Strategic Regional Planning: mixing data, experts and GIS

Hemayet Hossain, Adam Hood, Victor Sposito, Stephen Cook

ABSTRACT

A strategic approach to guide sustainable development of South Gippsland Shire in Victoria (Australia) initiated application of GIS methods in concert with data and experts.

Two major models have been developed by the Strategic Resources Planning team at the Department of Natural Resources and Environment using ArcView Model Builder to map suitability for agricultural and urban land use. Both models use a GIS-based Multi-criteria modelling approach combining empirical data with experts' judgement.

Agricultural Suitability model considered soil, landscape and climate criteria whereas Urban Buildability model assessed physio-environmental, socio-economic and spatial phenomena to define locational suitability.

Keywords: Strategic Regional Planning, Local Government, Agricultural Suitability Model, Urban Buildability Model, GIS, Expert Modelling Systems, Analytical Hierarchical Process, Multi-criteria Evaluation.

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1 INTRODUCTION

1.1 Shire Strategic Planning in Victoria

Regional Planning is regaining importance as a necessary platform to achieve integrated development in terms of environmental and socio-economic sustainability. The development framework perceives urban and rural settlements as part of a functional continuum (McHarg 1969) and regional systems needs to be planned to strengthen this continuum.

Many rural Shires (local Government) in Victoria, Australia are looking for Strategic Regional Plan to guide development of their land resources. The importance of Land Resource Assessment at a strategic level is emphasized in Victorian Local Government planning processes. Under the Environment and Planning Act, Victoria (1994), local councils are expected to complete Municipal Strategic Statements (MSS).

A major goal of the 'Our Rural Landscape' vision of the Victorian Government is to plan and develop its rural and peri-urban landscape in an integrated cohesive manner to achieve ecologically and economically sustainable livable communities.

1.2 Project Initiation

The South Gippsland Shire covers an area of approximately 3,297 sq km and is located about 100 km south east of metropolitan Melbourne. The South-east Growth Area of Melbourne, comprising the municipalities of Casey and Cardinia, is one of Australia's fastest growing regions with a projected population of some 300,000 people by the year 2021.

In 2000 the South Gippsland Shire Council (Victoria) invited the Strategic Resources Planning (SRP) unit of the Department of Natural Resources and Environment (recently restructured as Department of Primary Industries) to study and formulate a strategic plan to guide development of its land resources in the Shire. This was followed by another project in 2001 to do a detail plan for the Coastal region of South Gippsland Shire including the urban structure plans for the coastal townships. These projects allowed SRP to undertake development of two major models (Agricultural land Suitability and Urban Buildability) utilising Geographic Information Systems (GIS) techniques.

Following this, SRP has been invited to develop strategic plans for other rural Shires in Victoria. This paper is based on the outcomes of several such projects.

2 THE APPROACH : MIXING DATA, EXPERTS AND GIS

2.1 Multicriteria Evaluation

In order to define the suitability of an area for a specific practice, several criteria need to be evaluated. The methodology applied integrates a Multi-criteria Evaluation (MCE) method within the Geographic Information Systems (GIS) environment. MCE has been developed to improve spatial decision making when a set of alternatives need to be evaluated on the basis of conflicting and incommensurate criteria (Malczewski 1999). MCE is an effective decision-making tool for complex issues that uses both qualitative and quantitative information.

MCE has been utilised around the world for Land Suitability Modelling and is concerned with how to combine the information from several criteria to form a single composite index of evaluation. A criterion may be a *factor* providing suitability of phenomenon of *continuous* measure or may be a *constraint* to limit the alternatives under consideration (Eastman 1999).

Unlike MCE, the traditional land suitability models use *Boolean* aggregation method of constructing suitability indexes that present a rigid binary choice of acceptance or rejection.

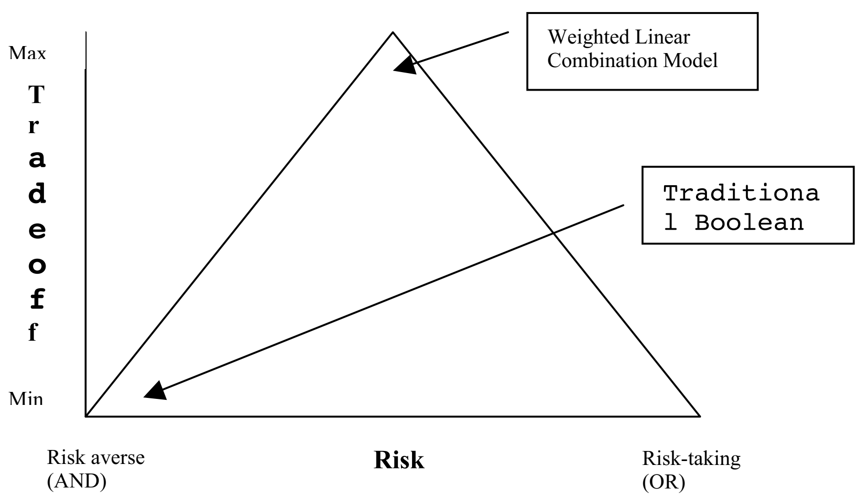

Figure 1 : Decision Strategy Space
(Source : Eastman 1999)

The MCE in its *Weighted Linear Combination (WLC)* method introduces a soft or "fuzzy" concept of suitability in standardising criteria. Instead of hard Boolean decision of assigning absolute suitability or unsuitability to a location for a given criteria, it is scaled to a particular common range where suitable and unsuitable areas are continuous measures. The aggregation method uses weighted linear combination, which retains the variability of continuous criteria and allows criteria to trade off with each other (Eastman 1999). A low suitability defined by one criterion may be compensated by a high suitability score in another criterion. Trade-off between criteria will depend on *weights* assigned to them. As depicted in the decision strategy space above, this model is a significant improvement over the Boolean approach by avoiding its extreme risk aversion (binary rejection) and extreme risk taking (binary acceptance) nature.

