SPATIAL (GIS-BASED) DECISION SUPPORT SYSTEM FOR THE WESTERNPORT REGION

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This paper presents the conceptual design of a spatial decision support system (SDSS) proposed for Victoria's Westernport region that aims for the sustainable and integrated (whole-of-catchment) management of regional natural resources. It is a solution integrating a range of approaches including, GIS technology, a scenario management tool, state-of-art terrestrial and marine models, environmental management strategy evaluation and multi-criteria techniques.

Traditionally, GIS are key to (spatial) data management, but lack problem domain modelling capability. This means additional processing or analytical capabilities are needed to extend functionality for decision making. The Westernport SDSS builds upon a GIS but draws on models and data processing systems and interacts with other parts of an overall information system to support decision-making. This system utilises a number of models that are interlinked through a cascade of their results. Put simply, one set of model results input into the next in a modelling chain. The system will derive a set of socio-economic-environmental measures (performance indicators), such as land use, nutrient and sediment concentration in water (water quality measures), and other relevant indicators for coastal and bay ecosystems. Users will then be able to systematically compare alternative natural resource management plans and strategies in light of multiple and possibly conflicting criteria. By integrating relevant models within a structured framework, the system will promote transparency of policy development and natural resources management.

1. INTRODUCTION

The call for sustainable development is marked by the publication of *Our Common Future* (also known as the Brundtland Report, WCED, 1987) and the subsequent 1992 World Commission on Environment and Development (Earth Summit Rio) sponsored by the United Nations. While the *Brundtland Report* (WCED, 1987) articulates the fundamental concept of sustainable development and the change of politics needed for achieving that, the *Earth Summit* Rio represents the first major manifestation of the popularisation of sustainable development. Since then, an often cited definition of sustainable development states that sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987, p23).

The bold call issued from the Earth Summit to recalibrate institutional mechanisms at global, national and local levels, to promote sustainable development reflected on the policy, visions and development strategies of many countries. In Australia, the first response to that was the development of the National Strategy for Ecologically Sustainable Development (NSESD, 1992[1]), which defines ecologically sustainable development (ESD) as "using, conserving and enhancing the community's resources so that ecological processes, on which life depends, are maintained, and the total quality of life, now and in the future, can be increased".

In retrospect, 18 years since the Earth Summit in Rio, the cooperative global environmental governance regime envisioned is still an institutional incubator (Haque, 1999; Sneddon et al., 2006). While the broad goals were widely embraced, steps towards their implementation are still challenging. Policies and Strategic plans for implementing and monitoring sustainable development at national and local levels are numerous, however these plans have been "unconsolidated" and suffer from a lack of consistency either within or external to governmental channels (Sneddon et al., 2006). A recent study (Lafferty and Meadowcroft, 2000) examines the extent to which sustainable development policies have been achieved in industrialised countries, including Australia, confirms an impression of inaction and uneven implementation among high consumption societies and burgeoning environmental degradation.

Facing this reality, in March 2000, the Premier of the State of Victoria, Australia, convened a Summit of key opinion leaders, called the Growing Victoria Together Summit, to discuss the priorities for Victoria. Out of this summit, a strong view emerged on the importance of medium-term (5–10 years) direction setting by the Victoria Government in the economic, social and environmental spheres. *Growing Victoria Together*[2] aims to balance socio economic and environmental demands in what is termed Ecologically Sustainable Development (ESD) or the "triple bottom line" approach.

Achieving sustainable development and ESD in the State of Victoria is challenging. Successful delivery of ESD means integrating natural resources and human activities into the economy. Natural resources occur within complex biophysical and socioeconomic systems and multiple users/sectors interact strongly and impact cumulatively on these systems. While wealthy industries compete for land, labour and capital, many natural resources, however, fall outside this economy. Groups and industries that value natural resources are often unable to effectively communicate and transmit their values to other groups and industries. This can lead to a situation of unsustainable use, conflict in use and inadequate investment in natural resources. We attempt to manage natural resources through institutions, but the complexity of institutional and jurisdictional arrangements also poses impediments to sound management.

Clearly, for the delivery of ESD we must integrate or coordinate the management of these different users and industry sectors, and explicitly engage natural resources in the economy so that different users can communicate their values effectively, conflicts can be made transparent and resolutions found.

Based on the above, DPI and CSIRO, in collaboration with other Victorian Government agencies and organisations (e.g. Port Phillip and Westernport Catchment Management Authority, Environment Protection Authority, Landcare, Local Councils, Parks Victoria, Department of Sustainability and Environment) are working towards a joint initiative to develop a spatial decision support system (SDSS) for the integrated (whole-of-catchment) and sustainable management of natural resources.

This study will combine GIS technology, a scenario management tool, methods from economics, state-of-art terrestrial and marine ecological models, and multi-criteria technique with a method for multiple-use management strategy evaluation. The linking of smart technologies and new theories from multiple disciplines will be used to generate a SDSS that provides a coordinated approach to policy development and natural resources management, as well supporting the integrated management of multiple uses.

The aim of the project is to develop and demonstrate how such a SDSS can assist the implementation of sustainable policy and management strategies, as well as sustainable policy redevelopment, using Westernport and its Catchment as a case study (see **Figure 1**). The study is hereafter named “The Westernport (WP) Project”.

The Westernport study area comprises 3395 square kilometres in southern Victoria, Australia, containing a large part of the Mornington Peninsula, Frankston, Casey, Cardinia, Bass Coast, Baw Baw and South Gippsland, the Westernport Bay a number of rivers basins and French and Phillip Islands. This region is well-known for its major conservation and environmental values, being recognised as an UNESCO Biosphere. The region contains a rich and diverse ecosystem and its seagrasses, mangroves and salt marshes form part of the internationally listed RAMSAR wetlands for migratory birds. Located within 70 km of Melbourne, the major threats to the region are the residential, commercial and industrial growth of Melbourne’s metropolis expanding within the catchment and port development, land clearing for agriculture and recreational development prejudicial to the present environmental values. Native vegetation has already been cleared from 70-80% of the catchment for agricultural purposes. The Westernport region’s population is forecast to increase from its current level of 195,200 to 280,106 by 2011 and to 370,502 by 2021.

