soil drainage class (Table 10). The use of soil colour (low chroma) and soil drainage class is the least accurate method of determining wetness status, but they are often the only methods available. Low-chroma colour percentages are generally reliable indicators of reduced and oxygen-deficient conditions where the colour pattern is not relict, and where a causal relationship with wetness or reduction can be shown. Low-chroma class limits (Table 10) are based on weighted average low-chroma percentage in the soil mass within specified depths.

Air-filled porosity at field capacity (AFP)

AFP provides an index of the quality of the potential rooting depth as a medium for gas exchange processes, and may be combined with climatic data to indicate likely seasonal aeration constraints (Wilson 1984). AFP also affects trafficability, ease of drainage and degree of waterlogging and leaching losses.

Gradwell (1966) suggests that AFPs of 10% and 5% at field capacity represent adequate and limiting aeration, respectively. Field capacity, or the upper drainable limit in soils, varies over the range –5 to –20 kPa pressure potential. Criteria for upper drainable limit pressure potential are given in Table 11. The pressure potential to which well-drained soils drain is approximately –10 kPa. That to which wet or slowly permeable soils drain is about –5 kPa.

The AFP percentage is measured from total porosity and the water release determination, as described Gradwell and Birrell (1979), and is calculated as:

AFP (> 0.06 mm) %
= total porosity –5 kPa water retention % v/v

AFP (> 0.03 mm) %
= total porosity –10 kPa water retention % v/v

Classes for AFP are presented in Table 12. AFP values should be recorded as weighted averages from the base of the Ap horizon to 0.45 m, 0.45–0.90 m, and 0.9–1.2 m, or to the potential rooting depth.

Where measurements of water retention are not available, the percentage of large pores may

Table 8. *Wetness status based on days of wetness occurring within different soil depth increments (derived from Jarvis and Mackney 1973).*

Days of wetness within depth increments			Description	Rating
0–0.45 m	0.45–0.9 m	0.9–1.2 m		
0	0	<30	nil	1
0	<30	any	minimal	2
<30	30–90	any	very low	3
30–90	90–180	any	low	4
90–180	180–300	any	moderate	5
180–300	>300	any	high	6
>300	any	any	very high	7

Table 9. Wetness status based on days with reduced soil conditions within specified percentages of soil mass occurring within different soil depth increments.

Days with reduced conditions and percentage of soil mass reduced within depth increments: 0–0.45 m		0.45–0.9 m		0.9–1.2 m		Wetness	Rating
Days	Soil mass (%)	Days	Soil mass (%)	Days	Soil mass (%)		
0	0	0	0	<30	<5	nil	1
0	0	<30	<5	any	any	minimal	2
<30	<5	30–90	<5	any	any	very low	3
<90	<20	<180	<20	any	any	low	4
<180	>20	<300	>20	any	any	moderate	5
180–300	>20	>300	>20	any	any	high	6
>300	>20	any	any	any	any	very high	7

Table 10. Wetness status based on mottle pattern and/or drainage class. The table is used as a key, beginning at the top. Criteria for both high- and low-chroma mottles must be true within any depth increment.

Percentage occurrence of mottles within depth increments: <0.15 m below topsoil		0.3–0.6 m		0.6–0.9 m		Wetness	Drainage class	Rating
High-[1] chroma mottles	Low-[2] chroma mottles	High-chroma mottles	Low-chroma mottles	High-chroma mottles	Low-chroma mottles			
0	0	0	0	<2	0	nil	well drained	1
0	0	<2	0	any	any	minimal	well drained	2
1–10	0	≥2	<50	any	≥50	very low	moderate	3
≥2	1–10	any	≥50	any	any	low	imperfect	4
≥2	10–50	any	≥50	any	any	moderate	imperfect to poor	5
any	≥50	any	any	any	any	high	poor	6
<2	≥85	any	any	any	any	very high	very poor[3]	7

[1] High-chroma mottles are any mottle with higher chroma than the soil matrix.

[2] Low-chroma mottles have moist chroma of 2 or less, or moist chroma of 3 with a value of 6 or more.

[3] Requires an organic topsoil (Clayden and Hewitt 1989).

Table 11. Criteria to determine pressure potential at the upper drainable limit.

Upper drainable limit pressure potential	Defining criteria
−10 kPa	Profile permeability moderately slow or faster.
−5 kPa	Profile permeability slower than moderately slow; **or** wet conditions occur within 0.2 m of any specified layer where sand >80%, or within 0.5 m where clay >40%, otherwise within 0.3 m of any specified layer.
>−1 kPa	Wet conditions.

