Waikato Regional Council Technical Report 2013/36

# WISE

## Waikato Integrated Scenario Explorer

## Technical Specifications
## Version 1.3.0

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## Disclaimer

Creating Futures

WISE
Waikato Integrated Scenario Explorer

Technical Specifications
Version 1.3.0

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Creating Futures (FRST Project ENVW0601, 2006-2010)
Waikato Regional Council

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Product information
WISE (Waikato Integrated Scenarios Explorer) is an Integrated Spatial Decision Support System (ISDSS) designed especially for the Creating Futures project funded by the New Zealand Foundation for Research, Science and Technology (FRST). WISE has been developed for the Waikato region to support Waikato Regional Council's long term integrated spatial planning and decision-making. Information about the 'Creating Futures' project is available on the Internet, including an electronic copy of this report: http://www.creatingfutures.org.nz.

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### Disclaimer

# WISE
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## Version 1.3.0

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# Contents

# WISE Overview

## Project and Client

Creating Futures (formerly Choosing Regional Futures) was a 4-year project funded by the New Zealand Foundation for Research, Science and Technology. The project brought together an interdisciplinary team consisting of a regional council and social, environmental and economic researchers. The project aimed to develop new methods and tools to support integrated, long-term planning by 1) developing processes to evaluate, deliberate, and choose regional futures through scenario analysis and multi-criteria deliberation frameworks, and 2) developing an integrated spatial decision support system (ISDSS), dubbed the Waikato Integrated Scenario Explorer or WISE, to support the evaluation and deliberation processes. Together those tools were designed to help councils identify links and explore trade-offs between economic, environmental and social/cultural outcomes and the cumulative effects of many decisions over space and time.

This report outlines the technical specifications for WISE Version 1.3.0, which was developed under Objective 2 of the Creating Futures project. WISE is an integrated framework designed to help examine weakly structured or unstructured problems characterised by many actors, many possibilities, and high uncertainty. WISE was developed for the Waikato region to support and facilitate a range of integrated, long-term policy development and planning processes undertaken by Waikato Regional Council, in particular the development of regional policy and planning under the Resource Management Act and long-term council community planning under the Local Government Act.

WISE is intended to help Waikato Regional Council explore possible long-term regional futures considering in a holistic manner by integrating the following topics (listed alphabetically):

- Climate Change
- Demographics
- Economics
- Hydrology
- Land Use Change
- Terrestrial Biodiversity
- Water Quality.

## Objective

- Develop WISE to support evaluation and deliberation of different policy and planning strategies and scenarios in the context of long-term integrated planning as required by the Local Government Act and the Resource Management Act. In addition WISE could help explore the consequences of alternative strategies and options under non-statutory planning processes such as, for example, Future Proof, Shore Futures, or Coromandel Blueprint.

**WISE Specifications**

- Overview
  - WISE permits simulations of regional development from the period 2006–2050 at an annual time step.
  - WISE specifications consist of an overall systems design that includes integrated components operating at four spatial scales:
    - NZ & the World
    - Waikato region
    - Districts
    - Local (e.g., 200 m × 200 m grid cells for the Land Use Change model).
  - Users can change various model parameters or input assumptions to explore the consequences of different strategies or actions.
  - WISE is implemented in the GEONAMICA® framework. GEONAMICA® is an object-oriented application framework developed by the Research Institute for Knowledge Systems. GEONAMICA® is a programming framework specially tailored for developing ISDSSs that feature integrated dynamic models as core elements and has an extendible toolbox containing ready-to-use software building blocks required for the development of models, analysis tools and user interfaces.
- Scale: New Zealand to Global
  - Climate Change Scenarios – consist of three climate change scenarios downscaled from IPCC global 4$^{th}$ Assessment report scenarios (Low, +1.8°C global mean warming at 2100; Medium, 2.8°C global mean warming by 2100, High,+4.0°C global mean warming by 2100) for use at sub-national scales in New Zealand. It includes three climate variables: average annual temperature (°C), average annual rainfall (mm), average annual potential evapotranspiration (mm). The user may select from one of four possible options:
    - No climate change
    - Historic interannual variation only
    - Climate change trend only (low, medium, or high)
    - Climate change and historic interannual variation
  - External Economic Drivers – consist of 4 key economic factors that may strongly influence New Zealand and/or the Waikato region:
    - International exports (million \$NZ $\text{Dollars}_{2007}$)
    - Interregional exports (million \$NZ $\text{Dollars}_{2007}$)
    - Gross Fixed Capital Formation (million \$NZ $\text{Dollars}_{2007}$)
- Regional Scale
  - Waikato Region Dynamic Economy-Environment Model (WRDEEM) – a model of region-wide environment-economy interactions adapted from a model developed for Auckland. WRDEEM estimates future economic activity in approximately 50 industries (constant \$ NZ $\text{Dollars}_{2007}$) in the region based on regional household demand and the external economic drivers discussed above. Economic activities generate demand for land, which is an input to the Land Use Change model. The Land Use Change model determines the actual land supplied to WRDEEM, which then adjusts final economic activity to reflect that supply. In addition to modelling economic activity, WRDEEM also models the labour force and several environmental factors including energy use, energy-related $CO_2$ emissions, and solid waste generated.

  - Hydrology – consists of a simple hydrological simulation model developed specifically for WISE. The model simulates total annual surface runoff (mm/year) and summer flow yields (litres/second/$km^2$) based on inputs of rainfall, potential evapotranspiration and land use.
  - Water Quality – an adaptation of the U.S Geological Survey SPARROW model to New Zealand (Elliott et al. 2005). SPARROW estimates pollution loads of nitrogen and phosphorus (tonners/year) for each individual reach as defined within subcatchments of the Waikato river network.
- District Scale
  - Zoning – consists of a tool that allows users to input individual zoning rules and regulations. Zoning indicates where different land uses may or may not occur. Rules or regulations can apply to different areas and also be in force for different periods of time. A user can specify the precedence among the different rules and regulations and also specify the likelihood for a particular land use to occur based on its RMA activity status. For example, permitted activities would have a probability of 1, while prohibited activities would have a probability of 0.
  - Demographics – consists of the Whole-of-Waikato (WOW) demographic model that projects population over time, expressed as 1-year male and female age cohorts (number of persons). A separate model runs for each of the 11 districts (or parts thereof) that occur within the Waikato region.
- Local Scale
  - Land Use Change – a dynamic, spatially explicit cellular automata model that models land-use change across a 200 m × 200 m grid of the Waikato region for 25 classes of land use. For each grid cell at each time step, the model calculates the potential for a cell to transition to every land use based on four factors:
    - Accessibility – assesses the attractiveness of a location for different land uses based on the proximity to desirable or undesirable features (e.g., distance from a dairy farm to a dairy factory) using a distance-decay algorithm. Users can add new features for consideration and adjust the weightings used in the algorithm to test different assumptions about accessibility. Zonal accessibility is included statically and indicates global accessibility to activities (typically population and jobs) per district.
    - Local influence – assesses the attractiveness of a location (grid cell) for a land use based on the composition of land use in the surrounding neighbourhood. For each pair of land uses, the user specifies a function defining the strength (high, low, none) and direction (positive/negative) interaction out to a maximum distance of 8 grid cells (1600 m) from the cell of interest. The model sums up the weights of all the cells in the surrounding neighbourhood to produce a composite score for each cell of interest. Also each land use has a transition value at distance 0, i.e. the cell itself, which determines how easy or difficult it is to change from that land use.
    - Suitability – scored from 0 (unsuitable) to suitable (10) based on different combinations of factors. Users can use the suitability maps provided or develop their own suitability layers.
    - Zoning – see above for a discussion of the zoning.

    Land-use change is driven by external demands for land (hectares) from the WOW demographic model (residential uses) and the WRDEEM model (economic uses). The model attempts to meet the external demands by assigning cells with the highest transition potentials to the appropriate land use until the demand is met.

  - Terrestrial Biodiversity – tracks changes in regional threatened environment status for Land Environments of New Zealand (LENZ) Level II land environments (100 environment classes nationally) represented at 100 m × 100 m resolution. The threatened environment classification combines information on land cover with information on legally protected areas and land environments to provide information on terrestrial biodiversity status across a range of scales.
- Indictators
  - WISE produces a range of indicators that a user can examine.
  - Indicators include
    - Numeric indicators such as population or economic activity
    - Spatial indicators such as water quality or land use maps.
  - Users can opt to save indicator information as a time-series either in Excel spreadsheets (numeric) or maps/images (spatial).

**Future Development**

- Feedback on WISE was collected during the project
- Based on the feedback, a list of suggested improvements and enhancements was compiled and prioritised based on interactions between the project team and Waikato Regional Council
- Further improvements have been made in subsequent versions:
  - WISE version 1.1: addition of Zoning Tool; enhancements to the graphical user interface
  - WISE version 1.2: improved performance of Zoning Tool; changed the link between the hydrological, economic and land use models to give more consistent results.
  - WISE version 1.3: updated district boundaries; improved calibration of the land use model; addition of Monte Carlo tool; enhancements to the scenario manager.
- Waikato Regional Council has provided funding for on-going development of WISE as part of its Long-term Council Community Plan. They are currently exploring various possibilities for updating and improving WISE.

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# 1 Introduction: Creating Futures Project

## 1.1 Overview

Creating Futures (formerly Choosing Regional Futures) was a 4-year project funded by the Foundation for Research, Science and Technology (FRST) that began 01 July 2006 and finished 30 September 2010. Creating Futures aimed at developing, testing and implementing new methods and tools to help inform communities of the long-term effects of current development patterns and trends and to inform choices and planning for desired futures.

The project brought together an interdisciplinary team of stakeholders (Waikato Regional Council, the lead agency) and social, environmental and economic researchers within New Zealand (AgResearch, Landcare Research, Market Economics, Massey University, NIWA, Scion, University of Waikato) and internationally (Research Institute for Knowledge Systems – Netherlands and Université de Versailles Saint Quentin-en-Yvelines – France).