2.2 Analytical Hierarchy Process (AHP) and Experts

The MCE is implemented using the Experts Systems Modelling approach of Analytical Hierarchy Process (AHP) developed by Saaty (Saaty 1980). AHP provides a framework that incorporates experts participation in the decision-making process.

Compared to empirical models based purely on the correlation amongst the data, the Experts Modelling system incorporates the knowledge of the experts that can address many of the other issues and understandings that may be important to decision-making. The Experts model is also better suited when access to good data is limited.

The AHP orders critical factors into a hierarchy of importance. It also allows criteria to trade-off with each other depending on the importance weights assigned to them. Furthermore, AHP can deal with criteria that are interdependent, both from the effect on land and in the interaction between spatial units.

The principles utilised in AHP to solve problems are to construct hierarchies, establishing the priorities, and ensure logical consistency. The Analytic Hierarchy Process breaks down a complex unstructured situation into its component parts. These parts, or variables, are arranged into a hierarchical order with numerical values assigned to the subjective judgements based on the relative importance of each variable. These judgements are synthesised to determine which variables have the highest priority and should be acted upon to influence the outcome of the situation (Saaty, 1995).

In this respect, "AHP incorporates both the qualitative and the quantitative aspects of human thought: the qualitative to define the problem and its hierarchy and the quantitative to express judgements and preferences concisely. The process itself is designed to integrate these dual properties." (Saaty 1995).

AHP also provides an effective structure for group decision making by imposing a discipline on the group thought's processes. The necessity of assigning a numerical value (i.e., weight) to each variable of the problem helps decision makers to maintain cohesive thought patterns and to reach a conclusion. In addition, the consensual nature of group decision making improves the "consistency of judgments and enhances the reliability of the AHP as a decision-making tool" (Saaty, 1995).

Although a variety of techniques exist for the development of criterion weights, one of the most promising is that of pair-wise comparison in AHP. In the procedure for Multi-Criteria Evaluation using WLC, it is necessary that the weights sum to one. In AHP, these weights are calculated by taking the principal eigenvector of a square reciprocal matrix of pair-wise comparison between the criteria. All possible pairs of criteria are compared by experts on a 9-point continuous scale for their relative importance in determining the suitability of the stated objective. The ratings are then introduced in a matrix to calculate the weights (Eastman 1999).

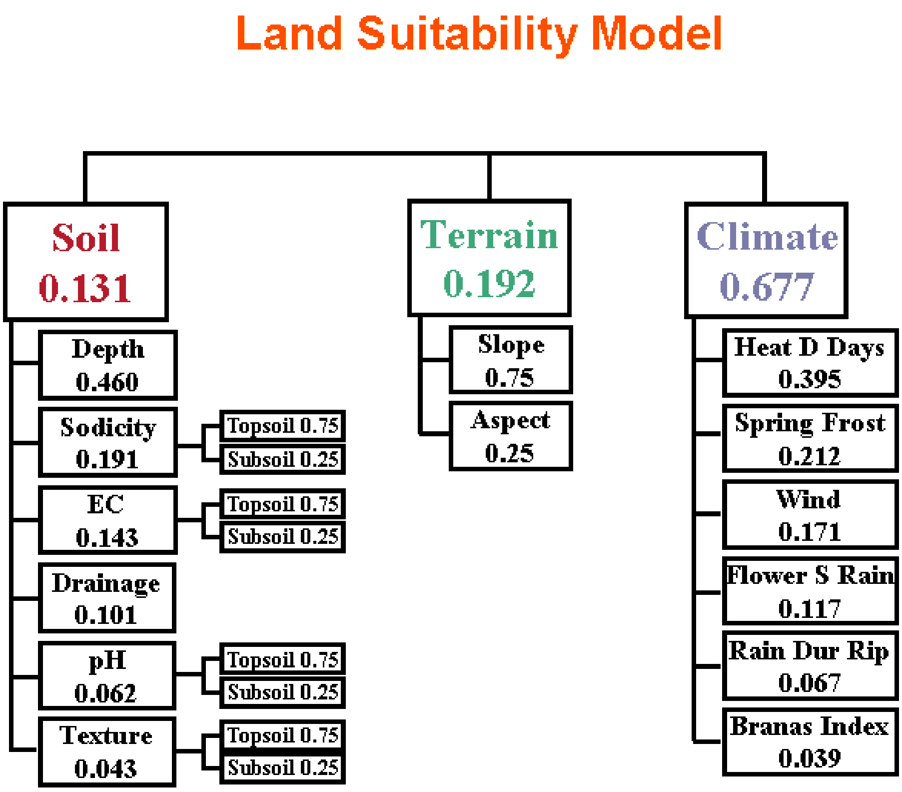

Figure 2: A simplified AHP hierarchy tree for land suitability model

2.3 An Outline of the Modelling Process

The procedure to carry out the MCE is the same for all situations, although certain steps may be given special emphasis depending on the problem of interest and repetition is often necessary. A panel of experts is chosen to provide advice for each commodity, which may include local growers, soil scientists, industry people and other various experts. The description below is specifically related to land suitability analysis. (Hossain and Tiller 2001)

- *Define the issue(s) or problem, and specify the solution desired.* The issue(s) are determined by the particular needs and concerns at the regional level.