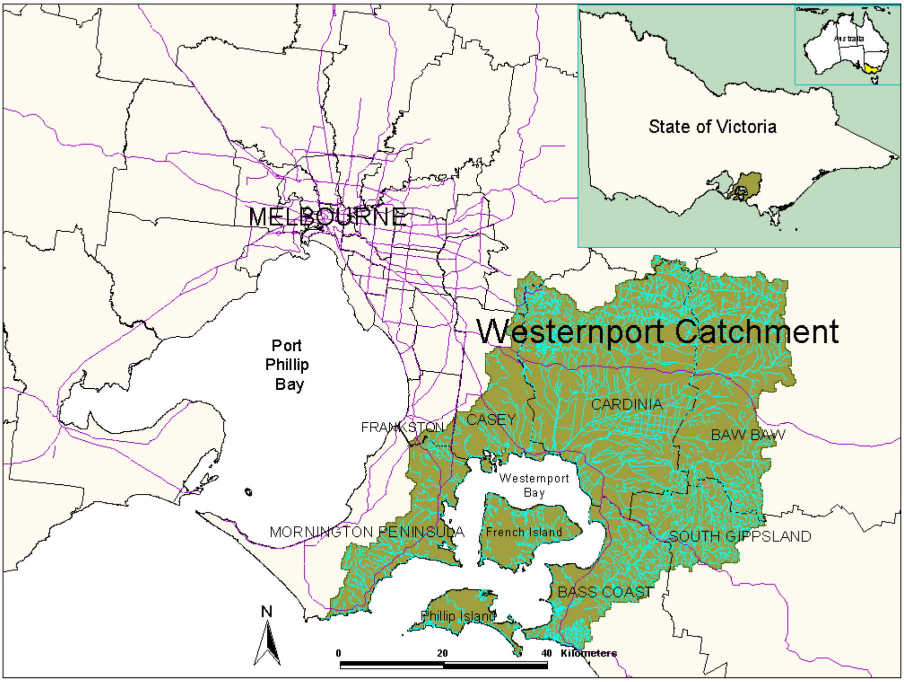

Figure 1 Case Study: The Westernport Region

This project must address policy and management challenges, which include:

- significant commercial and recreational fisheries, and aquaculture;
- significant port activities;
- significant agriculture production;
- a thriving tourism industry;
- high conservation values, including marine parks and reserves;
- strong community concerns regarding sustainability;
- complex institutional arrangements; and
- a rapid increase of Melbourne's urban fringe within the catchment.

The development of the *Westernport Spatial Decision Support System* (WPSDSS) will provide an important opportunity to show how the health of a catchment can be improved by the application of sophisticated decision-making methodologies and science. Critically, it will link closely with existing projects in the region (e.g. The Water Quality Improvement Plan[3]) to avoid duplication and take full advantage of existing work. The WPSDSS will also help to facilitate implementation of the *Port Phillip and Western Port Regional Catchment Strategy 2004–2009*[4] and subsequent strategies. In a broader scope, the project will provide an opportunity to demonstrate how this may be applied to other catchments in Australia where complex decisions require an integrated, scientifically-based approach.

The next section of this paper presents a literature review on (S)DSS and how these link with GIS, followed by a review on the importance of these tools in promoting best practices for natural resources management. Then, the conceptual design of the WPSDSS is presented. The reader should note that this project is still in the scoping phase, hence, most of the discussion will remain on the theoretical level. The paper ends with a discussion and identification of future work.

2. (S)DSS AND GIS

In the late 1960s and early 1970s, few firms and scholars began to develop Decision Support Systems (DSS), which became characterized as interactive computer-based systems that help decision makers utilize data and models to solve ill-defined or ill-structured problem (see Morton, 1971; Alter, 1980; Sprague and Carlson, 1982; Arentze, 1999). Problem structure is related to uncertainties regarding the objectives of decision makers and/or the cause-and-effect relationships of a problem. Ill-defined problems occur when the problem is not well understood and ill-structured problems occur when the problem is understood but possible actions and developments are uncertain. Thus, the decision process is characterized by complexity and open-endedness. The decision-making organization usually begins with little understanding of the decision it faces or the route to its solution, or has only a vague idea of what that solution might be and how it will be evaluated when developed (Arentze, 1999).

Indeed, a computer-based system that integrates data sources with modelling and analytical tools; facilitates development, analysis, and ranking of alternatives and assists in the management of uncertainty can enhance the overall problem comprehension (Mowrer, 2000). Thus, dealing with ill-defined or ill-structured problems is made more efficient by exploring with decision makers the consequence of certain actions, turning a decision problem into a choice problem. DSS allow a structured and systematic approach, by breaking down the problem into a set of dynamic and cyclic actions to produce an effective and transparent problem solving process (Pelizaro, 2005).

SDSS is an important subset of DSS whose fast growth has been facilitated by technical developments and the availability of appropriately inexpensive technologies for manipulating spatial data (Keenan, 1997). Spatial technologies, of which GIS are central, involve data driven software with explicit spatial or geographical dimensions. Data is geo-referenced for storage, manipulated, retrieved and spatially displayed (Batty and Densham, 1996).

While GIS may contain information relevant to a decision, it's usually a general-purpose system not focused on a particular decision class (Keenan, 1997). Indeed, data organisation of decision models is similar to existing GIS hence the increasing interest in GIS software for decision support in natural resources management (e.g. Gunn et al., 1999; Lazzari and Salvaneschi,1999; Booty, et al., 2001; Hill et al., 2004; Oxley et al., 2004; Blaschke, 2006).

GIS lack analytical or modelling capabilities (Nyerges, 1992; Batty, 1994; Batty and Densham, 1996; Longley and Clarke, 1995; Keenan, 1997; Yates and Bishop, 1998; Wegener, 2001; Booty et al., 2001; Geertman, 2002; Yeh and Qiao, 2003) and when applied to natural resources management (NRM), "better data and computers won't lead to improvements and or advances in planning and management" (Keenan, 1997). What is also required is to fully explore the rich information produced from scientific enquiring, monitoring, management analysis and data processing with the use of relevant analytical models.

The path towards understanding dynamic, complex and multi-dimensional issue or problems is better served by the intelligent combination of multiple approaches rather than a single technology or model (see Walker and Lowes, 1997; Lazzari and Salvaneschi ,1999; Oxley et al., 2004; Chen et al., 2005). To facilitate solution development for decision-making it is logical to separate data management from model management and then re-integrate the two in combination with a user interface to form a decision support application framework. This approach fosters inclusion of a variety of modelling techniques; a pre-requisite for an integrated modelling approach. The components of such a framework (illustrated in **Figure 2**) include (Sprague and Watson, 1993):

1. A *Database Management System* that includes tools to support data collection and storage, the management of data for models, and the ability to retrieve data from storage.
2. A *Model Management System* that provides a set of tools and models that is supported by item (1) and produces new information (description, explanation), relevant for the decision-making process. This new information is aligned/designed to management objectives and policy goals; and
3. A *User Interface* supporting the visualisation of the data sets and output from models (current and alternate scenarios) in a form that makes it clear whether management objectives and policy goals are being or are likely to be achieved.