The Creating Futures project had two objectives:

- Develop processes to enable evaluation, deliberation and choice of alternative futures for social, environmental, economic and cultural changes through the use of scenario analysis linked to multi-criteria evaluation frameworks
- Develop an integrated spatial decision support system (ISDSS) that integrates key aspects of the economy, environment, and society/culture. The ISDSS allows users to explore plausible futures of regional development in a quantitative and spatially explicit manner, evaluate and compare different policy and planning strategy options, and help monitor and report on progress towards achieving long-term sustainable community goals and outcomes.

The tools developed through the project were designed to help identify links and explore trade-offs among economic, environmental and social/cultural outcomes, including cumulative effects over space and time. The aim was that the information, knowledge and tools from the project could be widely used and applied for policy development, planning, and resource management, initially by regional and local/city councils and eventually by other organisations.

The research project was designed to insure close interaction between researchers and end-users such that the resulting ISDSS could be integrated into strategic planning and policy making and resource management by Waikato Regional Council and interested city and district councils. The question of exactly how the ISDSS will be used by councils remains an active area of investigation. By linking researchers and end-users from the beginning, the project provided a direct pathway for uptake of the information, tools and knowledge gained by councils and allowed them to gradually build their capacity and capability for using tools like the ISDSS as well as the associated deliberation methods to inform integrated, long-term planning.

This report provides the specifications for version 1.3 of the ISDSS produced by the Creating Futures project. The ISDSS was dubbed the Waikato Integrated Scenario Explorer or WISE. This report follows on from a draft specifications report prepared earlier (Rutledge et al. 2007a) and also incorporates additional feedback received during end-user workshops (Huser et al. 2008; van Delden et al . 2010) and case studies (Wedderburn et al. 2009). These specifications represent the fourth and final stage of ISDSS development, i.e. validation and optimisation, within the Creating Futures project (Figure 1).

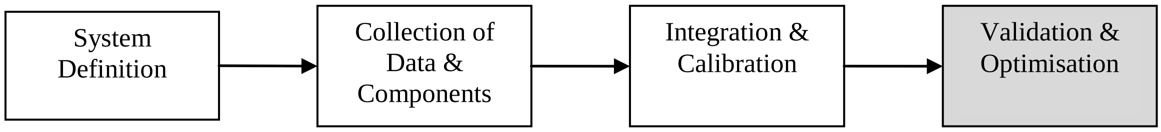



**Figure 1** Four stages of ISDSS development in Objective 2 of the Creating Futures Project.

This report provides the current specifications for WISE including the overall system design and detailed information for each model including metadata, a summary, a detailed description, equations, and links to/from other models.

## 1.2 Spatial Decision Support System Development

WISE (ISDSS) Development Plan

Objective 2 of Creating Futures sought to develop an ISDSS that allows users to explore "what-if" questions related to complex issues of sustainable development that require integrated planning and decision-making, e.g., for regional development and the community outcomes process required by the Local Government Act (Oxley et al. 2002; Englen et al. 2003; Rutledge et al. 2007b; Rutledge et al. 2008).

Advantages of such an approach include

1) Integration of cultural, economic, environmental, and societal issues
2) Identification of links and feedbacks among issues
3) Limitations are explicitly identified, i.e. only so much land, soil, labour supply, investment capital, etc.
4) Demonstration of the importance of location in determining environmental effects
5) Aggregation or disaggregation of information/data/indicators across scales from national to local.

Potential limitations for developing an ISDSS include

1) Lack of spatially explicit data at the appropriate resolution
2) Poor knowledge of single processes or links among processes
3) Technical complexity involved in developing such systems
4) Difficulty of calibrating and/or validating such models.

WISE development consisted of a 4-stage process: 1) system definition, 2) collection and development of data and components, 3) integration and calibration, and 4) optimisation (Figure 1).

*System definition (Stage 1)* consisted of identifying the issues and questions that WISE should address and the corresponding models, data, and links among them that would help address those issues and questions. The research team identified key research questions, reviewed regional community outcomes, and compiled lists of available and desired knowledge, data, and models. Based on that information, the team prepared a scoping report and technical specifications document (Rutledge et al. 2007a) that outlined the overall system design and provided draft specifications for suggested models. The proposed design attempted to balance prioritisation and feasibility of addressing key questions/issues/outcomes against customary project constraints (time, budget, staff) as well as availability of required information. The report was provided to Waikato Regional Council for review and comment.

*Collection and development of data and components (Stage 2)* consisted of 1) gathering existing data and models and adapting them for inclusion into WISE, 2) generating new data or models that were required for particular models, and 3) identifying links among models in WISE including determining the exact specifications of those links

*Integration and calibration (Stage 3)* involved integrating all data and models into WISE, calibrating individual models and adjusting model equations and parameters accordingly. Integration and calibration occurred using a staged, iterative process as follows:

1. Integration of the Land Use Change Model and WDREEM
2. Integration of WOW into #1
3. Integration of the Climate Change Scenarios, Hydrology, and Water Quality Models into #2
4. Integration of the Terrestrial Biodiversity model into #3
5. Integration of the Zoning Tool into #4.

The process was not exactly linear as depicted but instead iterative as various adjustments were made at each stage of integration. In additional to regular interaction with Waikato Regional Council staff, two workshops with a wide range of end-users were held in November 2008 and November 2009 to obtain broader feedback (Huser et al. 2009; van Delden et al. 2010). The workshops generated a substantial list of comments and suggestions for improving and enhancing WISE, some of which were incorporated into WISE Version 1.1. Most fell outside the original scope of the Creating Futures project but remain the subject of on-going future development (see below).

*Validation and optimisation (Stage 4)* were the final phase of WISE development. This phase involved validating the outputs from individual models incorporated into WISE against the results from the original stand-alone models (Elliott 2009; Schmidt 2009; Tait 2009; Cameron 2010; McDonald 2010; Price 2010). That process identified inconsistencies between outputs of the stand-alone WISE version of several models, specifically Hydrology (Schmidt 2009), Water Quality (Elliott 2009), WRDEEM (McDonald 2010), and WOW (Cameron 2010). In each case the reasons for the discrepancies were isolated (e.g., errors in the WISE code, incorrect equation or algorithm), and the WISE version of the model was corrected until the outputs matched. In addition a number of minor software improvements were undertaken to improve overall WISE performance and aspects of the WISE graphical user interface (GUI) were changed based on end-user feedback.

# 2 WISE Specifications

## 2.1 Overall System Design

### Overview

The overall system design for WISE Version 1.3 (Figure 2) consists of an integrated set of models that operate across four spatial scales: NZ & the World, the Waikato region, cities and districts (e.g., Hamilton, Waipa, Matamata-Piako), and local for the land use change (200 m × 200 m grid cells) and terrestrial biodiversity models (100 m × 100 m grid cells). Each model consists of more detailed sub-models, each of which varies in detail, data, and internal structure.

WISE operates on an annual time step, with simulations beginning in 2006 and ending in 2050.

Arrows represent links or flows among the different models. The direction of the arrow shows the direction of flow. For example, the WOW Demography model generates information on population at the district level. Population is pooled among all districts to create a supply of labour to the Labour Market component within WRDEEM, which in turn generates demand for workers from the Regional Economy.

Below are short summaries for each of the models within WISE. The sections that follow provide more detail on each model and its components.

### NZ to Global Scale

The New Zealand to Global scale includes Climate Scenarios and Economic Drivers. These contain information on conditions operating exogenously or outside the Waikato region that influence or "drive" events within the region. These drivers, as they are called, operate at broader national or global scales and are generally beyond the influence of decision-makers within the Waikato region. Climate Scenarios include 3 pre-defined scenarios derived from IPCC 4$^{th}$ Assessment Report (AR4) scenarios (Nakicenovic 2000) downscaled to New Zealand and adapted to the Waikato region. The three scenarios span the range of possible climatic trends over the next 40 years: low (IPCC AR4 B1 scenario), medium (A1B, and high (A2). The Climate Change scenarios include temperature (°C), rainfall (mm), and potential evapotranspiration (mm). The Climate Change Scenarios also include the ability to include historic inter-annual variability to reflect shorter-term climatic cycles such as El Nino/La Nina.

Economic drivers contain required information for the Waikato Regional Dynamic Economy-Environment model (WDREEM, discussed further below). There are four key external drivers:

1. International exports (i.e. demand outside New Zealand)
2. Inter-regional exports (i.e. demand within New Zealand from other regions)
3. Gross fixed capital formation (e.g., new buildings, equipment, etc.)
4. Changes in inventory (e.g., changes in goods not yet sold).

All values for 1–4 above are expressed in constant 2007 million $New Zealand dollars.

Users can explore different future scenarios based on different assumptions about future climate change and economic trends.