- *Identify the focus.* The *focus* forms the pinnacle of the hierarchy 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.

- *Construct the hierarchy.* The hierarchy is structured in the form of a decision tree with the overall objective, or focus, at the top. It enables to assess the impact of elements of a higher level on 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. “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 to greater depth and specificity” (Saaty, 1994). Where necessary, primary criteria ought to be broken down into secondary and tertiary criteria. The criteria may be reviewed and modified.

- *Assign intensity ratings* to the range of data values for 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 the suitability (plant growth for example) 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. The pair wise comparisons is a robust technique for capturing preferences as the user compares all factors against each other but only two factors at a time, and thus can make a more reliable judgement. The pair wise ratings are determined on a 9-point continuos scale and are entered into a pair wise comparison matrix. In the land suitability application, environmental factors that may contribute to, or impact upon, commodity (vegetable, tree or pasture) growth and production are weighted.

  The AHP weights are calculated using the WEIGHT module in IDRISI GIS software (IDRISI32 2000). A consistency ratio is also calculated to measure the consistency of the pair-wise comparison.

- *Model Development* is then done using the Model Builder in ArcView GIS (ESRI 2000). The suitability model is defined with the AHP hierarchy, criteria weights and data value ratings formulated previously. Model is then fed with necessary data and executed to produce the resultant suitability map.

- *Validate the Suitability Maps.* The resultant commodity 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, The final map ranks areas in terms of suitability for the production of a commodity that has an index range of 0 (zero) to 10 (ten), where 0 represents a site with little or no value and a site of 10 represents a near perfect site. For a regional or a local application this index can be categorised into a four class rating system, such as very low, low, moderate and high suitability.

  The same panel of experts is used to validate the final suitability outcome and ensure the accuracy of the maps. If necessary, weighting's and intensity ratings of the 'criteria for growth' can be adjusted.

3 THE MODELS

3.1 Agricultural Suitability Model

The South Gippsland Shire council wanted to identify good agricultural land based on eight selected commodities (peas, carrots, brassicas, potatoes, sweet corn, pome & stone fruit, raspberries and cool climate grapes) and protect it from other developments as part of the strategic plan. In order to determine land suitability for these commodities, many criteria needed to be evaluated. The management potential for some of the criteria were also taken into consideration and applied as an improvement factor to the suitability. A panel of experts were chosen for each of the selected commodities, which included local growers, soil scientists, agronomists, natural resource analysts/planners, and industrialists. Within Victoria, experts have been derived from the Department of Natural Resources and Environment (DNRE), private consultancies, and other key State agencies. A day-long session for each of the commodities were held with experts to determine the criteria influencing the growth of the commodity, criteria weights and criteria intensity ratings.

When different land resources such as soil characteristics, landscape forms and local climatic conditions occur in certain combinations, they can provide suitable environmental conditions for different land uses and management. Deep, fertile, well-drained soils in flat, temperate valleys with low winds and regular seasonal rainfall are likely to be suitable for a producing range of agricultural commodities. Following are the criteria sets considered for the commodities:

Climate: rainfall, temperature, frost, chilling, branas index, and wind.

Soil: drainage, ph, sodicity, usable depth, texture, coarse fragments, EC,
light intensity

Landscape: slope and aspect

The individual commodity suitability maps were combined to produce the 'Agricultural Suitability' map shown below.

