

Advanced land use modelling and land suitability ranking using GIS

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Abstract: The paradigm of sustainable development has now been present in mainstream planning practice for a number of years. For the traditional modelling disciplines in all fields of planning, the new way of thinking is prevalent in the ever increasing requirements to integrate modelling platforms. Traditional models (i.e. land use, transport, water) are faced with ever more complex and demanding data formats from different sources. Data exchange interfaces are causing significant barriers for the requirements of integration, particularly in terms of the increasing demand to incorporate spatial dataset formats. In addition, the integration paradigm requires that the modelling disciplines integrate new information that comes from environmental monitoring and carrying capacity analysis. New innovative system approaches are required to provide interoperable tools that are suitable to integrate these tasks, to ensure data consistency, and to avoid redundancies. At the same time, Geographic Information Science has evolved to deliver the much needed framework for the implementation of these systems. This paper describes the concept for integrated land use analysis at a territorial authority in New Zealand. It shows how the local land use modelling has been implemented in a GIS environment. It also looks at the various uses of GIS data within local government, and the added value that planning support systems can help to extract from existing data. The framework for land use modelling presented here suggests an innovative way for integrating other modelling disciplines with land use modelling. It enhances the platform by a set of indicators that integrate the social, economic, and environmental planning objectives from existing frameworks. A traditional GIS method for land use analysis – land suitability ranking – is used to feed these indicators fed back into the land use model. Using this method for building land use scenarios has also advantages in terms of consistency and transparency. The dynamic exchange of land use modelling data also allows performance monitoring to be conducted within the same system, thus reducing data redundancy and resource needs.

Key Words: Land use, GIS, land suitability ranking, model

1 Introduction

There is increasing awareness within the land use modelling discipline that more integration between models is required, both in terms of reflecting current best planning practice and to give effect to sustainable development objectives within the

models. However, traditional linked model approaches – which are by and large representative for most local government organisations in New Zealand - are unsuitable to efficiently serve these requirements. The single models are inextricably linked to specific software architectures and to the divisional configuration of the organisation. The outputs are often limited to some very specific measures like cost-benefit or economic performance indicators [1]. Moreover, the definition of scenarios plays a crucial role but is not necessarily a traceable process. It often simply depends on how the modeller translates “soft” planning objectives into quantifiable model parameters.

When looking at the nature of the data most models are using it becomes clear that spatial information is at the base of the modelling process. Across disciplines, planning models make use of spatial information that is either part of a GIS or a result of a GIS analysis process. As GIS technology evolves, many models integrate graphical user interfaces, some GIS functionality, or provide interfaces for working with GIS.

From an integrated planning point of view, these additions to traditional modelling packages are insufficient. The challenge to progress the modelling disciplines into the integrative world of GIS lies in the establishment of frameworks that comprehensively reflect the relationships between economic, social, and environmental activities of the natural and built environment. Indicators to measure these relationships have long been stated within statutory and strategic planning documents, and GIS applications exist that analyse model outputs to calculate these indicators and monitor progress. The value of the integrated framework becomes even more relevant when looking at the potential synergies of having dynamic modelling outputs available within the performance monitoring processes.

The purpose of this paper is to describe the design of a framework that meets these requirements, illustrated through the planning processes at a New Zealand local authority. It focuses on the implementation of a land use modelling component within a corporate GIS environment, highlighting the potential synergies, but also critically analysing the inherent challenges and risks. It also incorporates a transparent methodology for scenario building through a GIS-based land suitability ranking, integrated within the modelling framework.

2 Integrated land use analysis

The author of this paper has been employed as a transport planner and integrated planning analyst at a New Zealand Council for a number of years. The concept for integrated land use analysis presented here draws from this experience. At the same time, it is representative for similar developments in other government organisations as well.