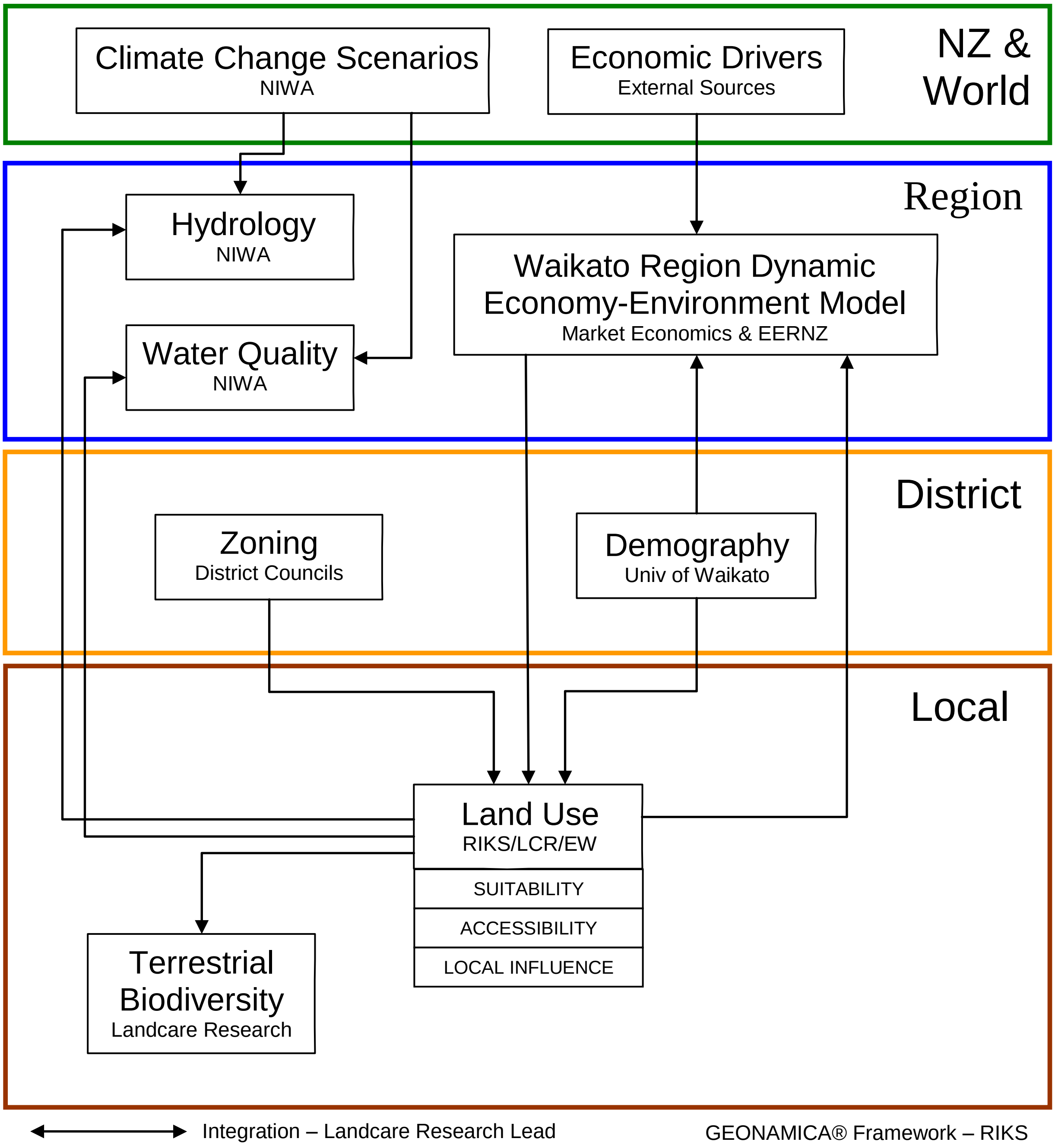



**Figure 2** WISE Version 1.3 system design.

## Regional Scale

The regional scale contains three models: Waikato Region Dynamic Economy-Environment Model (WRDEEM), Hydrology, and Water Quality. WRDEEM is a dynamic systems model of the regional economy and environment-economy interactions. WRDEEM consists of three sub-modules:

1. Demand-side
2. Supply-side
3. Reporting.

WRDEEM models trends in approximately 50 industries of the regional economy and provides information on economic activity, environmental use, and labour markets. The demand-side module estimates demand by industry, which is the sum of the four external economic drivers described above and regional household consumption (demand). Associated with each economic industry is a demand for land, which depends on an eco-efficiency index (hectares required /$ economic output). WRDEEM presents demand for land to the Land Use Change model (see below), which determines the final amount of land supplied to each land use. The supply-side module adjusts, if necessary, final economic activity depending on the amount of land allocated to each economic industry by the Land Use Change model. The reporting module provides information and indicators related to the economy (e.g., final demand in constant $New Zealand dollars$_{2007}$), environment, (e.g., resource use or residual outputs in appropriate units), or labour markets (e.g., employment, labour force productivity).

The Hydrology model estimates annual surface water runoff and the expected water yield in the driest summer month for a 500 m × 500 m grid across the region. These are calculated from spatially varying climate, soil and vegetation hydrological responses.

Water Quality consists of a version of the SPARROW model developed by the U.S. Geological Survey that has been adapted to New Zealand conditions. SPARROW estimates total annual loads of nitrogen and phosphorus (tonnes/year) for sub-catchments within the region as a function of climate, land use, soils, and point-source pollution sources.

## District Scale

The District scale contains two models: Zoning Tool and Demographics. The Zoning Tool determines where different land uses may or may not occur. The Zoning Tool allows a user to input various zones, plan, rules, designations, overlays etc. as desired to simulate the effects of different zoning policies on future land-use development. For each zone, rule, etc., the user may specify a probability of change ranging from 0 (land use prohibited) to 1 (land use permitted). Each zoning rule may operate over the entire simulation (2006–2050) or for specified periods of time only, e.g., a targeted economic growth zone in effect from 2015 to 2025.

The Whole of Waikato (WOW) demographics model consists of 11 1-year age-sex cohort component models, one for each district or part district in the Waikato region.[1] The model includes information on fertility, mortality, net migration among districts, and net migration to/from each district to outside the region. Users may vary global fertility and mortality (i.e. adjusted each up/down for each age-sex cohort) and vary net migration for each district individually.

[1] As of September 2010. Effective 01 December 2010 the portion of Franklin District in the Waikato Region became part of the Waikato District as a result of the creation of the consolidation of the Auckland Region and several district councils, including parts of Franklin, into the new Auckland Council.

## Local Scale

The Local Scale consists of two models: Land Use Change and Terrestrial Biodiversity. In WISE land use is represented as a grid of 200 × 200 m cells, while the Terrestrial Biodiversity represents the status of land environments as a grid of 100 × 100 m grid cells.

The Land Use Change model dynamically models land-use change over time based on demand for residential land uses generated by the WOW model and demand for economic land uses generated by the WRDEEM model. Each year the model evaluates the potential for land use at each 200 × 200 m grid cell to transition to every other land use. For each grid cell the model ranks the transition potential of all the land uses based on a combined score from four factors:

1. Accessibility – distance from the grid cell in question to key relevant features, for example the distance from residential areas to the central business district
2. Local influence – composition of land use in the neighbourhood (8 cell radius or 1600 m) around each cell as well as the current land use
3. Suitability – estimated suitability of land for different uses scaled from 0 (not suitable) to 10 (highest suitability) based on various factor considered relevant to a particular land use
4. Zoning – the potential for future development to occur at a grid cell based on knowledge of regional and district plans and other statutory requirements, ranging from 0 (prohibited) to 1(permitted) or, in a few cases, >1 (actively stimulated).

The Land Use Change model operates as follows. First, it determines the vector of transition potentials for each grid cell for each land use. Second, it allocates land use to the cell with the highest regional potential for a demanded land use (residential or industry). Third, it continues to allocate land use iteratively until it meets the external demands for residential and economic land uses, if possible.

The Terrestrial Biodiversity model tracks annual changes the status of Threatened Environments. Threatened Environments are an indicator of ecosystem representativeness based on a combination of biodiversity condition (land cover), protection (New Zealand Protected Areas Network), and Land Environments of New Zealand (LENZ). The model accepts land use from the Land Use Change model as input, translates land use into land cover (native or non-native), and then determines the amount of native cover remaining by LENZ land environment and amount protected to calculate each land environments threat status.

# 3 Model Descriptions – Reader's Guide

To make it easier to locate information, each section describing a model follows a common format. This includes five primary subsections providing the following information:

- *Metadata:* table of pertinent metadata including
    - Name
    - Contact person
    - Scale
    - Input Data
    - Internal Data
    - Output Data.
- *Summary*: an overall summary of the model including a brief description of the inputs and outputs
- *Description*: a more detailed description of the concepts, ideas, and assumptions underpinning the model
- *Equations*: the full set of equations describing each model
- *Links*: table of inputs and outputs to/from other models within WISE. Specifically:
    - *Inputs*: data passed *from* other components within WISE including external drivers, policy options, user-definable data layers, or data from another model
    - *Outputs*: data passed *to* other models within WISE
    - *Comments*: descriptions of any methods required to transform data passed to or from one model to another or other important information of note.

The section describing GEONAMICA® deviates from this structure, as GEONAMICA® is a software framework for building integrated models and not a model itself.

# 4 GEONAMICA® Framework – RIKS

WISE was developed as an application within the GEONAMICA® software framework. GEONAMICA® is an object-oriented application framework (Fayad et al. 1999) developed by RIKS to build decision support systems based on spatial modelling and (geo) simulation. It has been developed over the past 15 years and has been used to generate integrated spatial decision support systems, such as

1. WADBOS (Engelen et al. 2003a) – an application to explore the state and management of the Wadden Sea north of the Netherlands
2. ENVIRONMENT EXPLORER (Engelen et al. 2003b) – an integrated spatial decision support system in which social, economic and ecological processes are simulated to explore policy alternatives in relation to the quality of the environment in which Dutch citizens live, work and recreate.
3. MEDACTION (Van Delden et al. 2007) – an integrated policy support application to assess the main issues underlying the causes and effects of land degradation and develop integrated planning policy options and mitigation strategies to combat desertification in the Northern Mediterranean region
4. XPLORAH (Van Delden 2008) – an integrated application to explore policy development, land use planning and resource management in Puerto Rico
5. MOLAND (Barredo et al. 2003) – a generalised dynamic system for modelling urbanised European regions.

Besides these, RIKS has used GEONAMICA® to develop METRONAMICA, a template ISDSS that includes a local dynamic land-use interaction model, a regional interaction model and/or a transport model – depending on the exact version. It can be used to set up a specific ISDSS without the need for additional software development by filling the system with data, calibrating the model and training the users.

An ISDSS such as WISE has three major components:

1. *Database* – to store information used by the system, including raster or vector map data, time series data and cross-sectional data
2. *Modelbase* – to manage the models within the system including specifying and scheduling interactions among them
3. *User interface* – to enable a user of the system to interact the models and data.