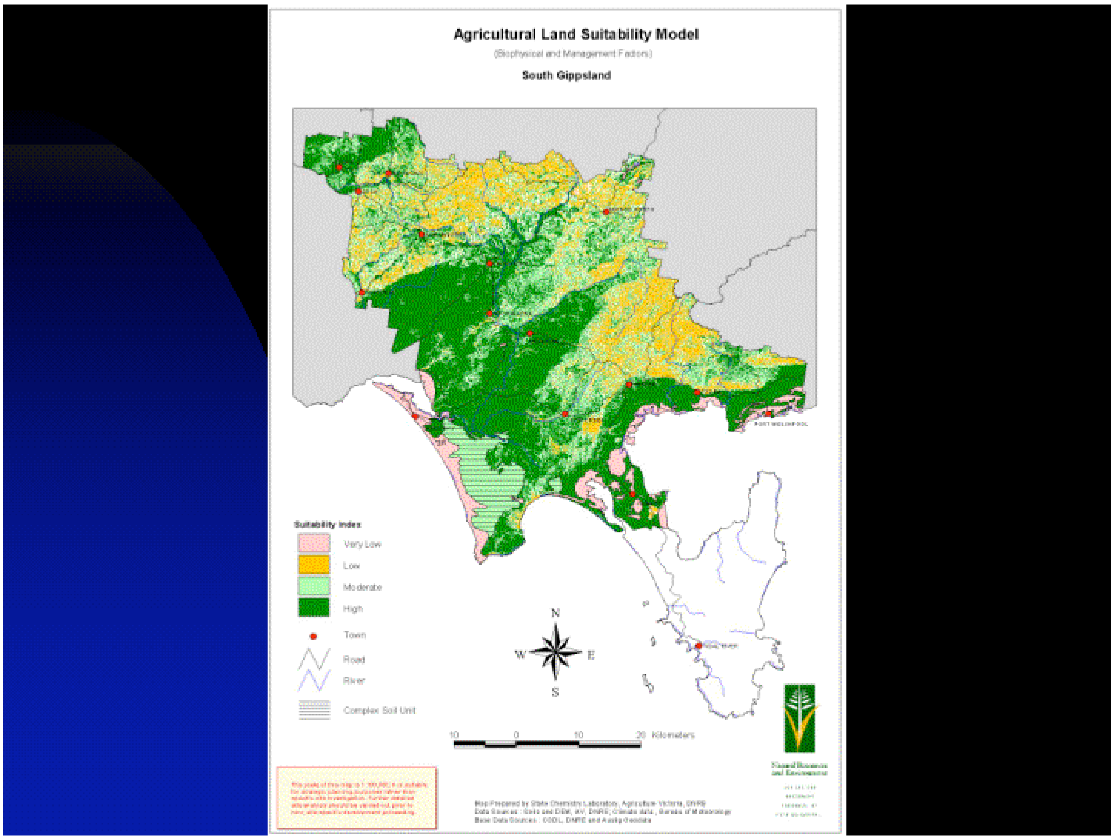

Figure 3 : Agricultural Suitability Map of South Gippsland
(Source : Sposito, et al 2000)

To date, SRP has developed a total of 25 such commodities or commodity group models to satisfy requirements of several Shires in Victoria. These commodities cover fruit, vegetables, agroforestry, pastures, crops and flowers. The separate treatment of management factor were abandoned from models developed later, since it was observed that experts were always responding based on the best-practice scenario.

Once the suitability maps are produced, a range of important environmental constraint overlays are created, which allow for other considerations of the region. These include conservation value layers and ecological vegetation classes. Environmental risk is also incorporated by including water quality and dryland salinity layers.

A set of 5 policy zones were created based on the integration of agricultural suitability, environmental overlays and socio-economic information. These zones were largely based on a combination of the major environmental issues and the socio-political factors driving natural resource management in the Shire.

The 'Planning Strategy' map below was produced as a final product of the project.

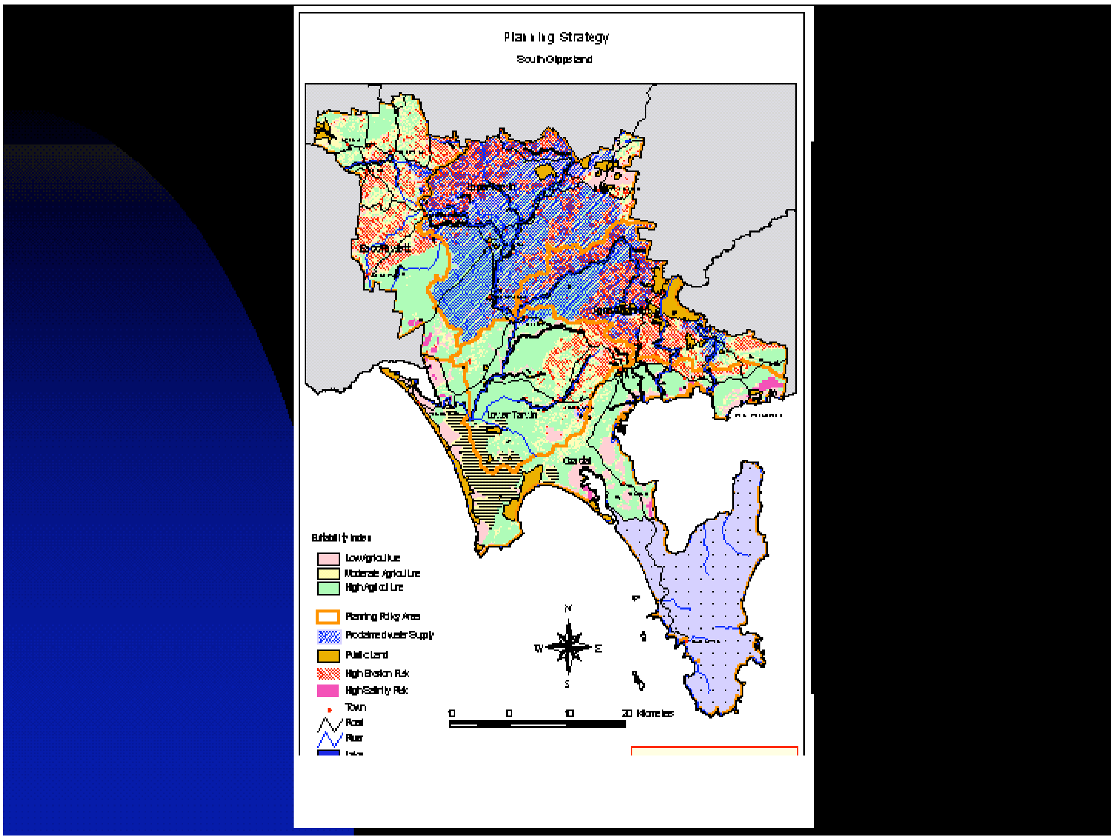

Figure 4 : South Gippsland Planning Strategy
(Source : Sposito, et al 2000)

3.2 Urban Buildability Model

One of the important components of a regional development plan is to identify land that is suitable for urban development. There are many economic, environmental and socioeconomic factors that influence the decision for urban locations.