Table 12. Air-filled porosity at field capacity (AFP) class.

AFP (volume %)	Description	Rating
>15	very high	1
10–15	high	2
7.5–15	moderate	3
5–7.5	low	4
<5	very low	5

be estimated from soil morphology using particle size and packing density predictors, as described by Wilson and Giltrap (1982a).

Stoniness

Stoniness may have both positive and negative effects on crop production and management. Here, stoniness is evaluated in terms of its negative affects on management. Stoniness affects cultivation (particularly rotary hoeing), germination, harvesting, drainage, mowing, fencing and trellising. The stone content of topsoil is a cost in implement 'wear and tear' and very stony topsoils can have marked negative effects on plant growth. The negative impacts of topsoil stoniness may be reduced by stone removal. Stoniness also has negative effects on water retention, rooting depth and soil water deficit, and positive effects on soil temperature and drainage properties. These effects are accounted for in other land characteristics.

Stoniness is assessed according to stone content and size in surface horizons (0–0.2 m), and by weighted average stone content and stone size over the remainder of the soil to a depth of 0.9 m (0.2–0.45, 0.45–0.9 m depth increments), using classes presented in Table 13. Profile stoniness may then be described in terms such as non-gravelly over gravelly – medium or moderately gravelly over extremely gravelly – medium. Use of a single descriptor, such as very stony, indicates no significant difference with depth.

Rock outcrop (includes surface boulders)

Rock outcrops or surface boulders create practical problems of access, and cultivation hazards. Rock outcrop classes are presented in Table 14.

Permeability profile

The permeability profile determines hazards of waterlogging and water loss (E. Griffiths, pers. comm.). Waterlogging and water-loss hazards are major determinants of irrigation scheduling, management of effluent disposal systems, drainage requirements, potential for water loss through runoff or drainage, and potential for development of reducing conditions (reducing conditions can have major effects on chemical transformations of nutrients and biocides). The permeability profile also has significant affects on potential rooting depth, aeration and trafficability.

Permeability is the quality of the soil that enables water or air to move through it. Permeability is estimated through assessment of 'saturated hydraulic conductivity', i.e. the rate at which soil transmits water when saturated.

The permeability of each horizon within 0–1.2 m can be measured or can be assessed by the methods of Griffiths (1985, 1991). The permeability of each horizon is classified into

Table 13. Stone content and size classes.

Gravel content			Gravel size		
Volume (%)	Description	Rating	Predominant size (mm)	Size class	Rating
<5	non-gravelly to very slightly gravelly	1	2–6	fine	1
			6–20	medium	2
5–15	slightly gravelly	2	20–60	coarse	3
15–35	moderately gravelly	3	60–200	very coarse	4
35–70	very gravelly	4	>200	bouldery	5
>70	extremely gravelly	5			

Table 14. Rock outcrop classes.

Area (%)	Description	Rating
0	non-rocky	1
<2	slightly rocky	2
2–10	moderately rocky	3
10–25	very rocky	4
>25	extremely rocky	5

permeability classes that are based on saturated hydraulic conductivity values of: slow = <4 mm/h, moderate = 4–72 mm/h, and rapid = >72 mm/h. The soil is then classified according to Table 15.

Minimum penetration resistance in topsoils

Penetration resistance values in topsoil horizons indicate the bearing strength of the soil in supporting the movement of machines and animals. The ability to carry out machine operations and grazing with minimal soil damage at critical times during the year is an important attribute in management. Trafficking over land with a low bearing strength may result in loss of traction, and soil compaction.

Table 16 presents critical values of penetration resistance. A record is needed of the length of time that topsoil horizon penetration resistance is likely to exceed the critical values. Monthly mean measurements are generally adequate to determine interpretations for trafficability (Wilson and Giltrap 1984). Records may be obtained by monitoring at reference sites or from observations during the year on similar soils under similar management. Where long-term monitoring is not feasible, the duration below critical values may be assessed from a reference penetration resistance at field capacity, and the duration of wetness in the surface horizon from soil wetness class. It is assumed that penetration resistance at field capacity is a reasonable estimate for moist to wet water states. Penetration resistance will be larger at lower water contents.

Days with topsoil water content less than the plastic limit

The number of days in which the water content of topsoil horizons is less than the plastic limit is used to determine the workability characteristics of soils for cropping land uses. Workability is assessed as the days over which the 0–0.20 m layer water content is less than the plastic limit.