The Council referred to is operating a number of modelling applications in different divisions of the organisation (Transport and Water Services, Policy and Planning, Environmental and Financial Services), mostly based on spreadsheet approaches or on specialist software packages designed for a single function. At the same time, the Council has a “Spatial Information Systems” group that serves all of the divisions, and modellers and GIS experts are exchanging ideas in a Model User Group. As ex-

plained above, there is a variety of workflows between GIS and modelling that could be greatly improved by integrating modelling applications into the corporate GIS system. Previously, these workflows were relying on manual data requests and the proper functioning of interfaces, which is prone to errors and inefficient. Figure 1 shows what processes relevant for planning would benefit from a dynamic integration of their outputs in a geodatabaseⁱ, i.e. if outputs from one process would be directly accessible as input to the other. The guiding element is the District Plan, which formulates the targets and objectives that these processes rely on. The District Plan monitoring process (top left) is specifically designed to collect data on the cities' performance against a set of indicators. These indicators and related objectives are often spatial in nature and intrinsically linked to modelling applications (i.e. water quality, accessibility). Carrying capacity analysis (center left) accounts for the amount of growth that can be supported by natural environmental systems of a particular area [2], a process that depends on detailed land use information in the GIS database, but also on the monitoring and analysis of environmental quality.

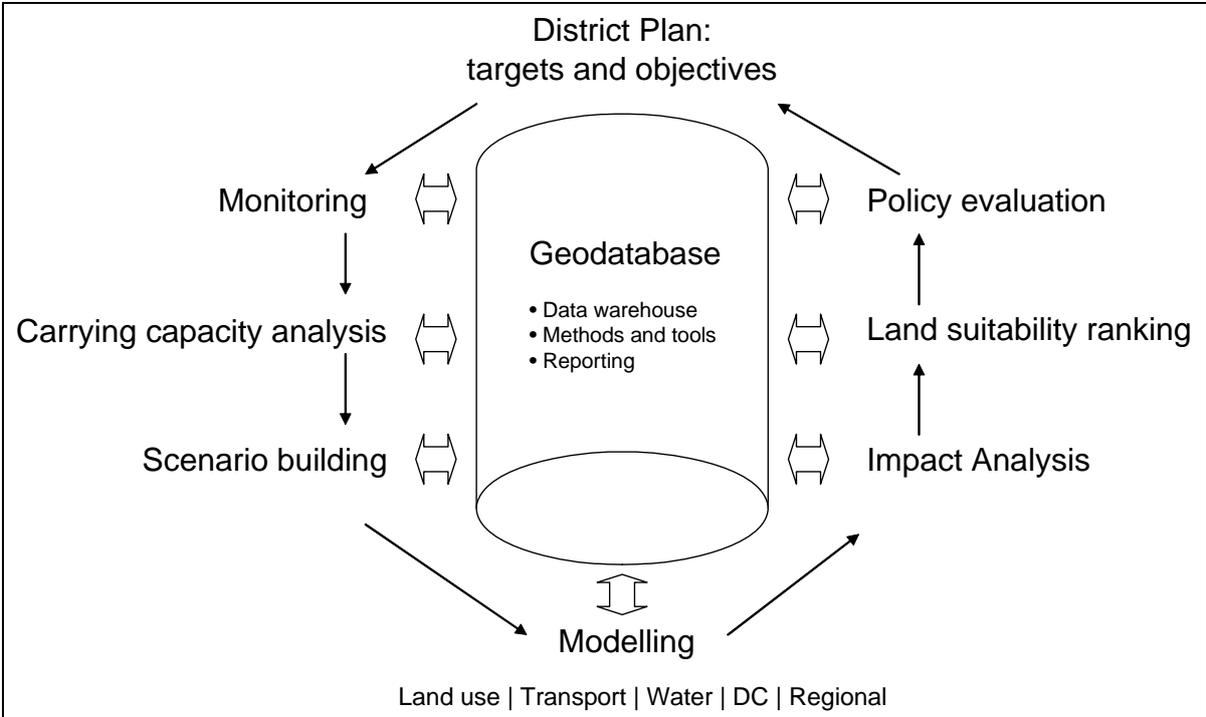


Figure 1: GIS framework for integrated land use analysis

If future planning is to be “sustainable”, subsequently formulated scenarios (bottom left) need to give effect to these limitations, drawn from the results of the carrying capacity analysis. The applications that model these scenarios are at the bottom of the diagram. The geodatabase architecture allows for data exchange where interfaces require information from other models (i.e. land use information for transport and water modelling, development contributionsⁱⁱ, regional models) or feed information back into another model. The results are then subject to impact analysis studies, a range of (GIS-based) analysis techniques that determine the projected change in the value of environmental, social or economic quality in the city. Impact analysis is required where there are uncertainties around certain effects in the resource or building consent process, or where legal disputes occur. It can also be used to assess and report on the effects of modelled projections, with a focus on avoiding unsuitable develop-