GEONAMICA® offers set components for storing map data, time series and cross-sectional data. It provides a modelling framework based on the Discrete Event System Specification (DEVS) formalism (Zeigler et al. 2000) that includes a model controller for managing the models including ensuring that the models interact properly and scheduling models to perform actions at specified times. To create a user interface, GEONAMICA® includes a skeleton structure and a software class library of user interface components, such as map display and editing tools, list and table views and two-dimensional graph editing components.

The strength of GEONAMICA® lies in its modelling framework, which provides a generic structure for that facilitates the integration of a variety of different models and enabling the resulting integrated, complex, dynamic models to be executed easily and efficiently. The environment enables users to run simulations interactively, by allowing them to interact with the system and observe the results of their actions directly in a comprehensive manner and save the results for further analysis or presentation purposes.

## 4.1 Model Blocks

The GEONAMICA® modelling framework builds on the DEVS formalism such that models are composed of model blocks, which are encapsulated parts of a model that can communicate with each other and with the system through a standardised interface. A model block contributes to the entire model – in its simplest representation as a collection of variables and equations or algorithms – through the variables it contains and the procedures associated with it to compute the value of these variables.

Model blocks communicate with each other through input and output ports. An input port allows a model block to gain read-only access to a variable of another model block, such that it can be used for computation. An output port allows read-only access to one of the variables of a model block. By linking all input ports of a model block to output ports of other model blocks, we create a coupled component.

The collection of interlinked components forms the system that represents our entire model. For each particular system, the model is specified in an Extensible Markup Language (XML) file. The listed model blocks are activated and coupled at run-time, thereby allowing a change of the model without the explicit need for additional programming and allowing different versions of a model to be maintained in parallel. Data hiding is applied to model variables within a model block that should only be accessed through dedicated ports.

## 4.2 Simulation Engine

The simulation engine tells each model block when to compute the value of its variables for a specific point in time. The model block responds by telling the simulation engine when it should calculate again. To keep the model output comprehensible for the user, the simulation engine always keeps all model blocks up to date with the global simulation time.

A problem arises when trying to calculate more than one variable in a model block. Consider, for example, a model with two model blocks (Figure 3). Model block A has the variables X and Y and model block B has the variable Z. The value of the variables is calculated as:

$$A:\begin{cases} X_t = f\left(Y_{t-1}, Z_{t-1}\right) \\ Y_t = g\left(Z_t\right) \end{cases}$$

$$B:\left\{ Z_t = h\left(X_t\right) \right.$$

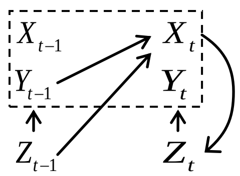


**Figure 3** Example of relationships between variables in different model blocks.

These relations are depicted schematically on the right hand side of Figure 3. The arrows indicate that a variable (head) is dependent on the value of another variable (tail). We can easily see that X should be calculated before Y and Z, and Z should be calculated before Y. However, if X and Y are in the same model block, they should be calculated simultaneously, because calculation procedures are associated with model blocks, not with individual variables. We must therefore make a distinction between variables that are dependent on a lagged value (accumulating variables)and variables that are only dependent on current values (transitory variables). So X is an accumulating variable and Y and Z are transitory variables. The complete determination of the type of a variable is depicted below in Figure 4.

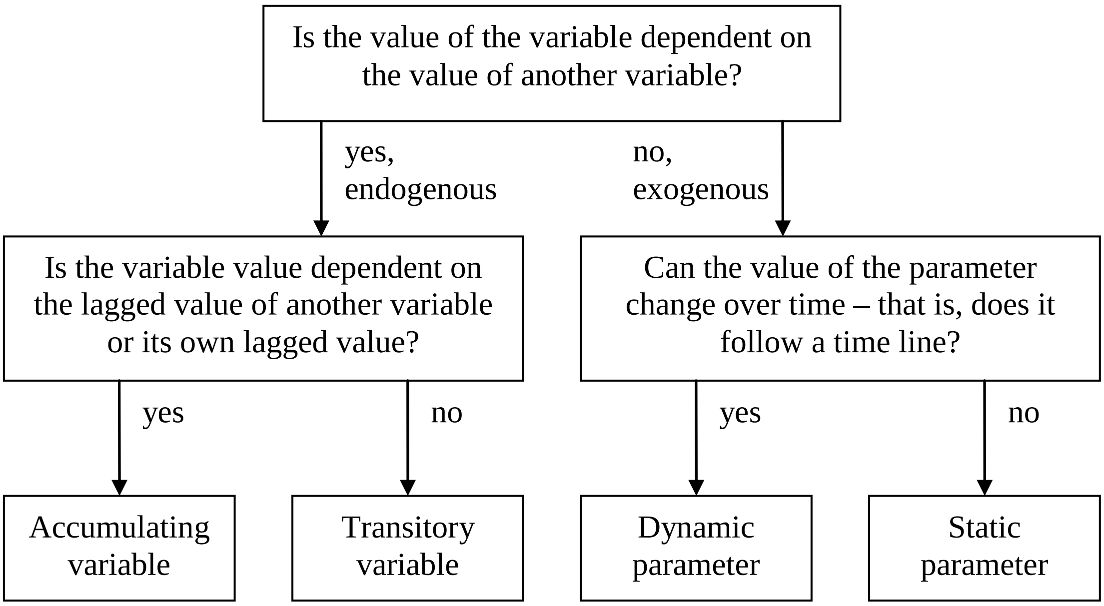



**Figure 4** Logic diagram showing differences between variables and parameters.

To model the example in Figure 3, we split the computation of a model block into two parts: one in which all accumulating variables are calculated and one in which all transitory variables are calculated. First, all accumulating variables are calculated for all model blocks. Next all transitory variables are calculated. This separation does not resolve all precedence relations. In the example above (Figure 3), we see that the transitory variables of model block A should still be calculated before those of model block B.

Because accumulating variables depend on lagged values, we need to specify an initial value at the start of a simulation. The initial value replaces the calculation procedure for accumulating variables at the beginning of a simulation. Once the simulation begins, the model calculates the transitory variables, which are then used to calculate and update the accumulating variables.

Once we know the dependencies between variables, the remaining precedence relations can be derived automatically. On the left in Figure 5, we see a non-lagged relation and on the right we see a lagged relation. Depending on the variable type, X and Y will have six different possibilities (Table 1).

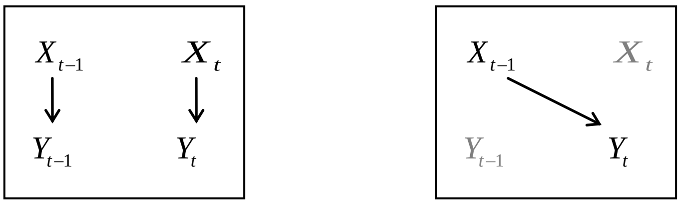



**Figure 5** Non-lagged (left image) and lagged (right image) relationships between model variables.

**Table 1** Six possible relationships between model variables. T stands for a transitory variable and A for an accumulating variable

| Relation | $X_{t-1}$ | $X_t$ | $Y_t$ | Meaning | Brief |
|---|---|---|---|---|---|
| $Y_t = f(X_t)$ | - | T | T | *X* must be calculated before *Y* is calculated. | $X < Y$ |
| $Y_t = f(X_t, Y_{t-1})$ | - | T | A | This is impossible, since all accumulating variables must be calculated before all transitory variables. | - |
| $Y_t = f(X_t)$ | - | A | T | OK; all accumulating variables are calculated before all transitory variables. | OK |
| $Y_t = f(X_t, Y_{t-1})$ | - | A | A | X must be calculated before Y is calculated. | $X < Y$ |
| $Y_t = f(X_{t-1}, Y_{t-1})$ | T | - | A | OK; all accumulating variables are calculated before all transitory variables. | OK |
| $Y_t = f(X_{t-1}, Y_{t-1})$ | A | - | A | Y must be calculated before X is calculated. | $Y < X$ |

The relations between variables can be derived from the connections between input and output ports. Hence, the order in which the variables of the model should be calculated can be derived once we know the model coupling. To upscale this order to model blocks, we add equality relations (in terms of precedence) between all accumulating and all transitory variables of the same model block. Note that, since the precedence relations between variables are relevant to either the accumulating or transitory computation phase, depending on the type of variables involved, the order in which model block calculate can differ in the two phases.

While the GEONAMICA® framework builds on the DEVS formalism, it does not comply with it fully. In the DEVS formalism, the distinction is made between rate and state variables. First, the change of all state variables are calculated and stored in rate variables. Next, the state variables are updated with the rate variables. This method allows model blocks to calculate completely independently at the cost of having to store the change of each variable explicitly, even when a variable could be updated directly. The GEONAMICA® model framework takes advantage of such redundancies to reduce the strain on resources. This comes at the cost of generality. Any specific model that can be implemented using the DEVS formalism can be also implemented using the GEONAMICA® modelling framework.

## 4.3 Incorporating User Input

The simulation engine keeps all model blocks up to date with the current simulation time to present a comprehensible output to the user. During the course of a simulation, we iteratively take time steps to advance the state of the system. At the start of a time step, we update parameter values changed by the user and recalculate the transitory variables dependent on these parameters. Next, we can advance the simulation clock and calculate the accumulating variables of each model block in the order derived from the precedence relations between variables. Finally, the transitory variables of each model block are updated in their respective order and the new output is presented to the user. The next simulation step is performed when the user instructs the system to do so or automatically if desired.

If we strictly follow the process outlined, a user could interact with the system only after a single time step is completed and before the next one starts. Allowing a user to alter parameter values in the middle of a simulation step could result in undetermined system behaviour, especially if they alter parameter that should remain constant, i.e. a parameter in a biophysical model that has been empirically determined. We therefore need a mechanism that allows the user to interact with the system during the course of a simulation step, but guarantees that parameter values remain constant during this period. This mechanism has been incorporated in the interface ports of model blocks.

Interface ports provide access to the parameter values of a model block that can be altered by the user between simulation steps. The changes made in the user interface are cached in the interface port to which the user interface is linked. At the beginning of a simulation step, the user interface ports are instructed to relay their cached changes to the actual parameter values. This way, we require no further synchronisation between user interface and model processes, as far as the updating of parameter values is concerned, thereby greatly reducing the overhead caused by such synchronisation issues.