The number of days with topsoil water content less than the plastic limit needs to be assessed in the period over which land is cultivated. The periods will vary with location, but are generally:

- spring cropping – 1 August to 31 November
- autumn cropping – 1 April to 30 May
- market gardening – all months except June and July.

Few records of plastic limit are available. Soil water records may be obtained by monitoring at

Table 15. Classification of permeability profile.

Permeability of slowest horizon within 0–1.2 m	Depth to horizon with slowest permeability (m)	Class
slow	0–0.45	S1
slow	0.45–0.6	S2
slow	0.6–0.9	S3
slow	0.9–1.2	S4
moderate	0–0.45	M1
moderate	0.45–0.6	M2
moderate	0.6–0.9	M3
moderate	0.9–1.2	M4
rapid		R

Table 16. Minimum penetration resistance (PR) in topsoil horizons.

Minimum PR (kPa)	Description	Rating
>600	high	1
300–600	moderate	2
<300	low	3

Table 17. Classes for clay content where smectite is the dominant clay mineral.

Clay content (%)	Rating
>35	1
18–35	2
<18	3

reference sites or from observations during the year on similar soils under similar management. Where long-term monitoring is not feasible, the evaporation/drainage required for a topsoil water content to drop below the plastic limit may be determined at a reference site and historical water-balance data used to estimate the number of days that the topsoil water content would have exceeded the plastic limit.

Clay content and mineralogy

The content and nature of clay minerals present in topsoils have effects on soil structural stability. Minerals considered to be important in stabilising soil structure in New Zealand are sesquioxides, aluminosilicates with short range order, and smectites. Sesquioxides and aluminosilicates with short range order can reduce the dispersibility of clay and contribute to bonds between other mineral particles (Kay 1990). Goldberg (1989) reports that sesquioxides and aluminosilicates with short range order increase aggregate stability, permeability, friability and porosity; they also reduce swelling, clay dispersion, bulk density, and modulus of rupture. Smectite clays have a high shrink–swell potential and enable topsoil structure to be recovered after cultivation.

Table 17 records the ratings for clay content in topsoils where smectite is the dominant mineral. Smectite is dominant where there are more smectites than any other mineral group. Phosphorus retention is used to estimate the amounts of sesquioxides and aluminosilicates with short range order, and ratings for phosphorus retention are given in Table 21 (see page 24).

Soil chemical characteristics

Nutrient content

Soil nutrient fertility refers to the ability of the soil to supply a balance of nutrients to a particular crop (Parfitt 1984). Nutrient fertility depends on the relationship between the soil's ability to supply the nutrients to plant roots and the need, or nutrient demand, of the crop.

The relationships between crop production and soil nutrients are essentially dependent upon threshold nutrient concentrations in the soil solution. Such relationships are traditionally approximated from analysis of the labile pool of soil nutrients, e.g. MAF 'quick tests'. The labile pool, however, is dynamic and depends on transformation rates from less or non-labile forms, and on gains and losses through fertiliser input, animal transfer, crop uptake and leaching loss pathways. Soil nutrient 'fertility' is transient and strongly dependent on management.

'Reserve' or non-labile nutrient 'pools' are dependent upon soil types, and information is available for these in the Landcare Research soil database. As the relationships between crop production and reserve nutrients have not been quantitatively determined and their relevance for production is uncertain, the non-labile nutrient pools are rated into only three classes (Table 18). The rating of nutrient reserves provides a qualitative estimate of a soil's potential to release, uptake or immobilise nutrients (Parfitt 1984).

The importance of nutrient reserves is strongly dependent upon land use. Soil nutrient characteristics are of minimal importance for high input horticultural or cropping uses where fertiliser inputs are a relatively minor cost within the production system. However, nutrient reserves have increasing importance where the cost of fertiliser inputs become high in relation to the net return for the crop. They are particularly important in low-input or 'organic' farming enterprises and for determining issues of sustainability of cropping systems in the long term.

Classes of fertility based on reserves of phosphorus (P), potassium (K), and available sulphur (S) are presented in Table 18 and are derived from proposals of Parfitt (1984). Methods of analysis are those of Blakemore et al. (1987). Reserves of P are determined from P extracted by 0.5 M H_2SO_4. Topsoil horizons are considered to be the main source of phosphorus. Soils with high P retention are all rated as having low P reserves because available P in these soils is strongly retained by soil particles. (Soils with high P retention in topsoil horizons are those formed from volcanic parent materials.) The K_c value gives a ranking of soils in terms of rate of release of K, particularly from reserves held in mica. Parfitt (1984) provides an estimate of the annual supply of P and K (in kg/ha) based on the level of reserves. Available sulphur is estimated from the values for phosphate-extractable sulphate.