ments. In contrast, land suitability ranking identifies areas within the city that are suitable for required land use changes. It is also used to mitigate or minimise conflicts where growth-related activities exceed current capacities. Used in this way, a GIS-based ranking scheme for land suitability analysis provides also crucial information on the levels of conflicts, which can be used for policy evaluation.

The framework described here reveals the conceptual opportunities of using GIS as a platform for integration. In practice, however, the implementation of such a system is not only technically challenging, it also requires that organisational structures and workflows within the Council are tailored towards the framework. From a technical perspective, a geodatabase that ensures consistency over the described datasets needs to rely on automated routines and data integrity rules that are difficult to implement and administer. From a planner's point of view, each project or study requires a specific approach for analysis. Standardised routines and datasets that help to improve system performance and support integration may not be suitable for a specific problem. It is therefore essential that this framework is implemented as an open system: it unlocks synergies on one hand, and is flexible enough to support individual analysis / modelling tasks.

2 The geodatabase approach

"A geodatabase is a database designed to store, query, and manipulate geographic information and spatial data. It is also known as a spatial database." [4]. The term "geodatabase" was coined by ESRI, a GIS software development firm from the US. The main advantage over traditional GIS data formats is the openness of the geodatabase approach. Information can be stored in standard relational databases (DB2, SQL Server, Informix), accessed through common database interfaces by a range of applications, including modelling and GIS front-end applications. Although it is a fairly new technology, more and more modelling applications that use the geodatabase approach penetrate the market. In hydraulic modelling, MikeUrban uses ESRI's ArcGIS framework and its geodatabase capacities as the backbone of its software architecture. Transport modelling extensions for ArcGIS have recently been introduced by Rapidis (TrafficAnalyst, a four-stage transportation model that builds on geodatabase functionalities). In addition, many user-built models exist within the GIS community, with functionalities that capitalise on the opportunities for data integration the geodatabase has to offer. Since the introduction of this new technology in the late 90s, many government organisations as well as research institutes have adapted their corporate GIS system architectures to geodatabases. Previously proprietary datasets are now available to a GIS-trained user community. In addition, metadata standards and well-documented data models have become essential requirements for GIS data management, assisting data exchange across divisional borders.

Like many other government organisations, the Council reported on here has developed its corporate GIS database in a very similar way. A dedicated division manages a GIS system architecture for different levels of users. Under this hierarchy, land use, transport and hydraulic modelling falls under the level of GIS analysis users. Hydraulic modelling is already being performed within the GIS framework, transport modelling is in the process of being migrated. The remainder of this paper describes how the planning department of the Council has redeveloped its land use model within a

GIS environment. Implementation was finished in 2007, and the model is now fully functional.

3 Land use modelling using GIS

The Council has been operating a land use model since 1998, based on Excel spreadsheets and links to GIS layers for zoning and land use data. The migration of this model to a geodatabase was undertaken in two phases: first, the functionality of the model was translated into a set of automated database routines, using the Structured Query Language (SQL) and a geodatabase programming interface (ArcObjects, Visual Basic). In the second phase, new routines were developed to add new functionalities. For example, data resources like building consents and information on vacant land held in the GIS database are now instantly being used for model calibration; the previously static zoning structure of the model was replaced by a set of GIS routines for aggregating and disaggregating data “on-the-fly”; and the calculation of development contributions could now be done on the basis of “household-unit equivalents”, contained in the GIS database.