The use and adaptation of GIS to modelling and linking various types of predictive and prescriptive models relevant to an integrated scientific support program is a major research effort (Yates and Bishop, 1998; Wesseling et al., 1996; Raper and Livingstone, 1995; Bennett, 1997;

Hopkins, 1999; Yeh and Qiao, 2003; Oxley et al., 2004). Linkage strategies range from weak to strong coupling.

The coupling of spatial models with GIS can be made in four different manners: isolated applications, loose coupling, tight coupling and full integration (Nyerges, 1992). In loose coupling applications, models are external to GIS offering independent and flexible development and testing advantages. On the other hand, users spend lots of time converting data and moving files between packages. For example, Clarke and Gaydos (1998) have used a loose-coupling approach to integrate cellular automata (CA) and GIS to predict long-term urban growth in San Francisco and Washington/Baltimore.

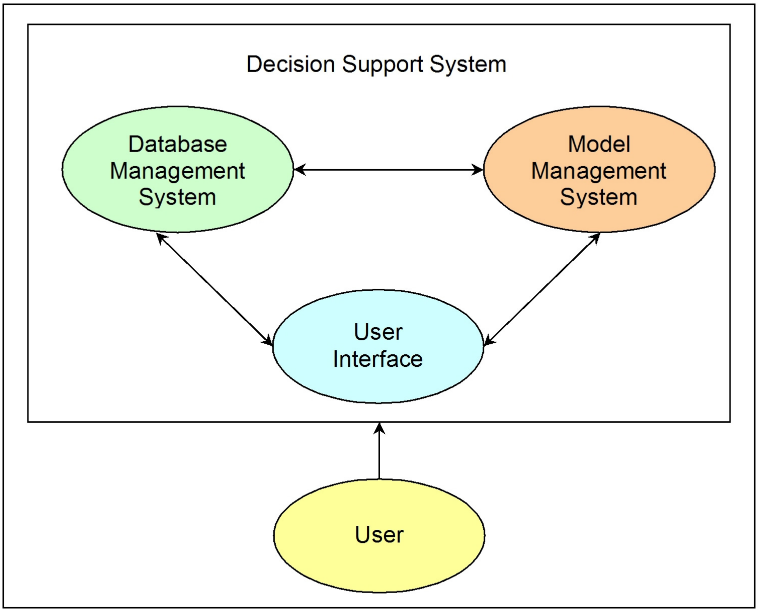

Figure 2 Decision Support Systems Framework

In more tightly coupled systems, GIS users have access to models through software "hooks" and/or built in macro-languages. For instance, *ArcView* GIS package (ESRI Trademark) has its own macro language, Avenue and *MapInfo* (MapInfo Corporation Trademark) provides some functionalities in the form of a library that can be plugged in. *MapInfo* has also its own language (Mapbasic) to add modelling functionalities, which is developed to become increasingly similar to other programming tools, such as Microsoft Visual Basic. Embedding the spatial model into the GIS has the advantage that all functions and data resources of the GIS can be used. Thus, this integration strategy can provide access to a consistent user interface and data structure (Bennett, 1997). For example, ASSESS (A System for Selecting Suitable Sites) is a spatial decision support system that has been used for multi-criteria decision analysis in a policy environment in Australia (Hill et al., 2004). It is written in the Arc Macro Language (AML) within the *ArcInfo* GIS (ESRI trademark).

Despite the efforts to build modelling functions into GIS directly and the suitability of specific GIS packages, it is likely that most numerical models, especially those requiring exhaustive calibration, will need to parallel, rather than to work within, the GIS (Clarke and Gaydos, 1998). For that matter, two or more separately developed software packages can be combined to produce an integrated modelling environment. The component of such an environment ought to include a database management system and a map-based visualisation tool, represented by GIS and a model management system that could be one or more of several systems built to support modelling activities, such as statistical packages (e.g. SAS, SPSS, LIMDEP, SPLUS, etc.), system dynamics packages (e.g. STELLA, VENSIM, EXTEND, TIME e-water) and linear and nonlinear program solvers (e.g. LPSOLVE, CPLEX, etc.) (Yates and Bishop, 1998). Many technical issues can be encountered during the integration of two or more packages (e.g. Oxley et al., 2004), because, in general, these software systems have been developed independently with their own specifications, interfaces, data models and data types. At the very least, advanced computational skills are required to enable communication and sharing of procedures between the different systems (see Raper and Livingstone, 1995; Bennett, 1997; Hopkins, 1999; Yeh and Qiao, 2003).

An example of tightly coupled SDSS is EDYNET (Lazzari and Salvaneschi, 1999), developed for landslide hazard monitoring in the region of Valtellina (Northern Italy). Several monitoring sub-systems check hydro-geological and climate aspects of the site (slope stability, geology, rainfall); the sensors are connected to remote data acquisition units, and their signals are transmitted via radio to a central acquisition system. EDYNET supports the data interpretation and analysis by means of artificial intelligence techniques and spatial representation using a GIS component. The application was developed using Visual Basic and Prolog2 programming language, *MapInfo* GIS (ESRI) and MS Access (database). Basically, Visual Basic uses Prolog2 as a DLL (Dynamic Link Library), while sharing data with MapInfo via OLE (Object Linking and Embedding). Another example is the "sustainable river basin land use management" (Chen *et al.*, 2005), developed by using the Vensim, MS Excel, ArcView, and Visual Basic software.

The tightly coupling of system dynamics (SD) packages (e.g. STELLA version 7.0.3 or higher, VENSIM, EXTEND) and GIS is being highly used to model a variety of physical and natural processes where the main interest is in the space-time interaction (e.g. environmental/water resources processes, natural resources management, climate change, ecosystem modelling, etc.). Given the strength of system dynamics (SD) in representing temporal processes with restricted spatial modelling capabilities, and the competency of GIS for spatial modelling, attempts have been made to integrate SD with GIS to model "spatial dynamic systems" (SSD) (Ahmad and Simonovic, 2004). The main strength of the SSD approach is a two-way exchange of data and information between SD and GIS, providing feedback in space and time. Technically, this is only possible when the GIS and SD packages in question support dynamic data exchange functionality (DDE - replaced with OLE, COM, OLE Automation or NetDDE). For example, Ahmad and Simonovic (2004) developed a SDSS for overland flooding using Stella for the system dynamic modelling and GIS ArcView for the geographic data processing and visualisation. There is dynamic data exchange between the SD model and GIS to simulate the flood propagation and to calculate any spatial and temporal variation of flood damage and area flooded.