Nitrogen is deficient in almost all soils in New Zealand, but the nitrogen status is highly dependent on management factors and is therefore not considered here. Magnesium and

Table 18. *Classes for reserves of phosphorus and potassium, and available sulphur (after Parfitt 1984).*

0.5 M H_2SO_4 for 0–0.2 m (g/100 g)	K_c for 0–0.6 m (meq./100 g)	Phosphate-extractable SO_4-S for 0–0.6 m (µg/g)	Nutrient class	Rating
>20*	>0.45	>10	high	1
10–20*	0.2–0.45	3–10	medium	2
<10	<0.2	<3	low	3

* All soils where phosphorus retention exceeds 60% are rated as low.

Table 19. The pH scale in relation to plant growth (after Parfitt 1984).

Minimum pH 0.2–0.6 m	Notes on plant growth relationships	Class	Rating
>7.5	May seriously interfere with plant growth.	high	1
6.5–7.5	May depress growth; possible deficiencies of some nutrients may be induced.	moderately high	2
5.8–6.4	Satisfactory pH for many plants.	near neutral	3
5.5–5.7	Earthworm numbers, microbial activity, and nutrient cycling may be restricted.	moderately low	4
4.9–5.4	Al often toxic and probably limits growth.	low	5
<4.9	Both Al and Mn are likely to be toxic.	very low	6

Table 20. Class limits for salinity based on electrical conductivity.

Soluble salts (%)	Conductivity (mS/cm)	Salinity class	Rating
<0.05	<0.15	very low	1
0.05–0.15	0.15–0.4	low	2
0.15–0.3	0.4–0.8	medium	3
0.3–0.7	0.8–2.0	high	4
>0.7	>2.0	very high	5

Table 21. Classes for cation-exchange capacity (CEC), organic matter content and P retention.

CEC within 0–0.6 m (meq./100 g)	Organic carbon within 0–0.2 m (g/100 g)	P retention within 0–0.2 m (%)	Class	Rating
>40	>20	>85	very high	1
25–40	10–20	60–85	high	2
12–25	4–10	30–60	medium	3
6–12	2–4	<30	low	4
<6	<2		very low	5

some trace elements are deficient in some soils, and under some cropping systems, and may be important in local situations.

pH

The pH value affects plant growth largely through its influence on nutrient availability and the presence of toxic ions. Classes for pH are presented in Table 19. Classes are given for the 0.2–0.6 m soil depth as adverse pH can have a significant effect on root growth at these depths and pH is very difficult to alter below the topsoil.

Salinity

Soil salinity problems are recognised in some soils of low-rainfall areas of Central Otago, and in some soils derived from estuarine sediments. Instances of secondary salinisation as a consequence of irrigation are also known to occur.

Soil salinity may be based on measurement of soluble salts or estimated from the electrical conductivity of a 1:5 soil-water extract at 25°C (Milne et al. 1991). Classes for electrical conductivity are presented in Table 20. A soil profile is rated according to the horizon with the highest conductivity within the upper 0.6 m.

Cation-exchange capacity (CEC)

CEC is used to estimate the buffering capacity of a soil. Soils with high buffering capacity retain soil nutrients and other cations against leaching losses and resist rapid acidification. The higher the CEC the greater is a soil's ability to absorb chemical contaminants.

The value of CEC is largely dependent upon the organic matter content and the amount and nature of clay minerals present. Table 21 presents classes for buffering capacity based on the average CEC value for the upper 0.6 m of soil material.

Organic matter

Organic matter promotes the formation of stable aggregation in topsoils, increases porosity and infiltration, and increases water-holding capacity. Organic matter has a high cation-adsorption capacity and is the primary substrate for soil microorganisms. It effects the retention and cycling of nutrients, and the retention, activity and degradation of herbicides and pesticides.

Classes for organic matter, based on values of organic carbon, are presented in Table 21. Classes are from Blakemore et al. (1987).

Phosphorus retention

P retention in topsoil horizons is an important determinant of phosphorus fixation and structural stability. Ratings are presented in Table 21.

Environmental characteristics

Erosion severity

Soil erosion is a form of soil degradation, causes pollution of water in streams, and results in crop production losses. Only limited data on rates of soil loss from erosion are available in New Zealand and soil erosion is usually assessed subjectively from past erosion features, soil dispersibility, climate and topography.