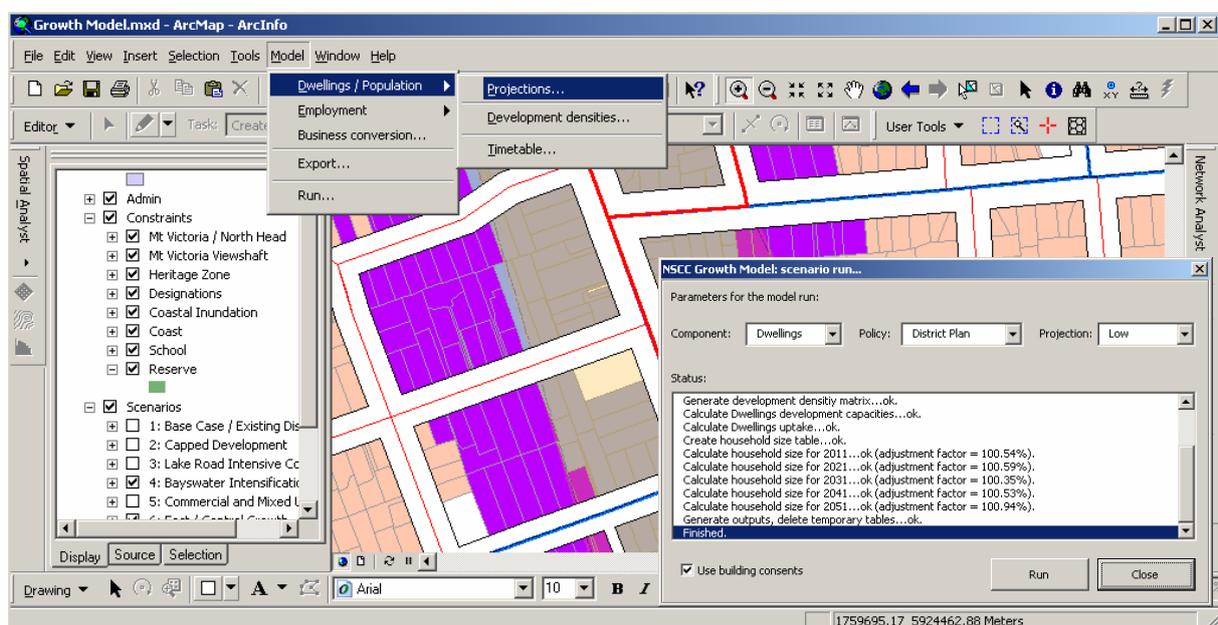


Figure 2: Land use model client.

Figure 2 shows the main interface for the land use modelling client. This application is a customised version of the main ArcGIS application ArcMap. As part of the customisation, the land use modeller manages inputs, parameters, and outputs through ArcMap menus and tools. Expert users can manipulate and query data through direct connections to the geodatabase SQL interface. From a technical point of view, this application serves as the land use modelling client for the integrated land use analysis framework described in the previous chapter. Model runs are saved as new versions in a land use geodatabase schema, which interacts with other database schemas in the framework. A model run triggers a message to other model users. It is exposed as a new parameter, i.e. each run is saved as a version of a scenario that other models can choose to process further (or go with the previous or any other version). Relationship classes and value domains control the interaction between these schemas, which is a powerful tool for the database administrator to ensure data in-

tegrity. In addition, different permission levels for accessing the database prevent clients from manipulating data outside the scope of their user rights. The downside of these restrictions is that data management becomes fairly complex, and processing documentation becomes a major task for GIS database analysts.

