Land Resource Assessment

Victor Sposito

Summary of

Actions Towards Sustainable Outcomes

Environmental Issues/Principal Impacts

- Land Resource Assessment (LRA) provides significant benefits because it defines criteria (i.e. critical factors) for the selection of the most appropriate sustainable use for a particular area.
- Environmental considerations are incorporated in land-use policies and controls to recognise the importance of the functions performed by natural systems, their fragility in the face of development and the irreversibility of the damage that may be done to them.
- Specific applications of environmental zoning include:
  - agriculture zoning, intended to protect prime agricultural land against competing uses
  - conservation zoning, which embraces a broad range of matters, including the protection of areas of high landscape value, or biodiversity; and
  - reserves aimed to protect and manage water, forest or minerals resources.
- Using resources more effectively has three advantages:
  - it slows resource degradation and depletion at one end of the value chain;
  - it lowers damaging impacts, including pollution, at the other end; and
  - provides the basis to increase employment with sustainable jobs.

Basic Strategies

In many design situations, boundaries and constraints limit the application of cutting EDGe actions. In these circumstances, designers should at least consider the following:

- Use the biophysical characteristics of landscape, such as landform, soil, vegetation and climate, to predict the suitability of land for different uses, or as indicators of vulnerability of the land to impact from various uses.
- Use Multiple Criteria Evaluation (MCE) methods in a Geographic Information Systems (GIS) environment to conduct Land Resource Assessment (LRA).

Cutting EDGe Strategies

- Use a combined MCE-GIS methodology to undertake strategic land use planning studies in metropolitan and town expansions, infrastructure, transport and natural resources management studies.
- Use LRA combined with climate change impact models to generate future scenarios for examining the potential impact of climate change on human and natural systems, and designing feasible adaptation options (Sposito et al, 2004). This approach will be explained in a forthcoming note of the BDP *Environment Design Guide*.

Synergies and References

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ENVIRONMENT DESIGN GUIDE

Sustainable Land Resource Assessment

Victor Sposito

The note describes a new procedure for Land Resource Assessment (LRA). It uses Multi-Criteria Evaluation Methods (MCE) in a Geographic Systems (GIS) environment. As an example, the LRA method is applied in determining land suitability for agricultural purposes. The method is appropriate for undertaking land use planning, town design, site selection, infrastructure studies and natural resource management studies. Town planners, civil engineers, architects and landscape architects would find it very useful.

1.0 Introduction

Land Resource Assessment (LRA) has, as one of its main purposes, the identification of environmental (i.e., biological and physical) conditions that present an opportunity, or pose a constraint, to proposed developmental actions. The following examples serve to illustrate some of the important applications of the approach.

A town planner, architect or builder, is looking for sites to develop a large housing estate; a transport and road construction agency is studying possible alignments for a new road; a catchment management authority, or a water board, is examining best uses for available water to encourage agriculture diversification. Each has not only specific design, engineering and economic requirements that must be met, but also certain biophysical constraints that must be recognised. Houses must not subside or be located on very steep slopes; highways will not be publicly supported if they endanger threatened species or their habitats; agricultural production should have minimum impact on the environment.

Although it is not required by legislation, LRA provides significant benefits because it outlines criteria for the selection of the most appropriate sustainable use for a particular area. Encompassed in this is the possibility of converting constraints into opportunities. For instance, an area of good organic soils, that is subject to flooding, is a poor site for a housing estate, though suitable and attractive for the necessary open spaces associated with the estate. Similarly, steep slopes often limit the location of buildings or certain agricultural uses, but are good places for the preservation of vegetation cover to prevent severe soil erosion and sedimentation of water features.

Governments and public agencies recognise the importance of the functions performed by natural systems, their fragility in the face of development, and the irreversibility of damage that may occur. For these reasons, environmental considerations are incorporated in land use policies and controls. Specific applications of environmental zoning include:

- agriculture zoning, intended to protect prime agricultural land against competing uses
- conservation zoning which embraces a broad range of matters including the protection of areas of high landscape value, or biodiversity; and
- reserves aimed to protect and manage water, forest or minerals resources.

More broadly, there is increasing evidence that current agricultural production systems in Australia are not ecologically sustainable in the long term. Current production systems can cause waterlogging, rising watertables and salinisation, or leaching of nutrients, particularly nitrate, which is reflected in accelerated rates of soil acidification. Nutrient leakage, when combined with overuse of fertilisers, subsequently leads to waterway eutrophication and algae blooms.