# 5 Climate Change Scenarios – NIWA

## 5.1 Metadata

| | | |
|---|---|---|
| 1. | Model Component | **CLIMATE CHANGE SCENARIOS** |
| 2. | Organisation | NIWA |
| 3. | Contact | Andrew Tait |
| 4. | Spatial Resolution | 0.05° lat/long (~ 5km) (as grid) |
| 5. | Temporal Resolution | Annual |
| 6. | Input Data | None |
| 7. | Internal Data | 1990 Temperature (°C, as grid)<br>2050 Temperature – IPCC Low Scenario (°C, as grid)<br>2050 Temperature – IPCC Medium Scenario (°C, as grid)<br>2050 Temperature – IPCC High Scenario (°C, as grid)<br>1990 Rainfall (mm, as grid)<br>2050 Rainfall – IPCC Low Scenario (mm, as grid)<br>2050 Rainfall – IPCC Medium Scenario (mm, as grid)<br>2050 Rainfall – IPCC High Scenario (mm, as grid)<br>1990 Potential Evapotranspiration (mm, as grid)<br>2050 Potential Evapotranspiration – IPCC Low Scenario (mm, as grid)<br>2050 Potential Evapotranspiration – IPCC Medium Scenario (mm, as grid)<br>2050 Potential Evapotranspiration – IPCC High Scenario (mm, as grid)<br>Annual Anomalies 1972–2007 – Temperature (°C, as series of grids)<br>Annual Anomalies 1972–2007 – Rainfall (mm, as series of grids)<br>Annual Anomalies 1972–2007 – Potential Evapotranspiration (mm, as series of grids) |
| 8. | Output Data | Temperature (°C, as grid)<br>Rainfall (mm, as grid)<br>Potential Evapotranspiration (mm, as grid) |

## 5.2 Summary

Climate change scenarios project trends to 2050 for annual rainfall (mm), annual average temperature (°C) and annual potential evapotranspiration (PET, mm). The three scenarios correspond to three greenhouse gas emissions scenarios produced as part of the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (Nakicenovic et al. 2000):

- Low, Scenario B1: +1.8°C global mean warming by 2100
- Medium, Scenario A1B: 2.8°C global mean warming by 2100
- High, Scenario A1FI: +4.0°C global mean warming by 2100.

The climate change scenario projections are based on the average of output from 12 Global Climate Models (GCMs) compiled for the IPCC AR4. GCM output has been statistically downscaled to 0.05° lat/long (approximately 5 km) spatial resolution for all of New Zealand.

A user may also specify no climate change trend. In addition a user may decide whether or not to include historic inter-annual variability, resulting in 8 possible climate scenarios (Figure 6). Historic inter-annual variability adds year-to-year variation to the long-run climate trends based on observed values related to shorter term climatic cycles such as El Niño/La Niña.

| | | Climate Change Scenario | | | |
|---|---|---|---|---|---|
| | | None | Low | Medium | High |
| Interannual Variability | Yes | | | | |
| | No | | | | |

**Figure 6** WISE climate scenario options.

## 5.3 Description

Predictions of future climate depend on projections of future concentrations of greenhouse gases and aerosols. These depend on projections of emissions, which depend on changes in population, economic growth, technology, energy availability and national and international policies. The IPCC developed 35 different future emissions pathways or ‘scenarios’ (Nakicenovic et al. 2000) as a basis for projecting future climate changes. These SRES scenarios formed the basis of much of the climate projection work done for the IPCC’s Third and Fourth Assessments (AR3 & AR4).

Figure 7 indicates a range of possible future global temperatures that reflect the range of plausible emissions scenarios and the range of Atmosphere-Ocean GCM (AOGCM) predictions for given scenarios. All the SRES scenarios project ongoing increases in the atmospheric *concentration* of greenhouse gases over the coming century, even those scenarios where the *emissions* start to decrease at some point before 2100. The projected global temperature increases from all scenarios over the next 50–100 years are much larger than those that have occurred over the past 1000 years. The IPCC does not contend that any one SRES scenario is more likely than any other – it is as if they have provided dice for predicting future conditions with 35 equally weighted sides.

To identify likely future climate changes across New Zealand, projections of global and large-scale regional changes must be ‘downscaled’. The New Zealand downscaled projections produced for WISE are B1, A1B and A2 changes relative to 1980–1999 (i.e. the 20-year period centred on 1990), which is identified as the “current climate”. Changes in the mean annual rainfall, mean annual temperature and PET are calculated for the future period 2040–2059 (i.e. the 20-year period centred on 2050). Intervening values (1990–20) are linearly interpolated between the start (1990) and end (2050) values.

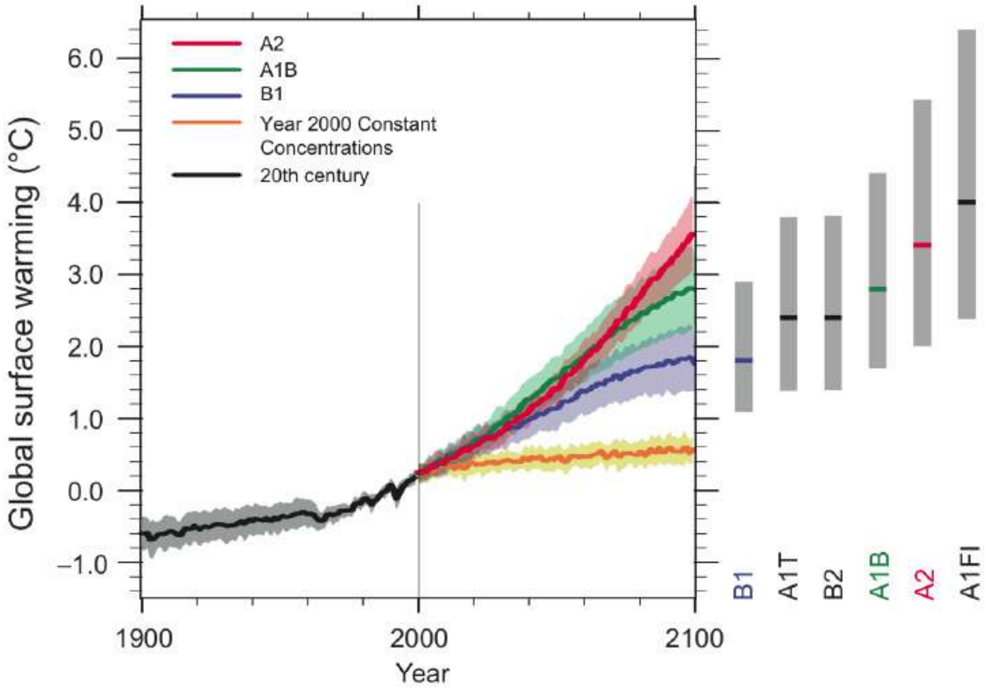



**Figure 7** IPCC multi-model temperature projections for selected scenarios. Solid lines are multi-model global averages of surface warming (relative to 1980–1999) for scenarios B1, A1B and A2, shown as continuations of the 20th century simulations. The solid orange line is for the future commitment experiment where concentrations were held constant at year 2000 values. The coloured shading denotes the ±1 standard deviation range of individual model annual averages. The grey bars at right indicate the best estimate (solid horizontal line within each grey bar) and the 'likely range' for all 6 SRES marker scenarios. (Source: Figure SPM-5, IPCC Summary for Policymakers, IPCC 2007.)

A range of possible values for each climate variable (rainfall, temperature and PET) is included in WISE. This reflects the range of greenhouse gas futures represented by 3 of the 6 main SRES scenarios (B1 = Low, A1B = Medium, A1F1 = High) evaluated in the AR4 process. Like the IPCC, we do not indicate whether any one emission scenario is more likely than another. The rainfall, temperature and PET changes are averaged from the 12 GCM models used in the downscaling exercise.

WISE also includes annual grids of temperature, rainfall and PET anomalies, which are annual differences from the long-term mean for the period 1972–2007 (35 years). If a user chooses, the inter-annual variability (anomalies) can be superimposed on the climate change trends to simulate natural year-to-year variations in weather patterns that are driven by events such as El Niño/La Niña. This 35-year data sequence is repeated to provide climate change estimations up to 2050 (Figure 8).

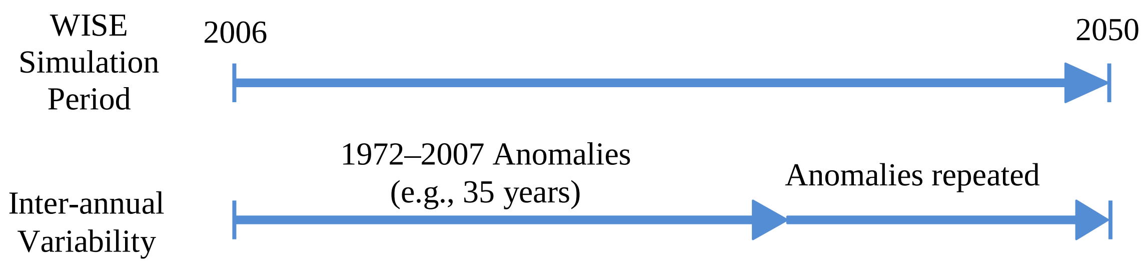



**Figure 8** Implementation of inter-annual climatic variability in WISE.

## 5.4 Equations

Climate change scenarios include values for the start year (1990) and end year (2050) for each cell of the 0.05° grid. Values for intervening years for each grid cell are linearly interpolated based on the slope between the climate scenario start year (1990) and end year (2050), such as for temperature:

$$Temp_{t,x,y} = \left( \frac{Temp_{2050,x,y} - Temp_{1990,x,y}}{60} \right) \times Temp_{1990,x,y}$$

where

$Temp_{t,x,y}$ = Temperature in current year *t* at grid cell *x*,*y* in °C

$Temp_{2050,x,y}$ = Temperature in 2050 at grid cell *x*,*y* in °C

$Temp_{1990,x,y}$ = Temperature in 1990 at grid cell *x*,*y* in °C

Note that the Climate Scenario start year (1990) is *not* the same as the start year of the WISE simulation (2006). Values for the climate layers at 2006 are interpolated as described above.