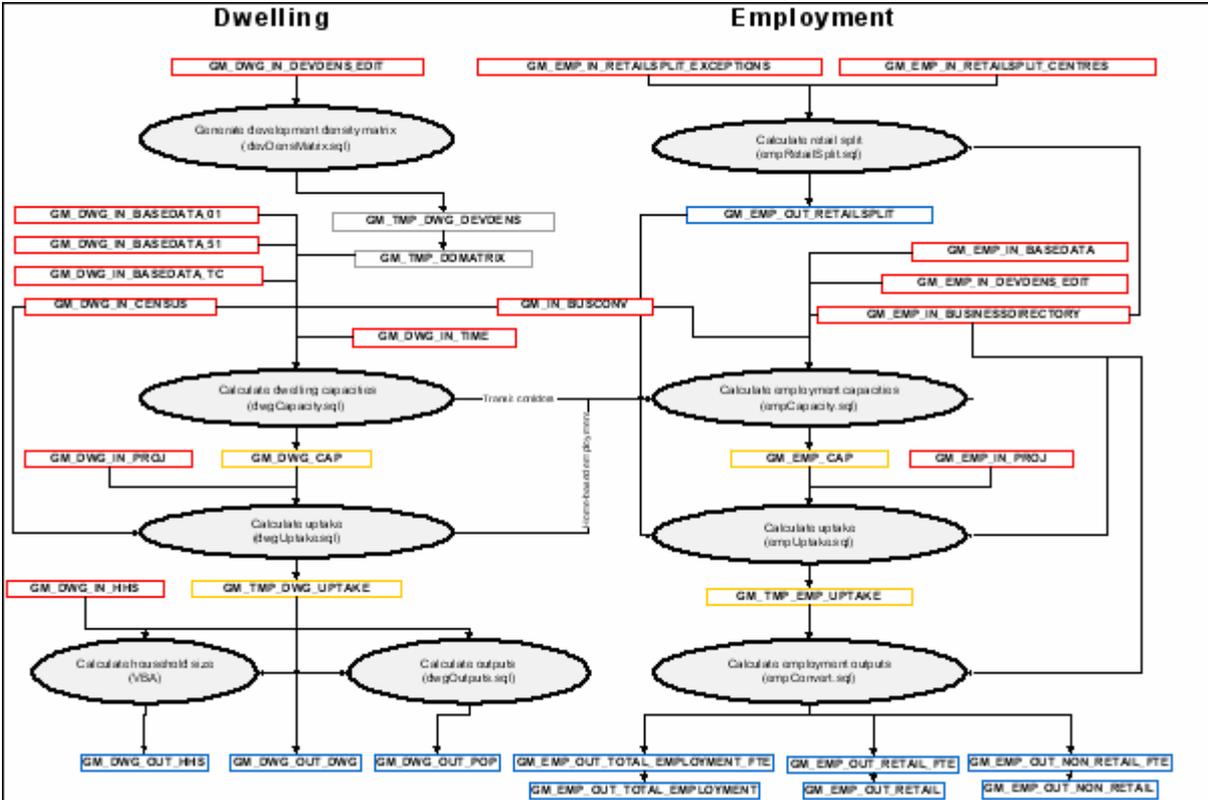


Figure 3: Processing schema for the geodatabase land use model.

Figure 3 shows the processing schema for the geodatabase implementation of the land use model. Input datasets are shown in red, outputs in yellow (intermediate) and blue (final). There are two overlapping workflows (components), one for the calculation of dwellings, the other for employment. Each processing task (oval shape) triggers the execution of a SQL scriptⁱⁱⁱ in the database. Processing is synchronous and follows the basic steps of (1) calculating dwelling and employment densities for the model run, (2) quantifying the available capacities, and (3) calculating the respective uptake rates. The flexibility to model different scenarios is given through variations of input datasets (high, medium, low projections) and processing options (for example the inclusion or exclusion of certain types of resource consents). From a spatial point of view, these processing steps are undertaken for zonal units that best fit the planning guidelines of the District Plan. Statistical data and indicators that refer to smaller or larger zones are either matched through lookup tables (1:n relationships) or through geoprocessing routines in the geodatabase (n:m relationships). Population figures are derived from the resulting number of dwellings and disaggregated household size projections.

The framework for integrated land use analysis is designed to work with automated routines and process data dynamically between modelling applications. This approach is ideal from a system architecture point of view, but has a number of shortcomings when it comes to calculating development capacities for the model. These

calculations rely on assumptions around a number of inputs that can not be quantified automatically. Previously, capacity figures were derived from a combination of quantitative and qualitative inputs, using information on historic development patterns, and (subjective) planning knowledge. Generalised development density values for dwellings and employment were then applied to certain types of zones, and multiplied by the available net land or floor area within that zone.