The assessment of land suitable for urban development is a critical task as this allows for an analysis that identifies opportunities and restrictions for development in the region. A regional development plan is often a multi-objective study that may be attempting to satisfy the needs of an expanding population without impinging on the existing environmental and cultural values of the landscape.

The purpose of this model is to locate areas suitable for urban development that do not impact negatively upon the environment. The decision-making process, when developing an urban expansion plan for a region involves two levels of focus. Firstly, at the broad strategic level, the development location must be placed within the context of the regional economy and landscape. Secondly, at a local level each parcel of land needs to be considered in terms of its suitability for a specific urban land use.

The evaluation of potential location of urban development at a regional level may involve consideration of the following criteria:

> Spatial Framework: The spatial framework of the region in terms of planning and management. This relates to the evaluation of each location's ability to provide services that would strengthen the rural-urban continuum and allow for equitable development across the region. This evaluation involves analysis of potential service areas of the location and can be broadly measured in terms of distances from existing regional service centres and networks
>
> Environmental Sustainability: This relates to evaluation of the location in terms of its effect on the environment and tries to ensure that the urban activities will not damage the long-term sustainability of the environment. This will involve identification of relevant environmental factors and ensuring protection of them in view of environmental sustainability.
>
> Physical Characteristics: This relates to broad physical suitability of the location in terms of urban development. This involves evaluation of soil, landscape and climatic factors considered critical to urban physical development

The location evaluation for specific land use in an urban centre occurs within the framework defined by the regional analysis and may include following criteria.

> Intra-urban Spatial Framework : This relates to the efficiency of the urban structure in providing services within the urban area and is achieved by establishing a suitable networks of service infrastructure and allocating various land uses to suitable locations. This evaluation involves analysis of potential service areas of the location and can be broadly measured in terms of distances from intra-urban service centres and networks and compatibility between neighbouring land usage.
>
> Physical Characteristics : This relates to physical suitability (Land Resource Data Atlas 1985) at a site-specific level. Soil condition and landscape of a site is evaluated for a particular land use.

The model development follows a multi-criteria suitability modelling approach utilising experts to identify important factors and calculate weights for them through the AHP technique.

The model identifies ranges of suitability for urban development across an area. This allows for the optimal areas in terms of planning and management to be identified, as well as areas with poor suitability for urban development that would encounter engineering difficulties and potential impacts to the environment if development were to proceed in these areas (see figures 5, 6,7).

Broad criteria that have been considered in the Urban Buildability model are:

Physical Development Factors: Building Foundation, Septic Foundation, Elevation and aspect of the landscape, Wind, Floodability

Planning and Management Factors: Land Use, Planning Zone, Infrastructure

Environmental Conservation : Agricultural Land, Water bodies, EVC, Environmentally significant landscape

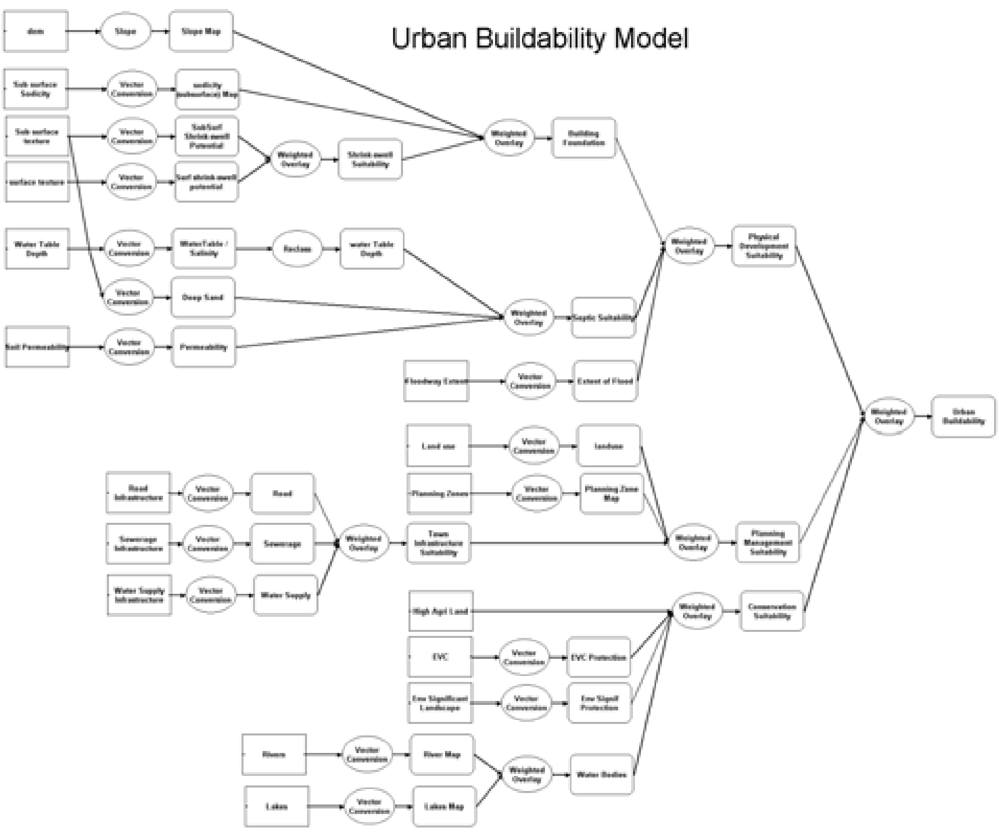

Figure 5 : Simplified Urban Buildability Model
(Source : Hossain 2002)