Soils are rated according to potential erosion risk. The most comprehensive inventory of potential erosion risk is contained in the Extended Legends to the Land Inventory Worksheets (NWASCO 1979). Potential erosion risk is defined as 'that under a grass cover with assumed average management and no conservation measures applied.' Where available, more accurate assessments based on field measurement, or information from catchment authorities or other sources, may be used. The classes used by NWASCO (1979) are slight, moderate, and severe. The type of erosion should also be noted.

Flood return interval

Flooding is the temporary covering of the soil surface by flowing water from any source including streams overflowing their banks, run-off from surrounding slopes and inflow from high tides. The probability of flooding plays an important role in management decisions concerning the type of land uses that may be considered. Flood risk is expressed as a flood return interval using the class limits presented in Table 22.

Information on flood risk may be obtained from regional councils. In the absence of flood data, estimates of flooding frequency may be

Table 22. *Class limits for flood return interval.*

Flood interval (years)	Class	Rating
nil	nil	1
<1 in 60	slight	2
1 in 20 – 1 in 60	moderate	3
1 in 10 – 1 in 20	moderately severe	4
1 in 5 – 1 in 10	severe	5
>1 in 5	very severe	6

Table 23. *Soil temperature regime classes (based on soil temperatures at 0.3 m depth).*

Code	Soil temperature regime	Mean annual soil temperature (°C)	Period <5°C (days)	Period >20°C (days)	Predicted range in growing degree-days	
					>10°C	>5°C
T	thermic	15–22	0	n/a	1100–1500	>2000
WM	warm mesic	11–15	0	>5	950–1100	1850–2000
MM	mild mesic	11–15	<60	0	650–1000	1500–1950
CM	cool mesic	8–11	<60	0	500–900	1300–1800
DM	cold mesic	8–11	>60	0	400–650	1150–1500
C	cryic*	<8	>60	0	<400	<1150

* Mean summer temperature <15°C.

deduced from soil profile and vegetation data. Where land is protected from flooding, the flood return interval used in classification should be that of the flood protection design works.

Climatic characteristics

On a regional basis, the type of crops that can be satisfactorily grown are to a large extent determined by climatic attributes, assuming an adequate soil medium. Many of the physiological

Table 24. *Frost severity classes.*

Minimum temperature (°C)	Frost severity	Rating
>–6	low	1
–7 to –14	moderate	2
>–14	high	3

Table 25. Classification of agro-climatic attributes.

Duration of frost-free period (days)	Growing-degree days (Nov–Apr)	Chill units	Sunshine hours (Oct–Apr)	Class	Rating
>300	>1400	>1500	>1400	very high	1
250–300	1100–1400	1000–1500	1300–1400	high	2
200–250	900–1100	600–1000	1200–1300	moderate	3
150–200	500–900	<600	1100–1200	low	4
100–150	<500		<1100	very low	5
<100				extremely high	6

processes which control the rate of crop development and growth are regulated by air temperature and solar radiation. Similarly, the amount and seasonal distribution of rainfall are important determinants of crop performance and cropping patterns. Soil temperature directly influences root function in crop production. Windiness, or other factors indicative of exposure, were considered to be too dependent on microtopographic features to be assessed either on a regional or soil type basis. Where wind is used in a classification it will often need to be analysed separately.

The source of climatic data should be referenced (most data may be obtained from NZ Meteorological Service publications). Where known, micro-climatic effects may also be discussed.

Table 26. Classes for soil water surplus or deficit.

Deficit or surplus (mm)	Class	Rating
<100	very low	1
100–200	low	2
200–300	moderate	3
300–400	high	4
400–500	very high	5
>500	extremely high	6

Climatic characteristics are given as a range to cover variability (Tables 23 and 24).

Soil temperatures

Soil temperature may be measured as described by Aldridge (1982) or predicted for horizontal sites by the regression models of Aldridge (1982) and Aldridge and Cook (1983).

Soil temperature regimes (Table 23) after Aldridge (1984) are based on mean annual soil temperature at 0.3 m depth, and the number of days above 5°C and 20°C. The number of days above 5°C is an expression of the duration above biological zero. Soil temperature and many air temperature variables are closely correlated, therefore the likely range in accumulated growing degree-days (November–April) above 5°C, and 10°C is also given. Soil temperature regime is also closely correlated with the duration of the frost-free period, with the exception of coastal sites (R. Aldridge, pers. comm.).