One limitation of the tightly coupling approach is its restricted portability, i.e. it can only be used with the GIS package for which the application is developed.

A more radical approach to building a SDSS is to start from a modelling perspective, where only the GIS functionalities required by the subroutines within the model are added. Hence, rather than embedding less elaborate models within a comprehensive GIS, it is possible to embed a limited range of GIS functions within a more elaborate modelling framework. The main application is usually developed from scratch using a particular programming language environment (e.g. C++, C, Java, etc. programming language environments) and OCX type applets or ActiveX controls used to provide some element of GIS functionality. A number of GIS related tools of this sort exist (the GIS ActiveX Controls), for example SylvanMaps (by Sylvan Ascet) or MapObjects (by ESRI), the market leader in GIS software. As Wegener (2001) noticed before, the benefits of this strategy are substantial as one gets rid of all the overhead and limitations of a particular general-purpose GIS software package.

An example of full-integration is the commercial SDSS shell, RAISON (Regional Analysis by Intelligent Systems ON microcomputers), which has evolved over the past decade at the National Water Research Institute of Environment, Canada (Booty, et al., 2001). The promise held by this "environmental decision support system" is that by having a modular framework such as that used in the RAISON DSS, the components required for a particular application can be easily added or modified. By providing the user with a simple development language and libraries of special development functions, the system can easily be modified to fit a wide range of applications. The system consists of the following modules:

I. database: Microsoft Access 2.0 as standard;
II. spreadsheet;
III. GIS: handling vector and raster maps, and support a number of map projection;
IV. Models: can be incorporated in the system in different ways (for an example see Lam et al., 2002);
V. Uncertainties Analysis;
VI. Neural network;
VII. Expert System: rule-based system with fuzzy logic;
VIII. Optimisation: linear programming and genetic algorithm methods are available;
IX. Visualisation: graphs, maps and tabular functions are available or can be customized within the system.

Other examples of full integrated SDSS can be found in Oxley, et al. (2004) and Pelizaro (2005).

There is no strong evidence in the literature to suggest which of the strategies to follow. The choice might very well depend on ad hoc trials, system's requirements, developer skills and/or preferences, and trade offs between budget and deadline.

3. HOW (S)DSS CAN BE USED IN NATURAL RESOURCE MANAGEMENT

Sustainable NRM requires a rethinking of how groups negotiate and organise natural resource use (Long and Villareal, 1994; Strigl, 2003; Rist et al., 2006). NRM is dependent on the informed actions of individual users and managers of the multiple resources. The growing recognition of the comprehensive linkages between natural (ecological and physical), economic and human (socio-political-institutional) subsystems makes the sustainable management of environmental systems more complex.

Legislative and societal expectations demand managers make decisions based on a rigorous, systematic consideration of alternatives and implications (Walker and Johnson, 1996; Gunn et al., 1999). Objectives, policy instruments and values of different groups vary and there is often an unequal distribution of power, leading to conflicts that hinder sustainable development (Berger, 2003). Therefore, we must understand how these can be transformed into strategic management actions, in specific situations of multiple and possibly conflicting objectives. To deliver decision-making to this standard, methods must integrate scientific understanding with an effective means of collating, interpreting, and using this understanding.

The variety of issues and problems requiring decisions by public or private entities gives rise to a multiplicity of solutions in terms of methodologies and combination of appropriate – problem specific – tools. DSS for NRM is designed to underpin cutting-edge decision problems and maximise effectiveness of environmental management objectives. These tools usually consist of various coupled environmental and socio-economic models, database and assessment tools that are integrated under a graphical user interface (GUI) and often supported by a GIS. The spatial dimension is very important as it promotes data and model integration through a common spatial reference and makes the interface more intuitive. For these reasons, a DSS often becomes a SDSS, by integrating spatial functionalities or coupling with existing GIS tools (Matthies et al., 2005).

SDSS help achieve sustainable natural resources management when they are well-designed and become useful tools for decision-makers, "allowing more effective and collective use of information in addressing complex and often poorly structured questions" (Walker and Lowes, 1997). In fact, it has been argued that effective practice of ecosystem management is not possible without the aid of adequately powerful SDSS (Rauscher, 1995).

In some cases (e.g. Fletcher, 1998; Ahmad and Simonovic, 2004), SDSS are needed to manage resource use and exploitation (operational level). In other cases, they support strategic planning, in policy-making and planning for which scenario analysis and simulation tools are particularly helpful (e.g. Lam et al. 1994; White and Engelen, 1997; White and Engelen, 2000; White et al., 2000; Chen et al., 2005). For instance, decisions about ecosystem rehabilitation or other material flow improvement in the field of natural resources management are societal decisions. Management objectives describe the desired state (or future scenarios), which should be achieved to meet legislative or other goals. The decision maker can interact with the system and compare the current state/present situation with the desired (projected) state given by the management objectives (e.g. Pelizaro, 2005). Several measures can be derived to analyse how to achieve the objectives (indicators). Projected climate, agro-economic and/or demographic changes have to be considered as important influences. Alternatively, SDSS could be used to assess the impact of certain management decisions (e.g. expansion of forestry activities in a certain region) or climate change impact on the environment (e.g. Solecki and Oliveri, 2004). In the case of new management decisions, a scenario representing future developments/changes can be assessed and compared against the current situation and/or against sustainable measures/targets (Pelizaro, 2005). In the case of climate change, environmental models can predict the impact, given different biophysical conditions.

4. WPSDSS CONCEPTUAL DESIGN

Based on the theoretical background presented in Section 2, the conceptual model shown in **Figure 3** has been proposed for the WPSDSS system's further development.

Viewed at a high level the WPSDSS is as a GIS-scenario-based decision support system. The GIS-based user interface allows the user to easily and graphically compose alternative scenarios to perform *what-if* analysis. Because a map-based user interface and graphical user interface are essential, our effort will be in using either strong coupling with GIS or the fully-integrated approach. The final choice however will depend on the limitations and potentials of models and tools integrated under this framework.