Ensuring that land use is compatible with the intrinsic characteristics of the Australian environment and accommodates the new matter and energy flows imposed upon it, is the key to improving natural resources management. The development and application of methods and practices, which result in biophysically optimal spatial and temporal land use patterns is, therefore, a fundamental and urgent requirement (Lovering and Crabb, 1997; Williams, 1999).

2.0 Land Resource Assessment – Biophsysical Suitability

Following accepted practice in Australia, the term land suitability is used here to refer to the evaluation of the immediate potential of the land for a specific purpose in a precise biophysical, socio-economic and technological setting. Land capability refers to land evaluation for broadly specified land uses, e.g., urban development, conservation, agriculture, forestry (Gunn, Beattie, Reid, and van de Graaf, 1988).

Soil, landform, vegetation and climate, or combinations of these ecosystem components have been used as indicators of a variety of biophysical characteristics in the different land evaluation, or assessment, systems developed and applied around the world (Westman, 1985). These biophysical characteristics can be used in predicting the suitability of land for different uses, or as indicators of the vulnerability of the land.

Typically, each landscape attribute, or factor, is separately mapped, and relevant maps overlaid to determine (homogeneous) land units that contain the landscape attributes of interest for particular land uses. Since the early 1960s, such approaches have rapidly evolved from hand-drawn transparency maps suitable for overlay (e.g., McHarg, 1969), to elaborated computerised systems using Geographic Information Systems (GIS) as platforms. Sometimes, the latter are attached to automatic systems of data input from satellite imagery using remote sensing.

The main output of a land suitability analysis is a set of maps (one for each land use) which shows the spatial pattern of requirements, preferences or predictors of some activity. This leads directly to two major tasks involved in any method:

- to identify homogeneous units of land for a particular use; and
- to rate the suitability of the land units for that particular use.

3.0 Land Suitability Analysis in a GIS Environment

3. 1 Application to Agricultural Land Suitability

The LRA methodology recommended by the author uses Multiple Criteria Evaluation (MCE) methods in a Geographic Information Systems (GIS) environment (Sposito, Lumb, Hood and Dean, 2000). MCE methods, such as the Analytic Hierarchy Process (AHP), have been developed to investigate alternatives (or choice possibilities) in the light of multiple objectives (or criteria) and conflicting preferences (or priorities).

The creator of the AHP, Dr Thomas Saaty, points out that: "(AHP) enables us to make effective decisions on complex issues by simplifying and expediting our natural decision-making process. Basically, the AHP is a method of breaking down a complex unstructured situation into its component parts; arranging these parts, or variables, into a hierarchical order; assigning numerical values to subjective judgements on the relative importance of each variable; and synthesising the judgements to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation." (Saaty, 1995, p 5). A most significant aspect of the AHP is the use of ratio scales. These special kinds of numbers can be multiplied down a hierarchy and still define a resulting ratio scale; ratio scales and hierarchies are well suited to be together.

GIS technology provides a support environment, a context to the MCE method. Integrating MCE with GIS in the way explained below enables the achievement of the full potential of both techniques for land use, spatial analysis and decision-making (see Figure 1).

An important element (Box 3) is the application of the AHP in a GIS platform. Climate, landform and soil, and combinations of these ecosystems' components are used as indicators of biophysical characteristics (Box 1). To gauge how well a commodity (vegetable, fruit, tree or pasture), or groups of them, will grow, the commodity has to be assessed to determine the climate, landscape or soil parameters that will impact upon productivity (Box 2). The land use maps (Box 7) can be prepared using satellite imagery and ancillary datasets such as cadastre and vegetation.