Frost severity

Frost severity limits the range of crops that can be grown successfully. Three classes are recognised (Table 25). Minimum temperatures are derived from the lowest recorded grass minimum temperature from NZ Meteorological Service (1984). Areas subject to frosts greater than 14°C are confined to upland areas or sites subject to the effects of temperature inversion within lowland areas.

Frost-free period (FFP)

Frost is defined as a screen frost at 0°C (Table 25). Note that frost occurrence can show large variations according to micro-climatic attributes. Also, the effect of frost depends on the frost-tolerance of species.

Growing degree-days (GDD)

Growing degree-days have been widely used by growers and processors as an index of crop development (Kerr et al. 1981). Threshold temperatures vary according to crop, and for each crop the required number of growing degree-days depends on variety. Growing degree-days are assessed above a base of 10°C over a November–April period (Table 25). For example, kiwifruit typically requires 1100 GDD to attain 6.2% soluble solids by mid-May.

Cool-season chill requirements

The period of exposure to cool temperatures necessary to induce flowering may be assessed as cumulative chilling units (Table 25). Inadequate winter chilling may lead to irregular and prolonged flowering. The initiation of the cool-season rest period is taken as the average of the first (autumn/winter) frost as given by Goulter (1981), and chilling units are calculated from then as by Kerr et al. (1983).

Sunshine hours

Crop requirements for solar radiation may be empirically estimated from sunshine hours (Table 25).

For example, the optimum requirements for apples are given as more than 1200 sunshine hours during October–March by Kerr et al. (1983), and for persimmons more than 1400 hours over October–April.

Soil water deficit/surplus

The extent to which rainfall meets evaporative demand on a seasonal basis is a major determinant of crop production, irrigation requirements, the capability of a site for effluent disposal, and the likelihood of pollution of waterways.

Soil water deficits and surpluses are calculated on a daily basis, as by NZ Meteorological Service (1986).

Classes for soil water deficits and surpluses are presented in Table 26. Soil water deficits represent the evapotranspiration demand (in mm) in excess of rainfall, when the available soil water is zero. Soil water surpluses represent the amount of water from rainfall which exceeds the evapotranspiration demand when the soil is at field capacity.

Classes for soil water deficits and surpluses for soils with different PAW in relation to climatic water balance are presented in Table 27.

Table 27. *Classes for soil water deficit and surplus for soils with different profile available water (PAW) in relation to climatic water balance. (For key to numbers, see Table 26.)*

Profile available water (mm)	**Average annual water deficit or surplus for soil with PAW of 160 mm**				
	<100 mm	**100–200 mm**	**200–300 mm**	**300–400 mm**	**400–50 mm**
>200	1	2	3	4	5
130–200	1	2	3	4	5
90–130	1	2	3	4	5
60–90	2	3	4	5	6
30–60	2	3	4	5	6
<30	3	4	5	6	6

Deriving classifications from the manual

It is intended that the manual will form a basis for developing rural land evaluation classifications for a range of land uses. The first derivative publication is 'Classification of land according to its versatility for orchard crop production' (Webb and Wilson 1994).

A general procedure for using the manual to develop a classification for land is:

Determine the kind of land evaluation

Determining the intended application of the land evaluation is the first step in the development of a classification. A land evaluator must identify who will use the classification and what their requirements are for analysis and output. This investigation should result in the selection of a relevant classification (e.g. the classification to be developed may be 'Suitability of Land for the Disposal of Septic Tank Effluent' as opposed to 'Versatility of Land for Renovation of Liquid Effluents').

Determine land use requirements

Different land uses require different inputs for evaluation. The classification must relate to specified crops, capital input levels, labour intensity, machinery and the level of land users' technical knowledge.

Derive land qualities

Once the intended land use has been defined, the land qualities affecting either the crop growth, crop quality or land management must be determined from the scientific literature or from field experience.

The list of land characteristics and land qualities in the manual (Table 1) provides a guide to attributes that need to be checked for significance.

The next task is to derive land qualities from the relevant land characteristics. Sources of data need to be investigated to determine how the selected land characteristics can be measured or estimated. The classification must be tailored according to the availability of data.

Develop relative ratings for land use

The final step in developing the classification is the creation of a procedure in which the land qualities are ranked in relation to one another to determine suitability/versatility ratings.

In deriving ratings, account should be taken of expected yield or performance level, the relative cost of applying technology to minimise the effects of any limitations, and the adverse effects of continuing limitations, if any, on social, economic or environmental values.

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