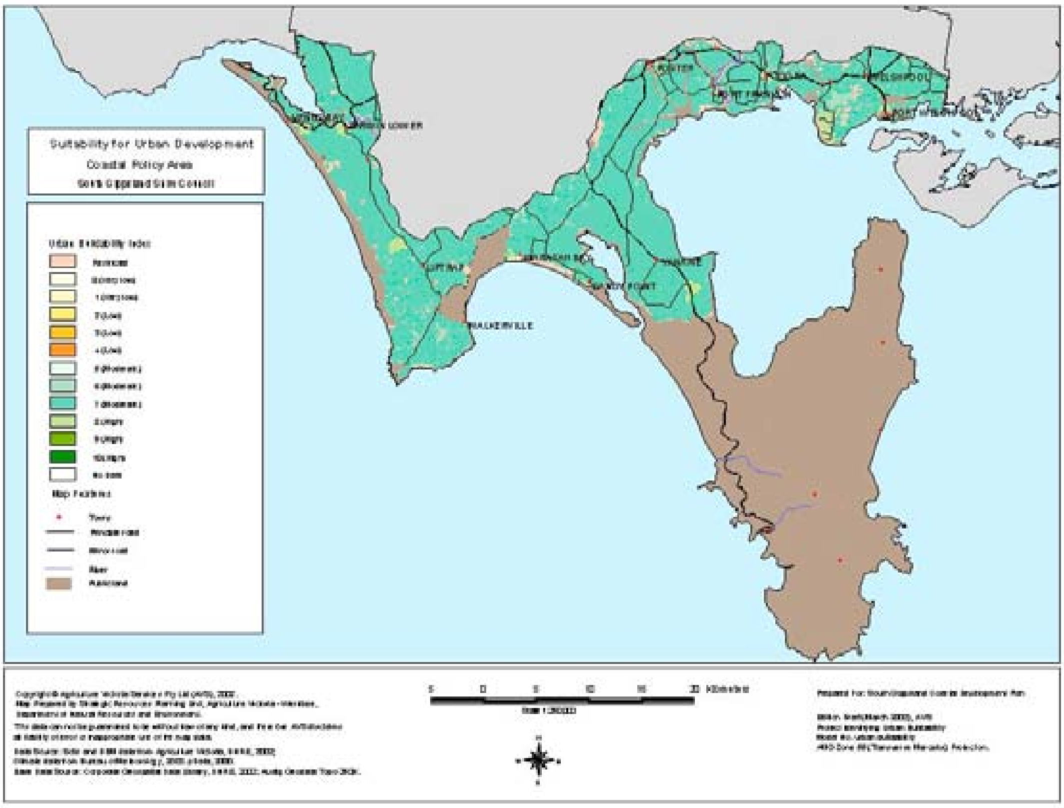

Figure 6 : Regional Urban Buildability
(Source : Sposito, et al 2002a)

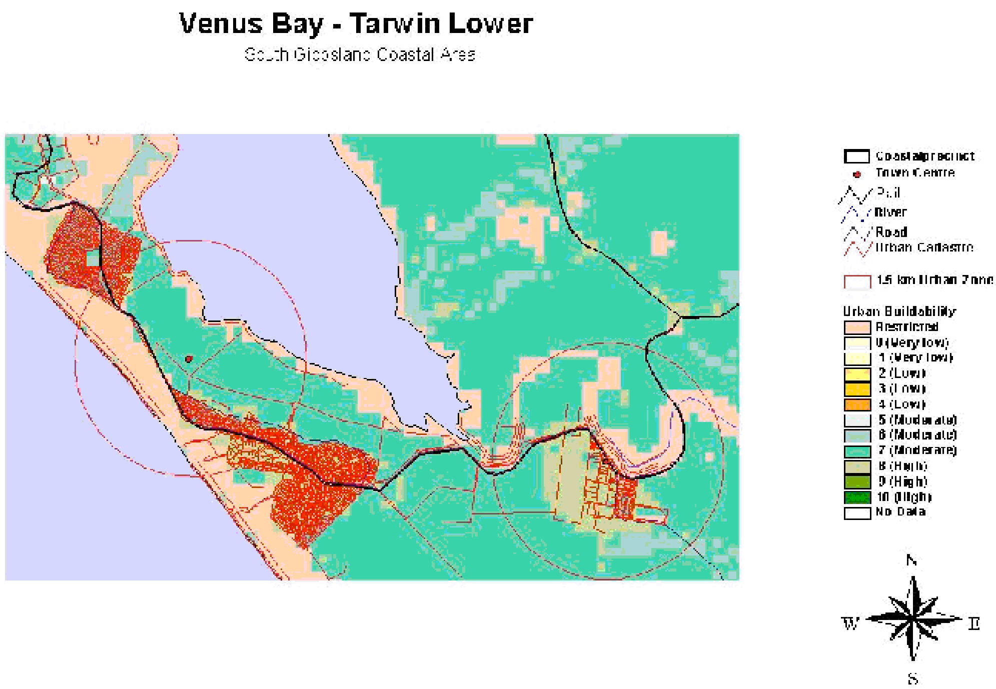

Figure 7 : Town Expansion Suitability
(Source : Sposito, et al 2002a)