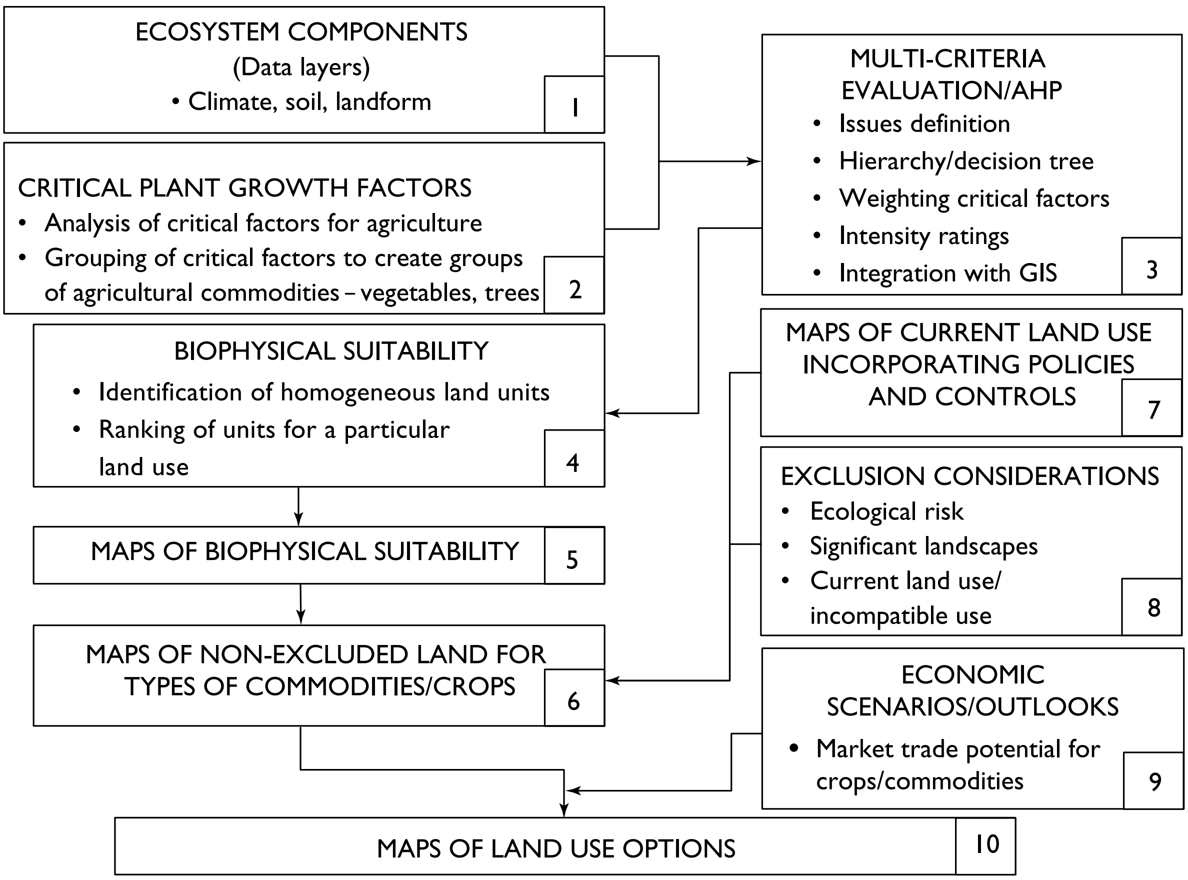


Figure 1. Methodological approach to biophysical land suitability

3. 2 Procedural Steps in the Analytic Hierarchy Process (AHP)

The procedure to carry out the AHP is the same for all situations, and repetition of certain steps (or iteration) is often necessary. It moves from the general concept to the particular and more detailed elements of the system (Saaty, 1995, pp 94 - 95). The description below is specifically related to land suitability analysis.

Define the issue(s) - problem(s) or opportunity(ies) - and specify the solution desired. The particular needs and concerns at the local, regional, state or national level determines the issue(s).

Identify the focus. The focus forms the pinnacle of the hierarchy (constructed in Step 4) and is the outcome being sought from the application of AHP.

Identify the criteria. Criteria in the form of critical factors for growth for selected commodities, or groups of them, are based on acknowledged bibliography and agreed upon by experts (e.g., soils scientists, agronomists, natural resource analysts/planners).

Construct the hierarchy. It is structured in the form of a decision tree with the overall objective, or focus, at the top. The hierarchy enables assessment of the impact of elements of a higher level to those of a lower level, or alternatively the contribution of elements in the lower level to the importance or fulfilment of the elements in the level above. There should be only five to nine criteria (factors) contributing to each issue. “Elements (criteria) that are of less immediate interest can be represented in general terms at the higher levels of the hierarchy, and elements critical to the problem at hand can be developed in greater depth and specificity.” (Saaty, 1994, p 96). Where necessary, primary criteria ought to be broken down into secondary and tertiary criteria. The criteria may be reviewed and modified.

Assign criteria/intensity ratings to the critical factors that have been identified. The rating is made in terms of the impact on each of the lowest level criteria (factors) for each primary criterion. By assigning intensity ratings, experts can provide an assessment of the critical factors in relation to the level at which they may become limiting to plant growth or protection of the environment.