There are no model equations associated with inter-annual variability. Each year is supplied as its own grid.

## 5.5 Links

The Climate Change Scenarios link to the Hydrology and Water Quality models as indicated in Table 2.

**Table 2** Links between the Climate Change Scenarios and other models

| Type | Model Component | Data Passed | Comments |
|---|---|---|---|
| Inputs | none | | |
| Outputs | Hydrology | Rainfall | |
| | | PET | |
| | Water Quality | Rainfall | Weighted average of the 4 nearest 0.05° grid cells applied to each sub-catchment |

# 6 Hydrology – NIWA

## 6.1 Metadata

| | | |
|---|---|---|
| 1. | Model Component | **Hydrology** |
| 2. | Organisation | NIWA |
| 3. | Contact | Daniel Collins and Ross Woods |
| 4. | Spatial Resolution | 500 m (as grid) |
| 5. | Temporal Resolution | Annual |
| 6. | Input Data Required | Annual rainfall (mm/y, as grid)<br>Annual potential evapotranspiration (mm/y, as grid)<br>Land use (as grid) |
| 7. | Internal Parameters | Seasonality of rainfall (dimensionless, 0–1, as grid)<br>Seasonality of potential evapotranspiration (dimensionless, 0–1, as grid)<br>Mean number of rain days per year (days, as grid)<br>Profile readily available water capacity in soil (mm, as grid)<br>Flow seasonality (no dimensions, 0–1, as grid)<br>Land use categories (as grid)<br>Canopy capacity (mm, as a parameter look-up table from Land Use categories) |
| 8. | Output Data | Annual runoff for the year (mm/year, as grid)<br>Minimum monthly summer flow yield per unit area (litres $s^{-1}$ $km^{-2}$, as grid) |

## 6.2 Summary

The Hydrology model is a simple hydrological simulation model developed specifically for WISE. It includes the impacts of spatially varying climate, soil and vegetation on hydrological response. The outputs of the model are the annual surface water runoff for each year and the expected water yield in the single driest summer month.

## 6.3 Description

The Hydrology model assumes that climate varies smoothly during each year, and that within this smooth seasonal variation, rain falls in random pulses. The random pulses of rain are stored on the plant canopy if there is sufficient capacity, and then evaporated. Excess rain overflows the canopy and reaches the ground, where it is assumed to gradually fill the soil moisture store. Once the soil moisture store fills (in winter), any additional rain produces runoff. Recharge of groundwater by deep seepage of excess soil water is assumed to be negligible. Water is evaporated from this soil water store at the potential evapotranspiration rate until the store is empty. The basic structure of the model for a grid cell is shown in Figure 9, and the seasonal filling and emptying of soil moisture are shown in Figure 10.

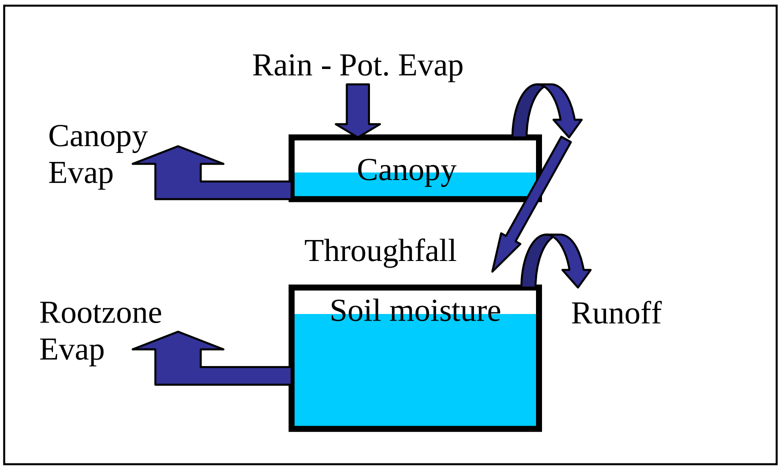



**Figure 9** The inputs, outputs, and storages of the annual hydrology model.

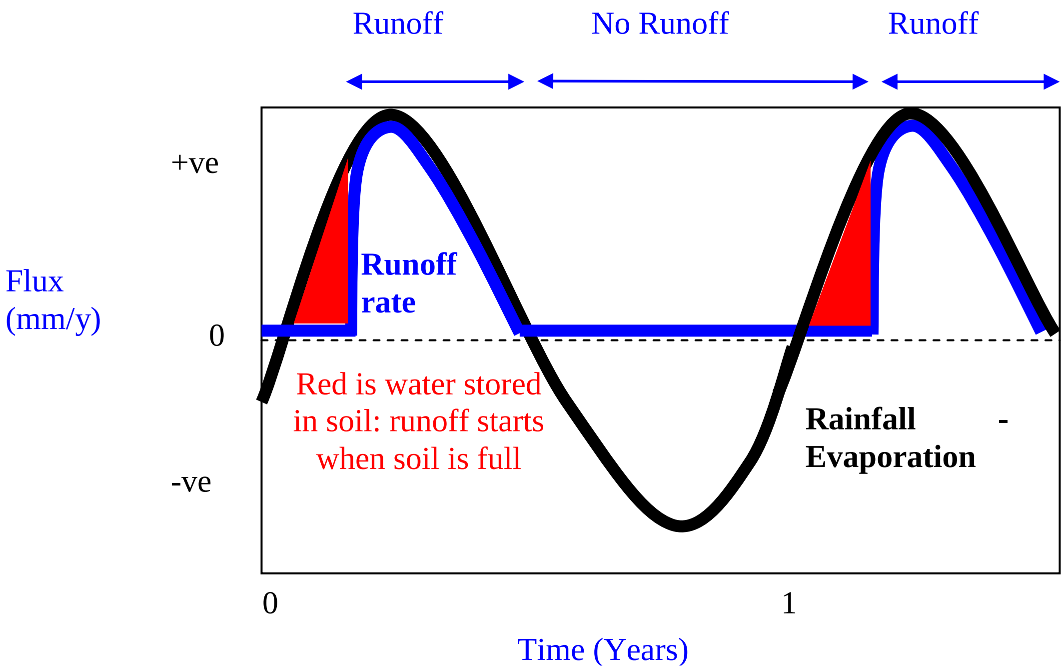



**Figure 10** The annual filling and emptying of soil moisture in response to climate seasonality.

If there are changes in the modelled climate or vegetation, then the model outputs will respond to this. Changes in climate affect the rainfall and potential evapotranspiration (PET), whereas changes in vegetation affect mainly the interception capacity of the plant canopy.

Calculations are made separately for a 500 m × 500 m grid using a simplified set of analytical solutions, based on Woods (2003, 2007). The summer flows are calculated as a predicted proportion of the flow for the year, based on empirical analysis of data from the Waikato region. Sample applications of this model for New Zealand, Australia and globally have been presented at a recent international conference (Woods 2008).

Canopy capacity is determined by current land use from the Land Use Change model through a look-up table. Soil water holding capacity comes from the Fundamental Soils Layer, which is found in the New Zealand Land Resource Inventory (Wilde et al. 2000); these values only apply to the upper 0.9m of the soil profile. The water holding capacity value is adjusted to account for increased rooting depth of tall vegetation (Schenk & Jackson 2002 J. Ecology).

## 6.4 Equations

### Climate component

The model is based on dimensionless variables (as indices) describing the various components of the water balance. As the first step, a non-dimensional climate dryness index $R$ is calculated, which describes mean annual potential evaporation as a fraction of mean annual rainfall. Small values of $R$ ($R<1$) mean that annual rainfall exceeds annual potential evaporation, i.e. a wet climate, whereas $R > 1$ indicates a dry climate. In the Waikato, $R$ ranges from about 0.3 (very wet) to 0.7 (moderately wet) on an annual basis:

$$R = \frac{E_P}{P}$$

where

$P$ = Annual rainfall (mm/y)

$E_P$ = Annual potential evaporation (mm/y)

The mean rate of rainfall and potential evaporation are assumed to vary seasonally as sine functions, with the amplitude and timing of the maxima and minima determined by the rainfall and potential evaporation seasonality parameters $\delta_P$ and $\delta_E$ (Woods 2003). Hence, a climate seasonality index, $S$, can be defined, where small values indicate that the ratio between potential evaporation and rainfall does not change much during the year:

$$S = |\delta_P - \delta_E R|$$

where

$\delta_P$ and $\delta_E$ = dimensionless seasonal amplitude of rainfall and potential evaporation

Specifically, the seasonal variations in rainfall and potential evaporation rates are modelled as sine curves whose amplitudes are $P\delta_P$ and $E_P\delta_E$, respectively. In winter, the rainfall and potential evaporation rates are $P(1+\delta_P)$, and $E_P(1+\delta_E)$, respectively, while in summer they are $P(1-\delta_P)$, and $E_P(1-\delta_E)$. In the Waikato, rainfall has a weak to mild winter maximum, implying $\delta_P$ values ranging from 0.1 to 0.3, and potential evaporation has a strong to moderate summer maximum, with $\delta_E$ values ranging from –0.9 to –0.7.[2] Typical values of $S$ are about 0.4 – 0.5 in the Waikato region.