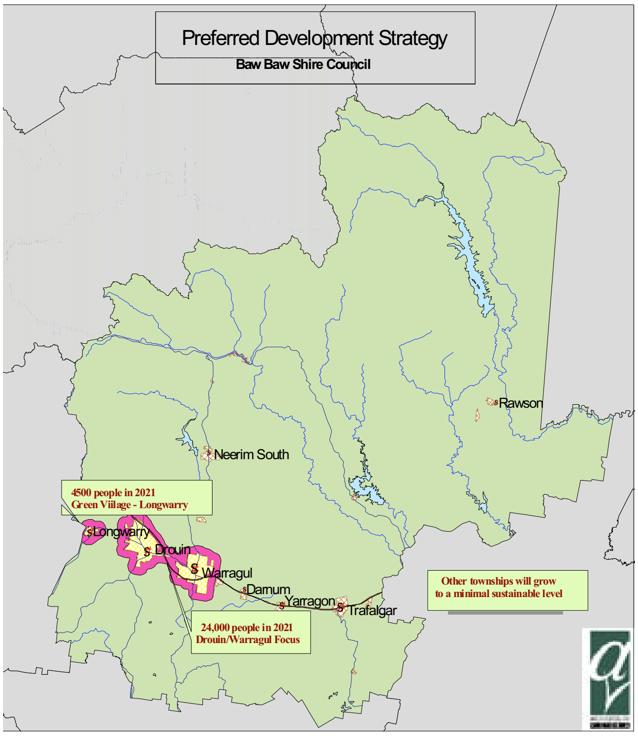

Figure 8 : Baw Baw Shire Urban Development Strategy
(Source : Sposito, et al 2002b)

3.3 Rural Living Model

In addition to agricultural and urban suitability models, several other models were developed including a Rural Living model. This model identifies areas suitable for rural residential living for people who want to live in the rural areas and may be involved in hobby farming.

The following factors were considered by experts for inclusion in the model:

- Lot Size
- Slope
- High Value Land
- Distance to Existing Towns
- Environmental Significance and Impact
- Accessibility
- Dairy Farm

The map below, shows areas that have been identified to be suitable for rural living in the Baw Baw Shire based on the factors listed above.

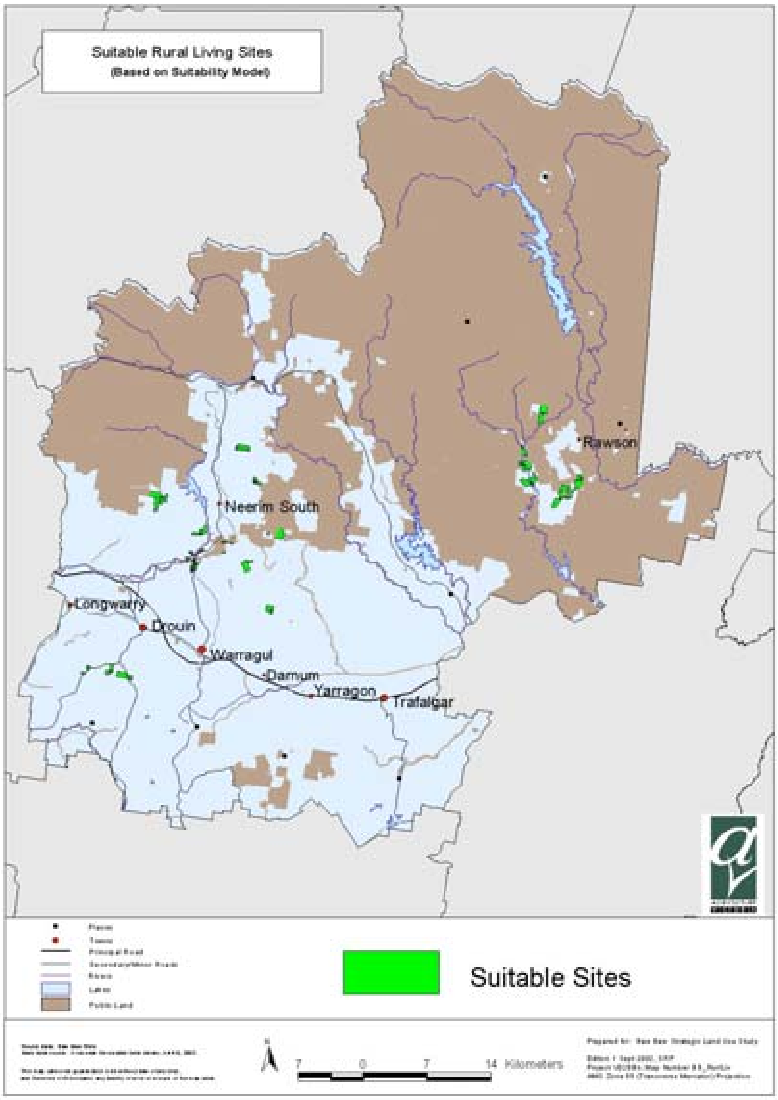

Figure 9 : Rural Living Suitability in Baw Baw Shire
(Source : Sposito, et al 2002b)

4 CONCERNS : UNCERTAINTY

Inaccuracy is endemic within any modelling exercise that is based on data-manipulation. Frequently the available data is of poor quality, barely able to support decision making and prohibitively expensive to repair. But immediate decisions still need to be taken to ensure the best possible planning and management of resources. The challenge is to make effective use of data we have, and in doing so one should be able to estimate the level of uncertainty involved in the modelling process.