In the new framework, this information is the outcome of a detailed land suitability ranking for distinct planning units. In this process, information layers on restrictions, conflicts, and opportunities for development are derived from existing GIS datasets. Restrictions are translated into “no-go-zones” for development (environmental restrictions, heritage zones, etc.), conflicts are evaluated as weighted penalties (proximity to industrial sites, roads, tracks, etc.), possibly offset by opportunities (proximity to employment opportunities, cultural services, schools, etc.). At the end of this process, each planning unit has a suitability ranking for certain development types assigned to it, which gets used in the modelling process. In addition, the net available land or floor area is calculated dynamically with respect to these constraints. For example, a layer for coastal inundation can be used in a climate change scenario, derived from hydraulic modellers. In this scenario, the expansion of coastal water features and floodplains reduces the amount of available land significantly (see figure 2). In another scenario (see figure 3), public transport accessibility is evaluated as an opportunity of a very high rank. The GIS provides these values, derived from outputs of the transport model (see figure 3, in minutes to the local transport hub, including walking and feeder bus services).



Figure 2: Coastal inundation



Figure 3: Public transport accessibility

Although the approach used previously was certainly not ignorant of the constraints described here, land suitability ranking has the advantage of being much more transparent, reproducible, and flexible. It ensures that the most up to date and comprehensive land use information available is used, and provides opportunities to communicate and report on scenario development and related model outputs that were previously not possible.

As a result, the development capacities for future land use scenarios are more robust. Figure 3 provides a sample visualisation of already modelled scenarios. The colours reflect the distribution of density categories, which is the outcome of the land suitability ranking.