### Canopy component

The intermittency of the rainfall distribution is described by the input variable $N$, the number of raindays per annum. The mean rainstorm event depth (mm) over that time can be derived as $P/N$. A dimensionless canopy storage capacity, $W_c$, can be calculated, indicating what proportion of an average rain event can be stored in canopy:

$$W_c = \frac{w_{cm}}{P/N}$$

---

[2] If $\delta_P$ is positive, the largest seasonal rainfall is at the end of July; if $\delta_P$ is negative, the largest seasonal rainfall is at the end of January; a positive value of $\delta_E$ indicates the potential evaporation has a seasonal maximum at the end of July (Northern Hemisphere), while a negative $\delta_E$ gives a January maximum (Southern Hemisphere).

where

$w_{cm}$ = Canopy capacity (mm)

$N$ = Number of raindays per annum

From the above the mean annual dimensionless canopy throughfall $Z_c$, can be calculated as a fraction of the annual rainfall (Woods 2003):

$$Z_c = \frac{1 - R^{-1}}{e^{W_c\left(1-R^{-1}\right)} - R^{-1}}$$

**Soil component**

The root zone dryness index, $R_r$ is calculated as the ratio of precipitation at the soil surface (= throughfall) to potential evaporation at the soil surface (= potential evaporation – canopy evaporation) (see Woods (2003) for derivation):

$$R_r = \frac{R - \left(1 - Z_c\right)}{Z_c}$$

In similar fashion, the seasonality index for the net root zone input, $S_r$, is derived from the climate seasonality index ($S$) as the dimensionless amplitude of net root zone input relative to mean throughfall. A large value of $S_r$ indicates a marked seasonal imbalance between supply and demand for root zone water:

$$S_r = \frac{S}{Z_c}$$

A dimensionless index for profile readily-available water, $W_r$, can be calculated, indicating how much annual rain can be stored in soil zone:

$$W_r = \frac{w_{rm}}{TP}$$

where

$w_{rm}$ = $w_{rm0}$ max[1, $(w_{cm} / w_{cm\_ref})^2$] this provides an adjusted water holding capacity, with allowance for deeper rooting depth of plants taller than pasture

$w_{rm\_ref}$ = canopy capacity of pasture (1 mm)

$w_{rm0}$ = Profile readily available water (mm, provided as soil attribute, see Wilde et al. 2000)

$T$ = 1 year

The seasonality index for the net input into the root zone can now be adjusted for the actual soil water storage capacity leading to the adjusted root zone input seasonality index $S_{rs}$ (Woods 2003):

$$S_{rs} = \max\left(S_r - \pi \frac{W_r}{Z_c}, 0\right)$$

**Runoff component**

With the above definitions, the mean annual runoff as fraction of throughfall, $Z_{rs}$, can be derived as follows (Woods 2003):

$$Z_{rs} = \max\left[\max\left(0,1-R_r\right), S_{rs}h_s\right]$$

where

$$h_s = \begin{cases} 0 & x_s > 1 \\ \dfrac{x_s \sin^{-1}\left(x_s\right) + \sqrt{1-x_s^2}}{\pi} - \dfrac{x_s}{2} & -1 \le x_s \le 1 \\ 1 & x_s < -1 \end{cases}$$

and

$$x_s = \frac{R_r - 1}{S_{rs}}$$

From the above, the mean annual runoff $Q_{ann}$ [mm/y] is derived by scaling mean annual rainfall $P$ with the dimensionless canopy throughfall $Z_c$ and $Z_{rs}$:

$$Q_{ann} = PZ_cZ_{rs}$$

Mean summer runoff, $Q_{summ}$ [mm], is derived by multiplying flow seasonality $q_{seas}$ (an input) with mean annual runoff:

$$Q_{summ} = Q_{ann}q_{seas}$$

where

$q_{seas}$ = Seasonality of flow (0–1, dimensionless)

Flow seasonality $q_{seas}$ is an indicator for how much the annual runoff is concentrated in summer: for the extreme case of $q_{seas}$ = 1 all the annual flow occurs in summer (no flow in winter), for $q_{seas}$ = 0 all the annual flow occurs in winter, for $q_{seas}$ = 0.5 half of the annual flow occurs in summer. For the Waikato region, higher summer runoff occurs in the headwaters of the central volcanic plateau, whereas the lower Waikato has a more equal flow distribution over the year.

Mean summer specific yield, $Y_{summ}$ [L $s^{-1}$ $km^{-2}$], is calculated from mean summer runoff, by unit conversion:

$$Y_{summ} = \frac{10^6}{365.25 \times 24 \times 3600} Q_{summ}$$

## 6.5 Links

The Hydrology model links to the Climate Change Scenario and the Land Use Change models as indicated in Table 3.

**Table 3** Links between the Hydrology model, the Climate Change model and Land Use Change models.

| Type | Model Component | Data Passed | Comments |
|---|---|---|---|

| | | | |
|---|---|---|---|
| Inputs | Climate Change Scenarios | Rainfall | Weighted average of the 4 nearest grid cells |
| | | PET | Weighted average of the 4 nearest grid cells |
| | Land Use Change | Land Use | Land use determines the canopy capacity $w_{cm}$ (mm) via a look-up table |
| Outputs | None | | |

# 7 Waikato Region Dynamic Economy-Environment Model (WRDEEM) – Market Economics and Massey University

## 7.1 Metadata

| | | |
|---|---|---|
| 1. | Name | Waikato Region Dynamic Environment-Economy Model (WRDEEM) |
| 2. | Organisation | Market Economics and Massey University |
| 3. | Contact | Garry McDonald |
| 4. | Spatial Resolution | Region |
| 5. | Temporal Resolution | Annual |
| 6. | Input Data | Population (# persons by age, sex)<br>International Exports ($\$_{2007}$million NZD, time series)<br>Inter-regional Exports ($\$_{2007}$million NZD, time series)<br>Gross Fixed Capital Formation ($\$_{2007}$million NZD, time series)<br>Change in Inventory ($\$_{2007}$million NZD, time series)<br>Land-Use Productivity Index (unitless)<br>Labour Force Productivity Rates (%, time series) |
| 7. | Internal Data | Leontief Input-Output Matrix Coefficients<br>Ghosh Supply Input-Output Matrix Coefficients<br>Age-Cohort Consumption Coefficients |
| 8. | Output Data | Final Output for approximately 50 Economic Industries ($\$_{2007}$million NZD)<br>Gross Regional Product ($\$_{2007}$million NZD)<br>Land Demanded by Economic Industry (hectares)<br>Labour Force Participation (%)<br>Employment (# of jobs)<br>Unemployment (%)<br>Resource Inputs (units vary)<br>Residual Outputs (units vary)<br>Energy Demands (Gigajoules) |

## 7.2 Summary

The section describes the structure of the Waikato Region Dynamic Environment-Economy Model (WRDEEM), followed by a detailed mathematical description of WRDEEM's modules. Appendix A is an index relating: (1) industry notations to their associated approximately 50 industry definitions; (2) the land-use category notations to their full descriptions; (3) the socio-economic reporting variable notations to their full names; (4) the employment reporting variable notations to their full names; and (5) the environmental reporting variable notations to their full names. Appendix B describes the method used to translate outputs provided by the WRDEEM model at the Australia-New Zealand Standard Industrial Code (ANZSIC) approximately 50-class level to the 25 land-use classes used within the Land Use Change model.

WRDEEM is based primarily on an analysis of economic activities within the Waikato region, with all economic activities categorised into one of  industry types (refer to Appendix A). The economic system is also conceptualised as open, in the sense that account is taken of international and inter-regional imports and exports. Finally, WRDEEM runs over a period of 43 years, beginning with a base year of 2007 and ending in 2050. Note, however, that the economic model in WISE has been extrapolated to begin in 2006.

Figure 11 depicts the causal structure of the WRDEEM model. This is followed below by a detailed commentary on the model structure. As a starting point, it can be noted that WRDEEM is composed of two economic modules, one relating to 'economic demand' the other to 'economic supply'. The demand and supply modules are not, however, directly connected. The Demand-Side module provides estimates of land demand by economic industry that then feed into the Land Use Change model. Subsequently, the outputs of the Land Use Change model act as an input to the Supply-Side module.

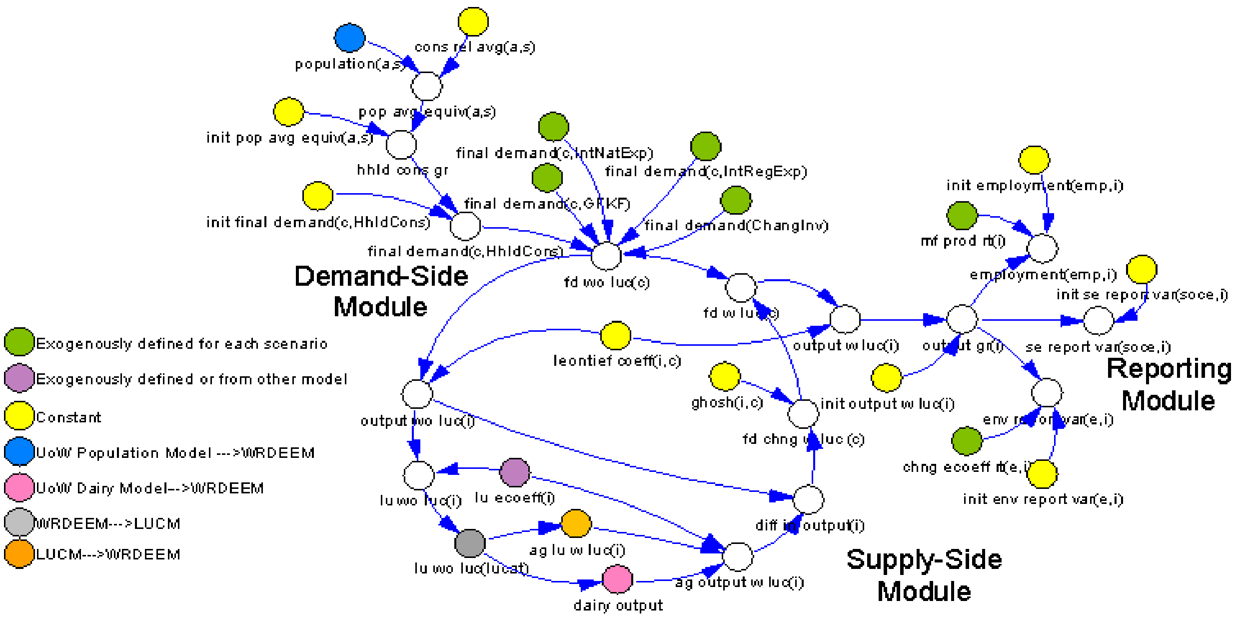



**Figure 11** WRDEEM system structure.

## 7.3 Description

The purpose of the two WRDEEM economic modules is to estimate future economic outputs for each of the  economic industries within the Waikato region. Once estimates of economic output are obtained, they are translated into socio-economic and environmental reporting variables.