Eastman (2001) has outlined the following uncertainty related to land suitability modelling:

- "evidence" - of errors within basic *measurements* of land suitability parameters such as soil characteristics and *spatial* error, such as that arising from the spreading of soil characteristics, measured at points only, across whole parishes based on certain underlying assumptions.

- the “decision set” - uncertainties stemming from the modeling process, for example, how different individual experts’ parameter weights were reconciled in order to derive a single estimate of each parameter’s weight.
- the “relation” - uncertainties around the specification of the model itself due to what was left out of the model or the way criteria were defined.

SRP has recently initiated a research project to examine these three problem areas by measuring errors within the basic data, simulating model-induced “error propagation” and independently scrutinizing how well the land suitability model has replicated real-world phenomena.

5 CONCLUSIONS

The land suitability technique provides a good base for the holistic sustainable approach to strategic land use management planning.

The following diagram shows the land suitability modelling process and indication of potential clients at each level of outputs.

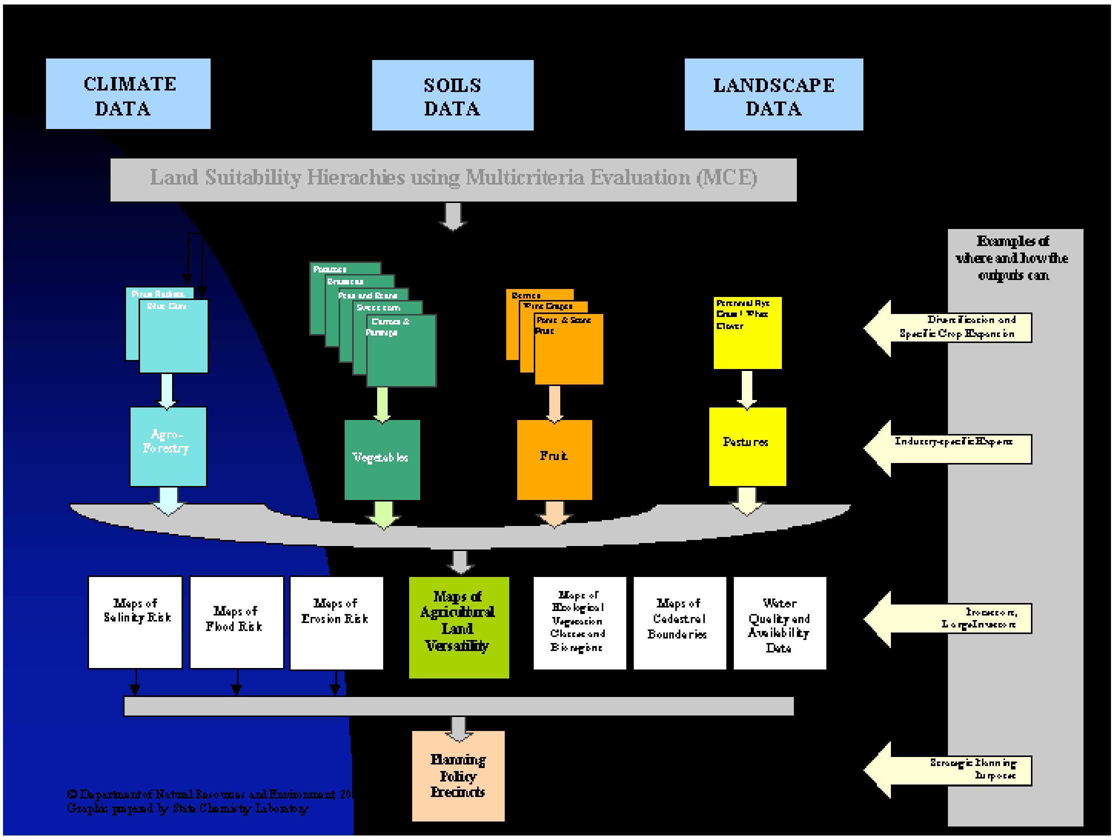

Figure 10: Land Suitability and Potential Clients

(Source : Sposito, et al 2002c)

The Strategic Development Plan has allowed for the development of action plans and the consideration of desirable and undesirable land uses to be represented spatially for local and regional sustainable development. In the case of Local Government, this method provides vital information for upcoming review of municipal strategic statements. The culmination of this work into a regional approach means that the consistency of a region-wide application allows for the whole region to be seen in context.

In a recent project, Agricultural Land Suitability models have been integrated with the Climate Change Model to predict the effect of climate change on agriculture in Victoria (Hood, et al 2002).

This land suitability model is under continuous development. At present, the Strategic Resources Planning team is involved in the further improvement of the models which will allow for the incorporation of financial prospects of commodities and more effective consideration of water availability. This will convert the suitability into a costing exercise, which can weigh environmental outcomes and financial outcomes of land use change.

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