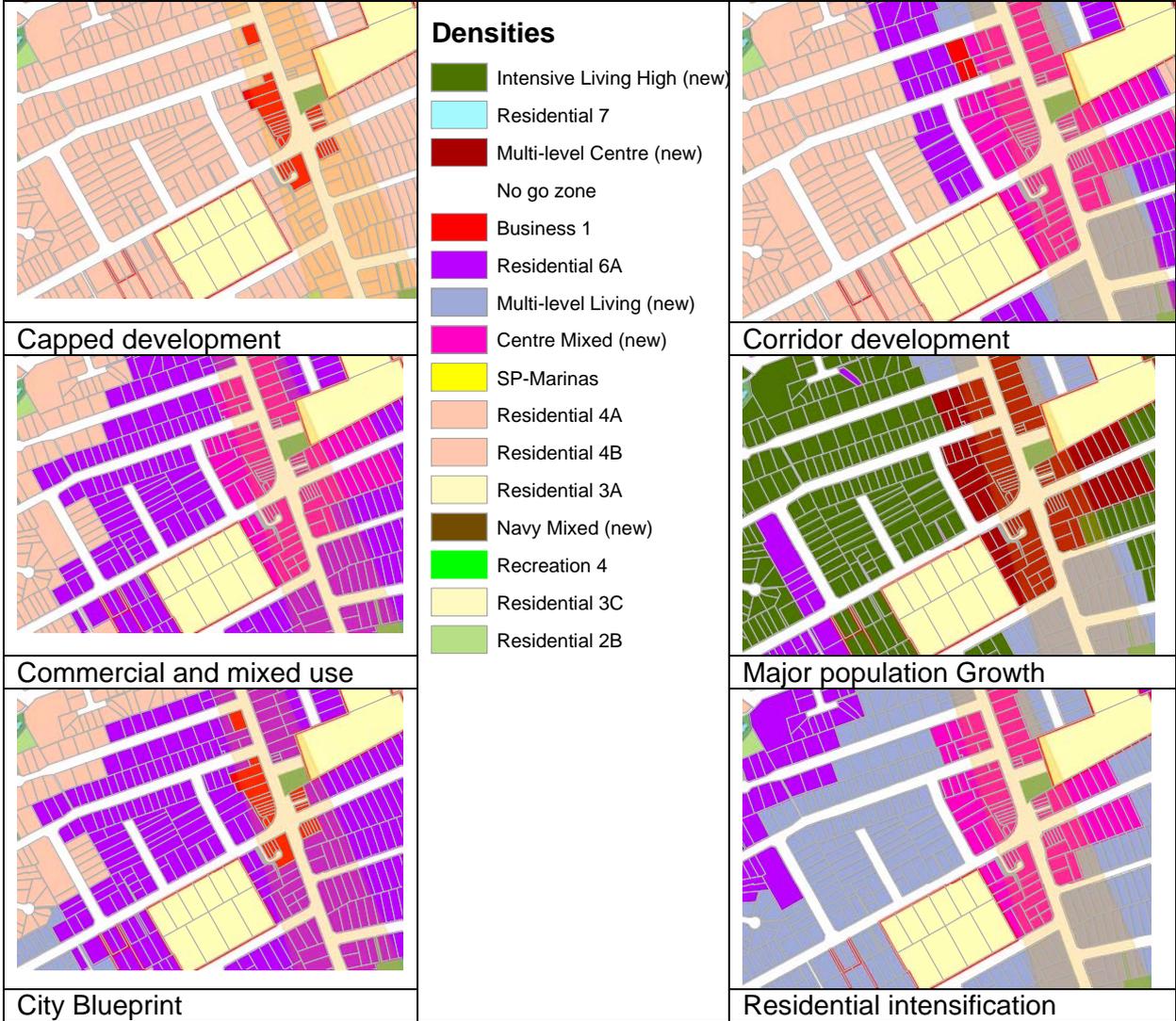


Figure 2: Graphical representations of land use model scenarios

The implementation of this model is only a small step in the construction of the integrated land use analysis framework described in the previous chapter. What has been achieved so far is that the existing land use model logic has been migrated to a geodatabase environment. On top of the advantages in terms of dynamic data exchange, this enables land suitability ranking to take place for scenario building. Next steps will have to look at integrating existing District Plan monitoring indicators. Multi-temporal data on these indicators exist, as well as from public participation dialogues (“community outcomes”). If quantifiable measures could be derived, these indicators could be used in a more comprehensive land suitability ranking process, possibly leading to new (combinations of) scenarios.

4 Conclusion

Land use modelling is an important task within local Council planning workflows. A number of applications rely on land use model outputs that they use as fixed parameters into their own modelling environments. In the past, these models were run in different divisions of the Council on separate software platforms, with inefficient interfaces for data exchange. With the evolution of database-driven GIS environments, a new technology has become available that has not been used for land use modelling so far. This paper has shown what potentials the geodatabase approach provides for integrated land use analysis, and what advantages can be achieved from a technical point of view. From a conceptual point of view, there are a range of synergies that can be used for modelling workflows, i.e. processes and data can be integrated more efficiently. As a first step, the migration of a spreadsheet-based land use model to a geodatabase environment was conducted, and extended to add new functionalities and significantly improve the scenario building process. Land suitability ranking is now being used for (re-) building old and new scenarios. This is the level in the land use analysis process where integration of outputs from other models occurs. Transparency and a flexible evaluation process are the main advantages. The resulting capacity and development density figures are then entering the land use modelling process, and instantly available as new inputs into applications further down the line.

The geodatabase approach to integrated land use analysis is fairly new. More and more modelling applications are entering the market using this technology, and further developments in this direction can be expected.

References

- [1] S. Guhathakurta (Ed.): Integrated Land Use and Environmental Models. A Survey of Current Applications and Research, Berlin, Germany: Springer Verlag, 2003, p.4
- [2] Berke, R., Godschalk, D., Kaiser, E., and D.Rodriguez (5th ed.): Urban Land Use Planning, Illinois, United States, 2006, p.188
- [3] Retrieved from <http://www.northshorecity.govt.nz/PDFs/dev-contributions/NEW/NSCC-DC-Overview.pdf> on 28.6.2008, p.1
- [4] Retrieved from <http://en.wikipedia.org/wiki/Geodatabase>, 21.6.2008

ⁱ A geodatabase is a database designed to store, query, and manipulate geographic information and spatial data [4].

ⁱⁱ Development contributions are contributions of money or, in some instances, land and are a means of funding the Council's growth-related capital expenditure....for network and community infrastructure, and reserves [3].

ⁱⁱⁱ Some of the scripts were implemented as stored procedures, due to inconsistencies in different SQL variations to implement non-deterministic iterative routines.