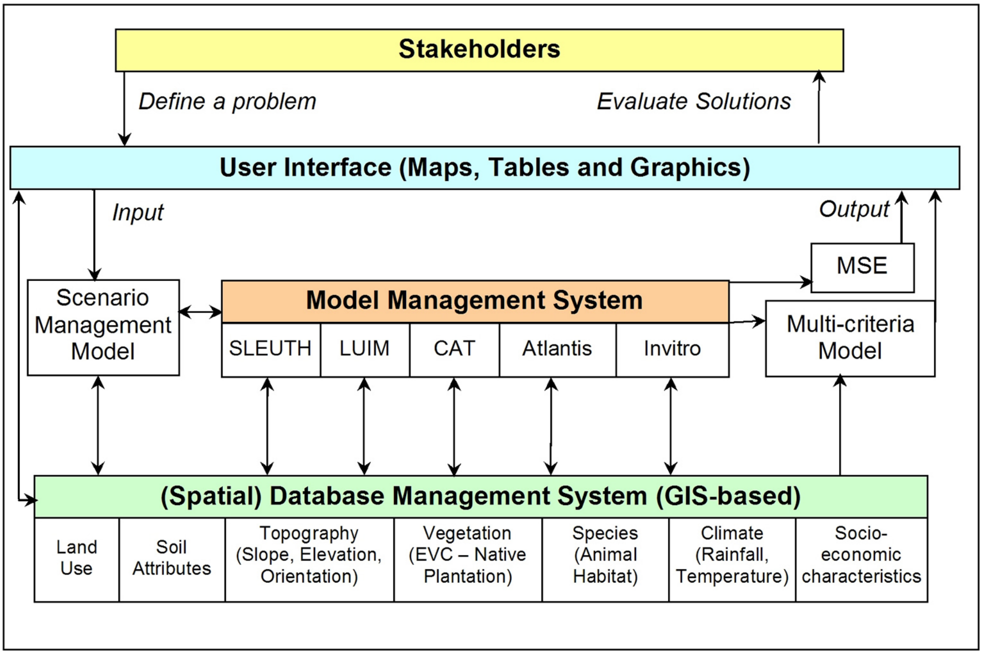

Figure 3 Westernport Spatial Decision Support System Framework

A significant capability of the WPSDSS is the analytical capability within the *Model Management System* (MMS), shown in **Figure 3**. The MMS allows the user to simulate changes in the environment or in any other influencing factor (objects and attributes). The database layer provides input data for the models. Once models run, the outputs can be stored and visualised in the form of tables, graphs and maps, via the user interface. For planning purposes, the ability to dynamically change information, forecast and perform sensitivity analysis is essential.

The MMS consists of an integrated modelling environment with a range of models, where each model will simulate a particular environmental subsystem (e.g. land use development, soil attributes, water catchment, coastal impacts, etc). A particular model output will contribute as an input to the next model in order to capture cause/effect relationships (interactions) between the environmental subsystems being simulated. In other words, the WPSDSS will be designed to utilise a set of models and a cascade of their results. One set of model results will be utilised as the input for a next set. Note that system's capabilities are likely to change depending on further stakeholder involvement and clarification of system's specification.

The choice on the particular models to be combined under the WPSDSS framework is still being investigated. **Figure 3** shows a list of the proposed models. *Sleuth*[5] (Clarke et al., 1996) is a probabilistic cellular automaton (CA) land use/land cover simulation model able to depict urban expansion into the landscape via urban growth. *Land Use Impact Model* (LUIM) maps likely mismatches between land use and land capabilities and helps natural resource managers understand the vulnerability of soil resources and areas at risk of soil degradation (MacEwan et al., 2004). *Catchment Analysis Tool* (CAT) is a catchment model capable of simulating catchment behaviour using biophysical information such as topography, weather, land use and hydrology at a range of scales (Weeks et al., 2005). This tool assesses the impact of change from a range of factors including landscape intervention/land use on stream flow, water quality and groundwater. *Atlantis* (Savina et al., 2005) supports the assessment of marine and coastal habitats for supporting multiple services such as biodiversity, conservation, recreation and commercial use. *Invitro* (McDonald et al., 2005) has a similar purpose to Atlantis, however it is a more sophisticated, spatially explicit agent-based, framework. The *Management Strategy Evaluation* (MSE, McDonald et al., 2005) traces the impact of a particular management strategy or institution on the actions of sector firms/agencies, the effect of these on the natural environment and impact on (pre-defined) performance indicators and measures.

Hence, the system will operate in the following way. First, the GIS-scenario-based management tool will allow the user to easily frame scenarios of changes in land use/land cover (as consequence of a new or existent policy enforcement, management strategy, or landscape intervention for a desired impact) that will feed models to enable the assessment of the socio, economic and environmental impacts on land, catchment, estuary and the bay.

Alternative to user constructed scenario projections, terrestrial models within the framework, like *Sleuth* (Clarke et al., 1996), can forecast the evolution of urban growth and land cover pattern. These predictions of future land cover can then be fed into the same integrated modelling framework as before. The whole modelling process in the context of the WP is important for a number of natural resources conservation and restoration goals, including water catchment analysis, targeting areas for restoration, assessing the impacts of possible restoration and mitigation scenarios, and determining the vulnerabilities of various resource lands to future land conversion.

The general process described above is supported by a number of component models. Having the current (status quo) or future (projection) scenarios, soil degradation processes can be assessed (LUIM – MacEwan et al., 2004). The likelihood that soil will be degraded is a product of the soil's inherent susceptibility to degradation and the imposed land use and associated practices.

Catchment models (CAT) will predict the impact of land use and land use change (intervention) on recharge, lateral and stream flows, water yield, salt and nutrients loads and some threats to biodiversity. It is a detailed process based model complete with feedbacks that has a recharge component (climate and land-use driven) that connects to a multi-layer aquifer ground-water system model. The CAT in itself is an example of a tightly coupled model system (Weeks et al., 2005; Wilson and Lowe, 2003).

The marine models (e.g. Atlantis and Invitro - Savina et al., 2005; McDonald et al., 2005) use stream flow and water quality (nutrient and sediment concentration) forecasted by the catchment models, and other terrestrial inputs (such as temperature) to predict the impact on the marine system. These track the nutrient flow through the main biological and detritus groups in marine ecosystems. Considering water movements and sediments in the bay, and bathymetry (particularly the distinction between channels and tidal flats), the marine models will simulate the nutrient flow of temperature marine ecosystems. The outputs of the model consist of deterministic time series for each component modelled in the system and assessment of marine and coastal habitats for supporting biodiversity, conservation, recreation and commercial use.