Weight the criteria by posing a set of questions between pairs of criterion at each level of the hierarchy to establish the relative importance, or priority, that is placed among them. Usually, the weightings for each level of the hierarchy are standardised and sum to 1 (one).

Check the consistency of the evaluation and reiterate if necessary. The consistency ratio of the hierarchy should be 10% or less. If it is not, the quality of the information should be improved – perhaps by revising the questions posed to make the pairwise comparisons.

Integrate the hierarchy and weighting information with mapped data for the study area. The linkage of the AHP decision making framework to a GIS platform requires a software that is written in Visual Basic and acts as a user-interface to ArcView and Spatial Analyst.[1] Thus, to create maps, which provide a ranking of areas/sites in terms of suitability for the production of the commodity or group, map themes (e.g., soil pH, temperature) and data fields are selected. Intensity ratings, in the range from 0 (zero) to 1 (one), are then assigned to each category in the field.

The resultant map is obtained from processing all the map overlays by reclassifying field values to AHP ratings, multiplying each by the associated weight and, afterwards, summing the maps together for each level of the hierarchy. A land suitability map, using this procedure, has values ranging continuously from 0 to 1, where 0 represents a site with little or no value and a site with a 1 represents a near perfect site. For a regional or a local application, a three, four - or five-class suitability rating system is often used, as it provides sufficient resolution for planning and management purposes.

Several of these steps require specialist input and judgement (e.g., assessment of critical factors and ranges for plant growth). It would also be essential to have access to relevant environmental data (e.g., soil, native vegetation and climate information). Government departments of natural resources and environment, and catchment management authorities normally have the data required and intend to make such data available to assist in improving decision making for sustainable development. In Victoria, for instance, relevant information to undertake land suitability analyses, including examples, is delivered through the Victorian Resources Online website (www.nre.vic.gov.au/vro). See also the August 2000 Newsletter of ACLEP (Australian Collaborative Land Evaluation Program) (CSIRO Land and Water, 2000).

3. 3 Further Development of the Method and Computer Software

A recent, further development of the land stability, described above, method identifies those factors (criteria) that can be managed or ameliorated through human-made actions, and factors that represent biophysical limitations that cannot be managed and hence limit absolutely the productive capacity of an area.

For instance, in the South Gippsland Rural Strategy, two different hierarchies were constructed for each commodity, or groups of them, and two land suitability maps were produced (Sposito, Hossain, Lumb, Dean, and Ryan, 2000). The first hierarchy (“inherent factors”) incorporates all factors (criteria) that influence/impact upon the productive capacity of the land for a given commodity. They are grouped under three ecosystem components:

- *soil* – soil pH, sodicity, texture, electrical conductivity (EC)

[1] *ArcView* and *Spatial Analyst* are trademarks of ESRI Inc, whereas *Visual Basic* is a trademark of the Microsoft Corporation.

- *climate* – rainfall, temperature; and
- *landform* – slope, topography (see Figure 2).

The second hierarchy incorporates biophysical limitations that can be ameliorated or overcome using standard management practices (see Figure 3). For example, acid soils can be treated with lime; poorly drained soils can be improved by hilling-up or by laying tile drains. These practices raise the input costs of production, but if input costs are less than or equal to the marginal return from production, they are justifiable.

Once the factors (criteria) have been classified into the two groups, structured into hierarchies, rated and mapped, the results are combined. The resultant two maps are superimposed to produce a final map showing areas of high, medium and low/very low suitability for the commodity in question. The final map (Figure 4) illustrates land suitability based on the inherent biophysical limitations and ease of amelioration of some of them, using existing management practices.

Current applications of this methodology by DNRE are based on the utilisation of the IDRISI[2] GIS computer software package, developed by Clark University (USA). The software includes a MCE module with several models to support decision making in a situation like land use planning, where many criteria need to be assessed and aggregated to construct a composite suitability index.

The Clark's Weighted Linear Combination (WLC) model uses a weighted combination approach. The model allows criteria to trade-off with each other depending on the importance of weights assigned to them. Thus, a low suitability score, defined by one factor (criteria), may be compensated by a high suitability score in another factor (criteria). The AHP is utilised to calculate the weights in the WLC model. For this, an interface between ArcView and IDRISI is necessary which is included in DNRE software (see footnote 2).

The presentation of the results of the complete, overall methodology for LRA, in a specific area or region, would generally contain land suitability assessment tables, area statements, and preferred land use maps for the selected agricultural commodities, or groups of them.

Land Suitability Assessment Tables comprise key climatic, landscape and soil criteria that are taken into account to determine the biophysical suitability of each homogeneous unit of land in the area or region of concern.