The *Management Strategy Evaluation* (MSE) deals with the many objectives and uncertainties of prediction. It assesses different management and policy options, and makes their associated tradeoffs clear. The computer program used for MSE traces the impact of a particular management strategy or institution on the actions of sector firms or agencies, their effect on the natural environment and impact on performance indicators and measures. In so doing, MSE tracks details in respect to sector response to regulatory and legal actions, sector performance, the natural system's response to sector-specific actions and important random or periodic events, and any strategy-mandated adjustments by managers as a result of sector and/or system response.

On the other hand, a multi-criteria analysis (MCA) model will guide users through conflicting decision situations and choose among alternative scenarios. MCA allows inter-criteria trade-offs, which is useful in investigating different plans/strategies in light of multiple and conflicting priorities (Voogd, 1983). The purpose of the tool is to structure and combine the different assessments to be taken into account in decision-making, whereby decision-making is made up of multiple choices and the treatment given to each of the choices condition the final decision to a large extent. There are several methods of multi-criteria analysis that cover a wide range of distinct approaches. The method applied in the development of the MCA model will be determined after careful examination of the robustness of the method in relation to the nature of the set of criteria under consideration.

As any (S)DSS, the WPSDSS is strongly dependent on data input. Spatial (see **Figures 4, 5, 6,** and 7) and non-spatial data coming from different sources provides data for modelling. The Database Management System (DBMS) involves the development and execution of architectures, practices and procedures that properly manage the full data lifecycle. Topics related to data architecture, data movement, data sharing, data modelling, data quality assurance, data security and meta-data management (data repositories, and their management) will be properly addressed during DBMS development/implementation. A detailed description of the DBMS development and management goes beyond the scope of this paper. It is suffice to say that this component will control the organisation, storage and retrieval of the data, ensuring data security, persistency, integrity, consistency, correctness, completeness and relevance. In other words, the DBMS will supply input data for the models. Once models run, the outputs can be stored and visualised in tables, graphs and maps, via the *user interface*. For planning, the ability to dynamically change information, forecast and perform sensitivity analysis is essential.

As suggested before, in the long term, tools and models will be adjusted and integrated to become an application package, the WPSDSS. In that case, models will communicate via a spatial database (GIS component), allowing intermediate data storage. This allows modelling routines to automatically extract the relevant data, without user intervention. The user will only intervene in the system to control the decision process and not to conduct the basic operations needed for data transformation and modelling interchange. This makes it easier to have WPSDSS implemented and operational in any of the sites of interest.

5. DISCUSSION AND FUTURE DEVELOPMENT

The WPSDSS is in the initial stage of development with the focus on engaging stakeholders and testing proposed functional alignment with business needs. So far it has been conceptually designed, and simplified versions of proposed models have been prototyped using available data. This first stage focuses on data preparation and models validation rather than system integration.

Although at this stage the models can be used to support planning and management strategy development in the region (including the Port Phillip and Western Port Regional Catchment Strategy) the DPI/CSIRO development team will operate the system as the approach requires more expertise than the lay user possesses. This will guarantee models have the appropriate support (model calibration and validation) and produce reliable results that can be treated seriously by decision makers, planners and other stakeholders. The development team needs to evaluate and pay close attention to the outputs of the models to observe model behaviour and suitability and thereby develop and understand associated confidence limits.

The choice on the deployment environment/technology and strategy to coupling models and tools will depend on evolving system requirements specifications with stakeholders, ad hoc trials, developer skills and preferences, and trade offs between budget and deadline. We can anticipate however, that re-using and applying models to provide management and policy support is not a trivial issue. From experience gained in previous scientific research, we foresee challenging ontological and technical issues evolving when integrating different models. For instance, it may not be possible to simply re-use research models for policy and management purposes, given the probable mismatch between model formulations and the needs of management strategies and policy questions. Our experience (and others too, see Oxley *et al.*, 2005) in building SDSS suggests that rebuilding the models in a single language and unified system to simplify problems of models communication, data flow and data management, will allow a fully-integrated, more efficient and tailored to the needs of policy questions SDSS.

Nevertheless, further research and application to real situations are required to advance beyond the conceptual design of the proposed system.

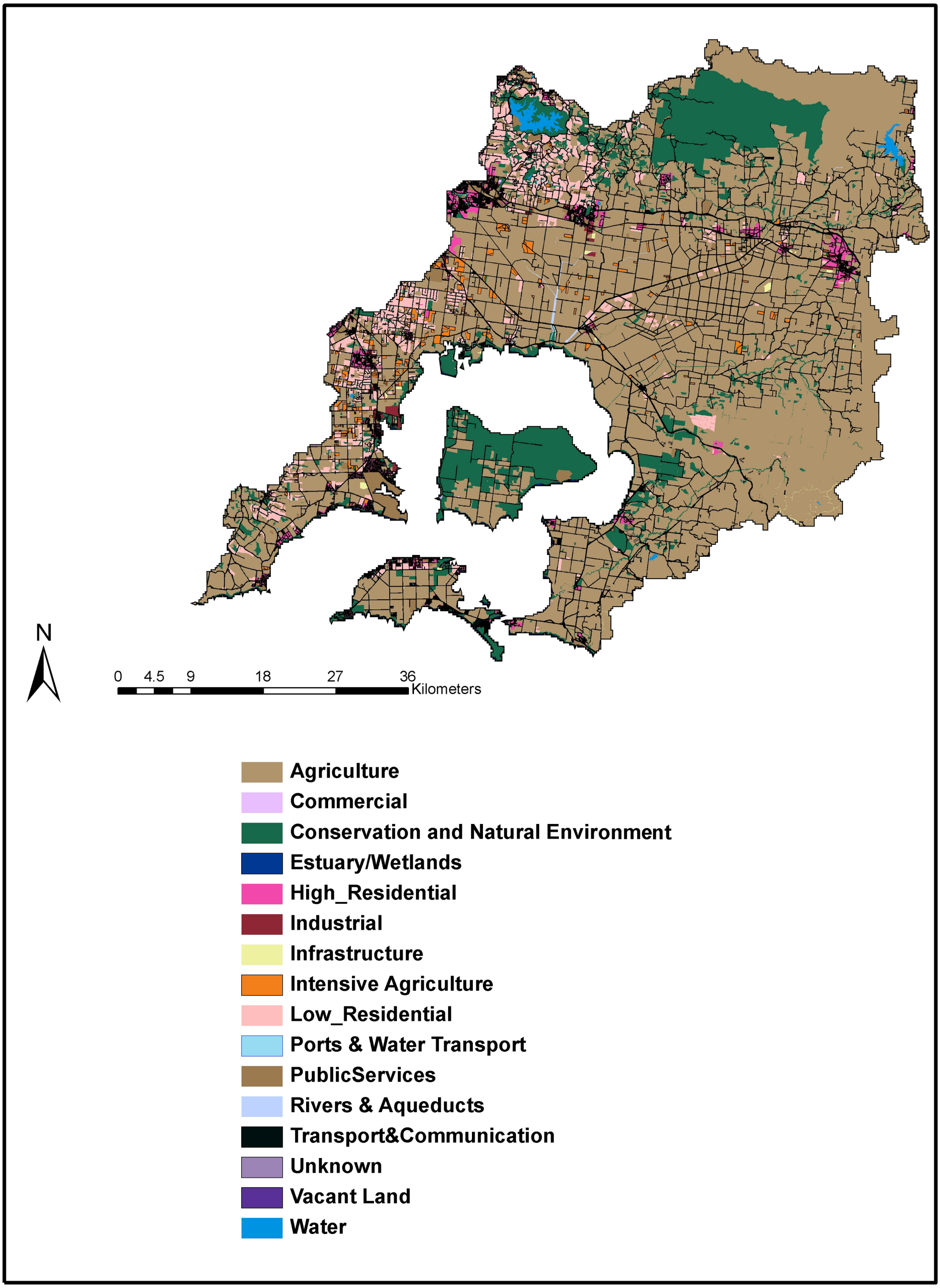

Figure 4 Current Land Use in the Westernport Region

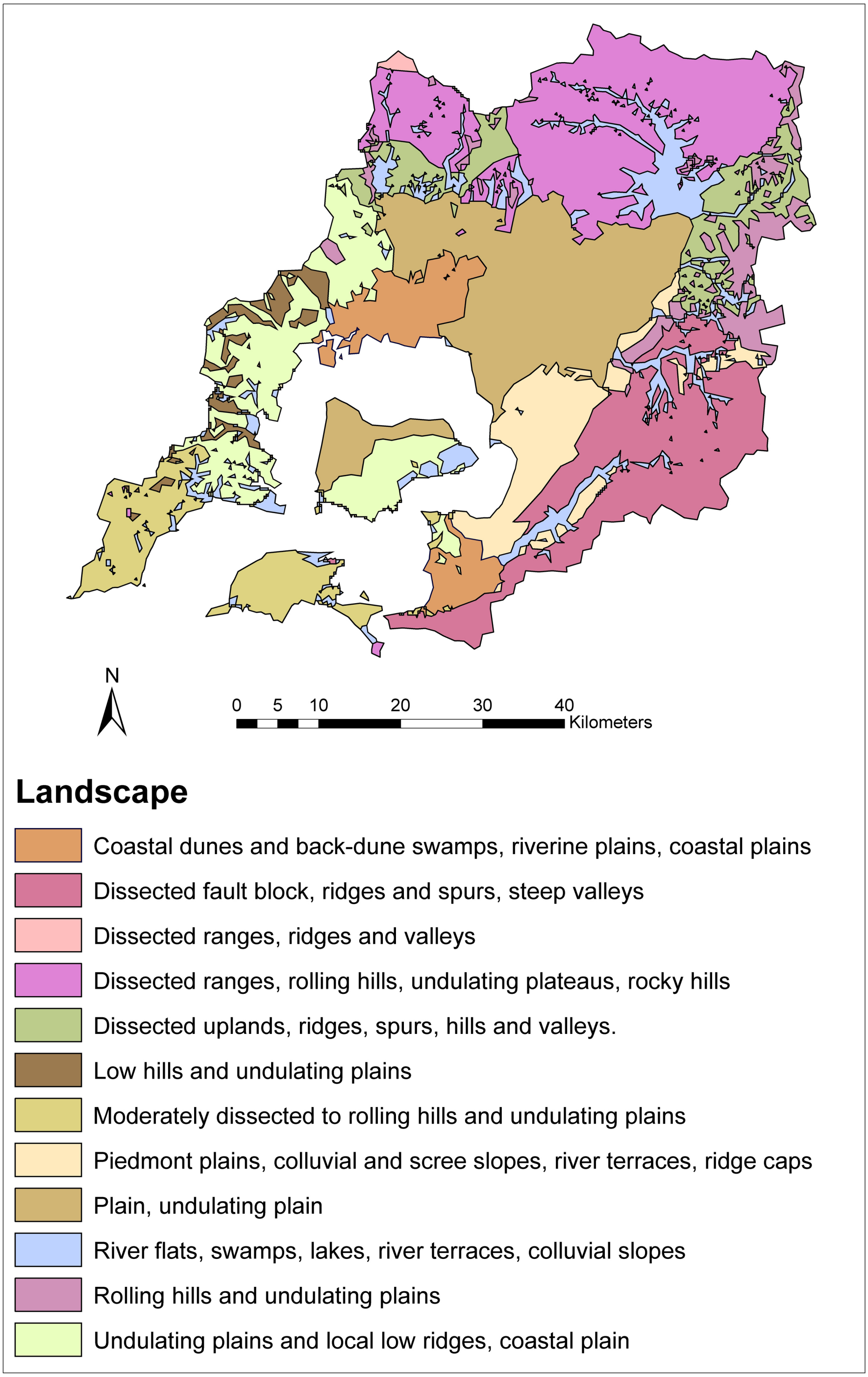

Figure 5 Current Landscape in the Westernport Region

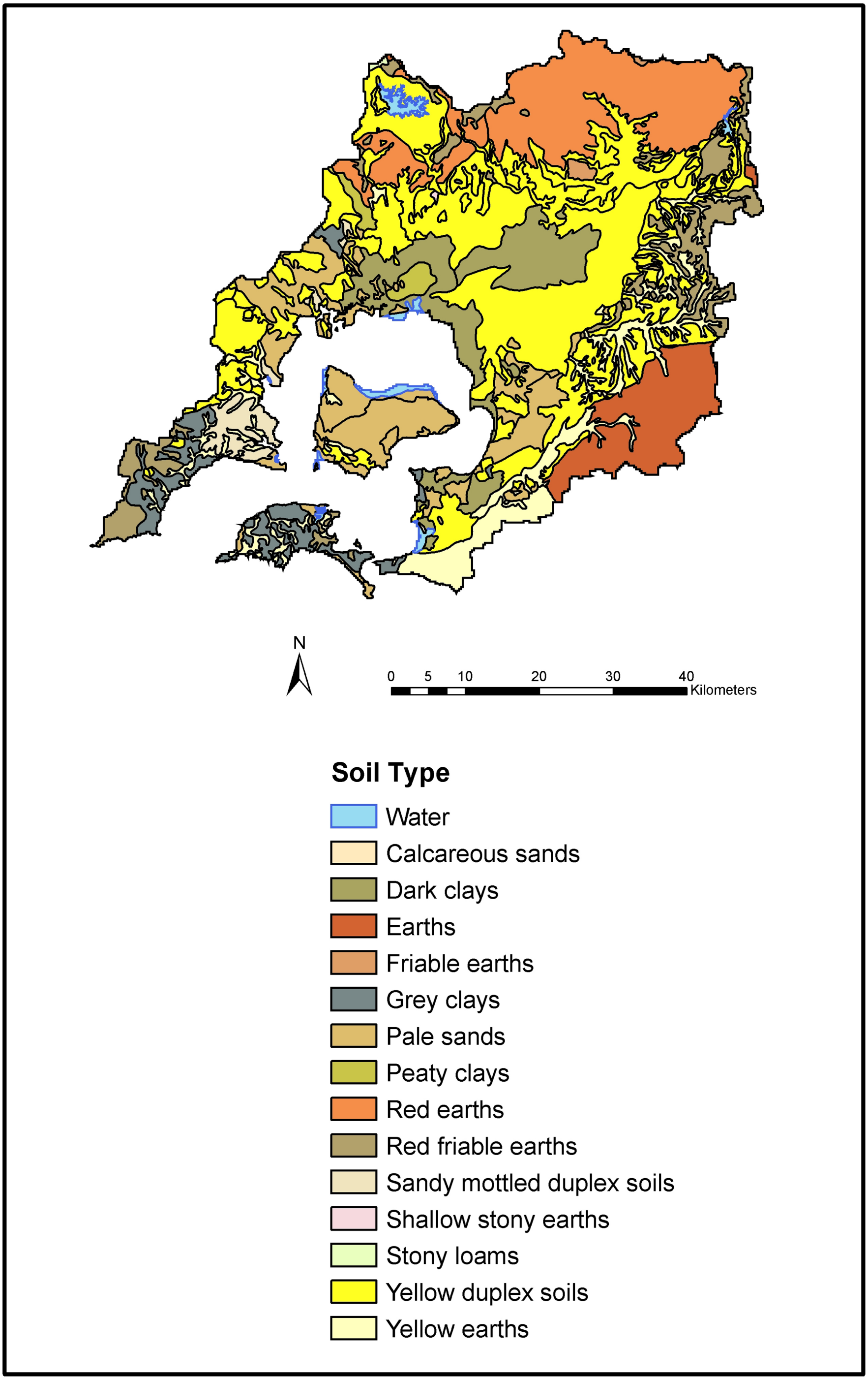

Figure 6 Type of Soils in the Westernport Region

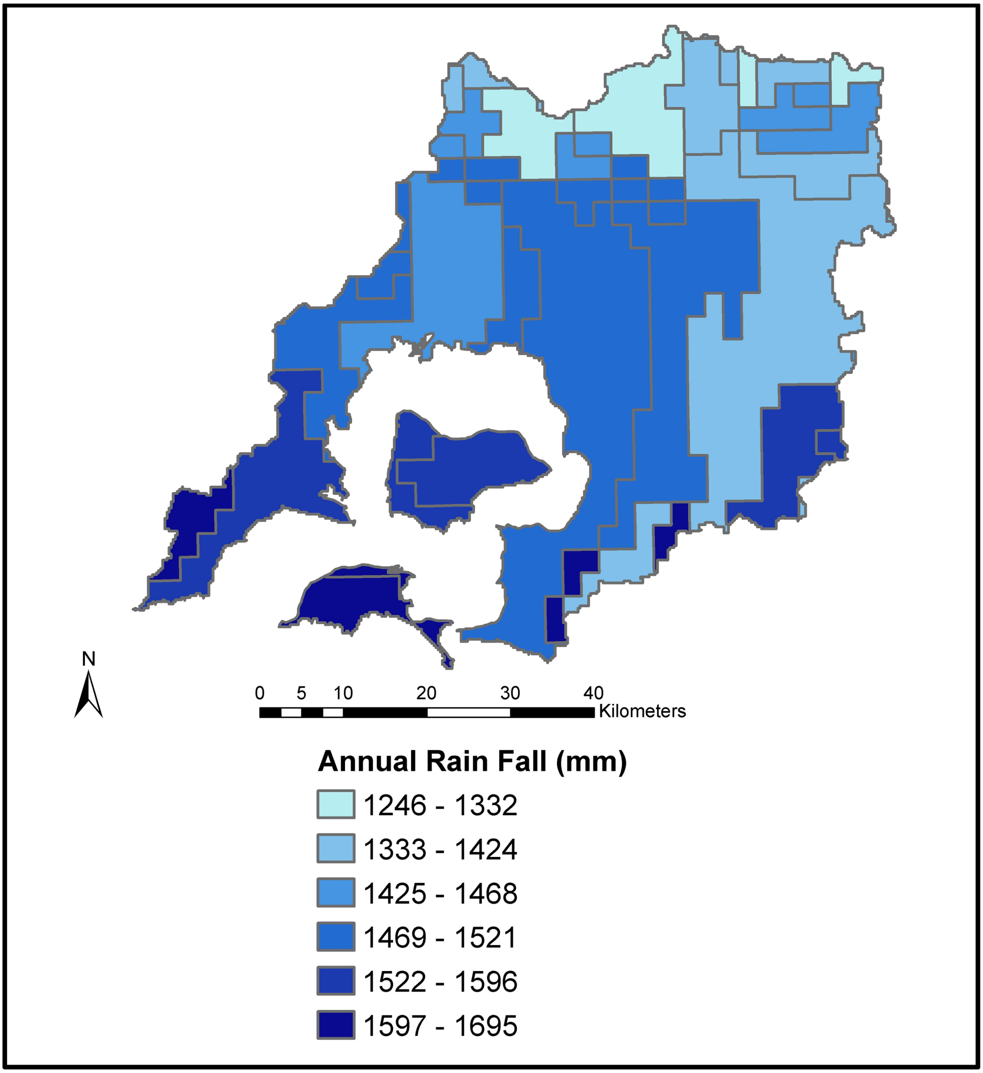

Figure 7 Rainfall in the Westernport Region

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ENDNOTES

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3 http://www.epa.wa.gov.au/template.asp?ID=47&area=CCI&Cat=Water+Quality+Improvement+Plan

4 http://www.ppwcma.vic.gov.au/publications_plans.htm

5 For more information on SLEUTH refer to http://www.ncgia.ucsb.edu/projects/gig/.

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