Area Statements indicate the extent of land in hectares or square kilometres that have various degrees of suitability for agricultural production (categorised in 3, 4 or 5 land classes). The statements usually include public land, declared water supply catchment and areas subject to erosion risks or salinity, or are of high landscape significance. These overlays represent a formal prohibition, or requirement, on a particular activity.

The maps illustrating preferred land uses are composite maps incorporating a number of overlays. The overlays include biophysical suitability, current land use, ancillary data such as Ecological Vegetation Classes (EVC), and

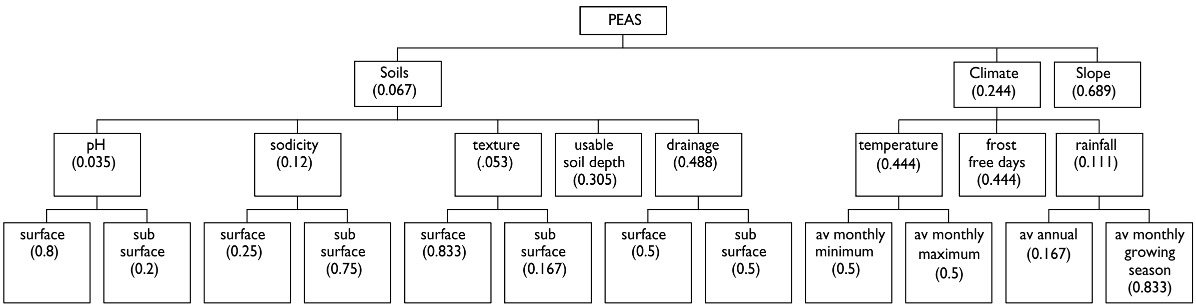


Figure 2. Hierarchy of critical factors for the growth of peas – Inherent factors

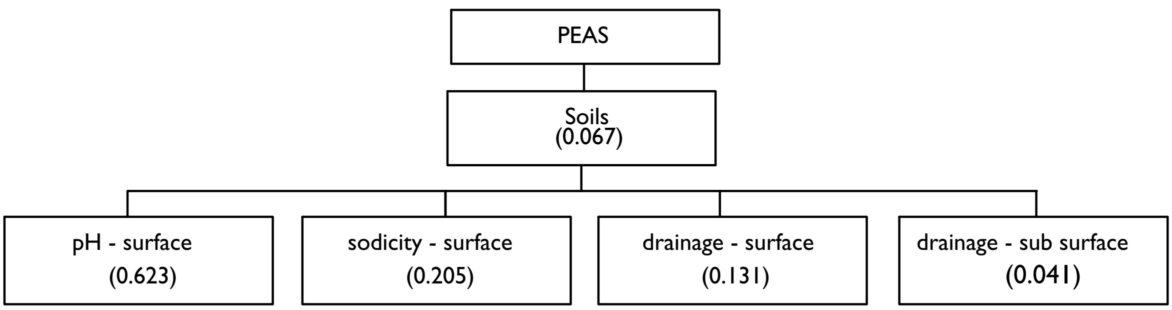
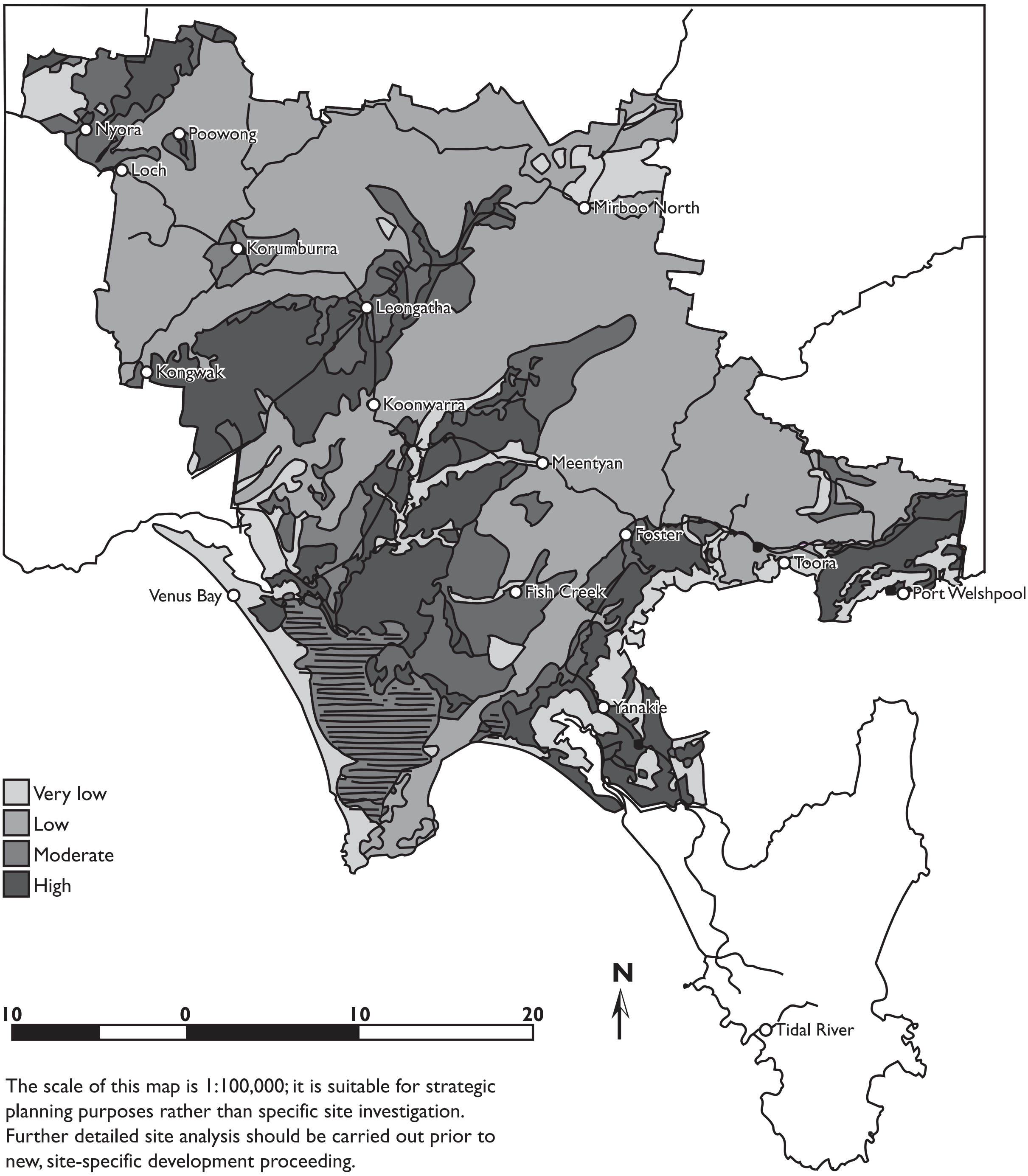


Figure 3. Hierarchy of the critical factors for the growth of peas – Management factors

2 *IDRISI* is a trademark of Clark University. The software, and further examples of the application, of the Land Resource Assessment methodology described in this article can be obtained from the author at the Victorian Department of Natural Resources and Environment (DNRE), Agriculture Victoria, corner Sneydes and South Roads, Werribee 3030; email: victor.sposito@nre.vic.gov.au.



The scale of this map is 1:100,000; it is suitable for strategic planning purposes rather than specific site investigation. Further detailed site analysis should be carried out prior to new, site-specific development proceeding.

Figure 4. Land Suitability for Peas (includes both inherent and management factors) South Gippsland Shire

policies and controls that apply to the study area. They should not be used in isolation, but in conjunction with other environmental overlays such as erosion risk, salinity and flooding, and infrastructure maps.

The level of resolution of the soil information would usually determine the resolution level of the overall analysis. For instance, in Victoria, land suitability maps are usually available at a geographic scale of 1:100,000 or 1:25,000, which are appropriate for strategic planning, purposes at the regional and sub-regional/catchment levels, rather than for specific site investigations.

4. 0 Conclusion

There are demonstrable benefits in applying the methodology described in Section 3 for Land Resource Assessment. Using resources more effectively has three advantages:

- it slows resource degradation and depletion at one end of the value chain
- lowers damaging impacts, including pollution, at the other end; and
- provides the basis to increase employment with sustainable jobs.

The combined MCE-GIS methodology is particularly appropriate for undertaking strategic land use planning studies in metropolitan and town expansions, infrastructure and natural resource management studies. Various applications for site selection, transport and land use planning studies can be seen in the bibliography mentioned below.

Recent developments in promoting integrated land use planning and catchment management at the national level have, at its core, the application of sustainable land use methods. For instance, developing strategies for improved integrated land use planning is a major area of the National Greenhouse Reduction Strategy.

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Biography

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