### 7.3.1 Demand-Side Module

WRDEEM's estimates of economic output by industry are primarily determined through the application of the Demand-Side module. First, the module estimates future outputs of each industry based on projections of future final demands for each industry's goods and services driven by within-regional household demand and exports to other regions in New Zealand and internationally. Second, the module translates demand-based output estimates to estimates of land demanded (hectares) by each industry. This translation is necessary so as to interface with the Land Use Change model. These two processes are discussed further below.

### 7.3.2 Demand-Side Estimates of Output by Industry

To derive demand-based estimates of output by each industry, the model first derives estimates of the total annual value of final demands for Waikato Region's commodities for each year of the study ($fd\ wo\ luc_c$). It then calculates the annual total economic output (intermediate and final goods) required to be produced by each industry within the region ($output\ wo\ luc_i$) to satisfy that level of final demands. Importantly, the model considers not only the *direct* impacts of changes in future final demand, but also the *indirect* supply-chain (or backward linkages) associated with these changes. Growth in a service industry final demand may, for example, result in growth in manufacturing and primary industry output because of supply-chain purchases. The application of economic interdependencies (also termed 'Leontief inverse coefficients') is essential for evaluating these indirect or supply-chain effects. The economic interdependencies used in the model ($leontief\ coeff_{i,c}$) are derived exogenously through application of input-output mathematics prescribed in the model.

The estimates of future total final demand by commodity comprise five categories: household consumption ($final\ demand_{c,HhldCons}$), international exports ($final\ demand_{c,IntNatExp}$), inter-regional exports ($final\ demand_{c,IntRegExp}$), gross fixed capital formation ($final\ demand_{c,GFKF}$), and changes in inventory ($final\ demand_{c,ChngInv}$). The process for deriving future estimates for each category is as follows:

(a) *Household Consumption*: WRDEEM derives estimates of future household consumption primarily though estimates of future population. Except as qualified below by the population ageing effect, it is assumed that each person within the Waikato Region consumes a constant mix of goods and services. Thus, any population growth for the region will result in a proportional increase in the amount of goods and services consumed. The model utilises Waikato region population projections by 1-year age-sex cohort as provided from Whole of Waikato demographic model (see Section 10 below).

To account for the implications of changing demographic structure on household consumption, WRDEEM multiplies each cohort projection for a particular year by a cohort-specific consumption scalar ($cons\ rel\ avg_{a,s}$). These scalars define the ratio of spending by an average person across all cohorts, to the spending of an average person within the subject cohort. The summed values across all cohorts for a given year are then normalized to $\$_{2007}$million NZD (the base year for WRDEEM0. The resulting value for a particular year provides an estimate of the growth in total household consumption (*hhld cons gr*) from the base year ($init\ final\ demand_{c,HhldCons}$).

(b) *International Exports*: Estimates of future international exports are exogenous inputs to the model and may be changed by the user to suit the scenario being investigated. WRDEEM includes baseline projects for future international exports that were generated by applying the national long-run average growth rates for export commodities by industry to the Waikato region's 2004 international export estimates obtained from Market Economics Ltd's multi-regional input-output table for the Waikato region (Market Economics Ltd 2005). The long-run growth rates by export commodity were determined according to econometric analysis. Selection of the time series techniques applied depended on the underlying dynamic behaviour of the industry output being analysed. Where historical observations fluctuate around a long-run mean, stationary time series methods were applied (e.g., the AMRA process) (Barron & Targett 1985). Where historical observations indicate a consistent upwards or downwards movement, non-stationary time series methods are used (e.g., Holt's method) (Barron & Targett 1985). The data utilised in this time series analysis were derived from Statistics New Zealand's Overseas Trade Exports – Trade, Merchandise: Monthly Estimates of all Harmonised System Items 1989–07.

*(c)* *Inter-regional Exports*: Inter-regional exports (i.e. exports to other regions within New Zealand) are exogenous inputs to the model and can be changed by the user to suit the scenario being investigated. WRDEEM includes a baseline series of the Waikato region's inter-regional exports that were obtained from Market Economics Ltd's (2004) proprietary Economic Futures Model (EFM) under a 'Business-as-Usual' scenario. Baseline inter-regional trade values were derived from the Waikato region estimates produced by EFM's multi-regional input-output table (MRIO). The values are determined as a by-project of the method used to generate the MRIO. That process provides the total value of inter-regional imports and exports; however, it does not partition the total value into specific regional import/export values. To overcome that limitation, linear programming techniques are used that incorporate known imports/exports by sector in each region as constraints and a distance decay function to select between regions, i.e. the model selects those suppliers with surplus outcome that are closest to the region which desires it.

(d) *Gross Fixed Capital Formation (GFKF)*: Estimates of future sales of commodities to gross fixed capital formation are exogenous inputs to the model and can be changed by the user to suit the scenario being investigated. Baseline estimates provided in the WRDEEM model were generated by applying long-run average growth rates to Waikato Region's 2004 GFKF values by industry as obtained from Market Economics Ltd's multi-regional input-output table for the Waikato Region. The growth rates were determined, as with international exports, through statistical time series (econometric) analysis. The data utilised in the time series analysis of GFKF are derived from Statistics New Zealand's National Accounts Gross Fixed Capital Formation by Industry.

*(e)* *Changes in Inventory*: Changes in inventory are also an exogenous input to the model and can also be changed by the user to suit the scenario being investigated. Baseline estimates provided in WRDEEM were calculated from Market Economics Ltd's (2004) proprietary Economic Futures Model. Note: for many industries changes in inventory are very small compared with international exports, inter-regional exports, and GFCF.

### 7.3.3 Demand-Side Estimates of Industry Land Use

The amount of land required by each industry within the Waikato Region ($lu\ wo\ luc_i$) is calculated directly from the estimates of industry output ($output\ wo\ luc_i$). For each year, the annual estimate of output for a particular industry is multiplied by the industry-specific land-use productivity rate ($lu\ ecoeff_i$), which defines the average number of hectares required per million dollars of output for that industry. In WISE, land-use productivity rates are set as constant values according to data calculated for the base year.

### 7.3.4 Interface with the Land Use Change Model

Estimates of land demanded by economic industry constitute the link between WRDEEM and the Land Use Change model. However, before the estimates of land demanded from WRDEEM can be input into the Land Use Change model, the outputs from WRDEEM's -industry classification system must be translated into the 25 land-use categories used in the Land Use Change model ($lu\ wo\ luc_{lucat}$). Appendix B contains the procedure for undertaking this translation.[3]

Once provided with estimates of the land demanded (hectares), the Land Use Change model determines the extent to which the demand can be satisfied by the available supply of land. It is possible that the demand for land, especially agricultural land, will not be met by the supply

[3] Note that $\sum_i lu\ wo\ luc_i$ is greater than $\sum_{lucat} lu\ wo\ luc_{lucat}$ as some of the industry categories (namely, Fishing, Road Transport and Water and Rail Transport) are not allocated to a land-use category. The land required for these activities is either not relevant to the Land Use Change model or will be determined by other models.

of suitable land within the Waikato region. The purpose of the Supply-Side module is therefore to adjust the initial demand-based estimates of economic output by industry so as to account for the potential constraints in the supply of land for different industries. The Land Use Change model provides the actual amount of land supplied by industry (hectares), which is translated to output supplied (million $\$NZD_{2007}$) by the inverse of the land-use productivity rate (1/ *lu* $ecoff_i$). The output supplied is fed back into WRDEEM's Supply-Side module.

### 7.3.5 Supply-Side Module

Once provided with estimates of the annual supply-constrained output, WRDEEM's Supply-Side module calculates the indirect flow on (or forward linkages) impacts of constraints on land use, for example, a reduction in the land used for Dairy Cattle Farming will result not only in a direct reduction in Dairy Cattle Farming output but also, through indirect forward linkages, in a reduction in Dairy Processing output. These effects are captured through the use of input-output mathematics (i.e. the $ghosh_{i,c}$), which enables calculation of the supply-constrained adjustments required to the original estimates of total final demand by commodity (*fd chng w* $luc_c$). Once these adjustments are made, new estimates of final demand for the Waikato Region are provided (*fd w* $luc_c$) that take account of potential constraints in the availability of land for Dairy Cattle Farming. To complete the Supply-Side module, the new estimates of total final demand by commodity are then translated into final estimates of industry output (*output w* $luc_i$) through application of input-output mathematics (*leontief* $coeff_{i,c}$).

### 7.3.6 Reporting Module

This module translates the estimates of industry output (*output w* $luc_i$) into various indicators for reporting. WRDEEM produces the following series of indicators:

*(1)* *Socio-economic*: Each indicator (*se report* $var_{soce,i}$) is calculated by taking estimates of the value of the indicator for industry *i* in the 2007 base year, and multiplying by a scalar that defines the total change in industry *i* output from the base year (*output* $gr_i$). All values are million $\$NZD_{2007.}$

  *a.* Added value

  *b.* International imports

  *c.* Final demand

  *d.* Output

  *e.* Household consumption

*(2)* *Employment/Occupation*: Employment/occupation (Modified Employment Counts or MCEs) for each industry *i* ($employment_{emp,i}$) are calculated in a similar method to the socio-economic indicators described in (1), with employment/occupations for industry *i* for the 2007 base year multiplied by a change in output scalar for the industry (*output* $gr_i$). A further multiplication is then required to take account for the rate of change in labour force productivity. Default productivity values have been incorporated into the model.

(3) *Environmental*: Seven environmental indicators are calculated for each industry. Their calculation begins by multiplying a particular industry's base environmental indicator for 2007 (*env report* $var_{e,i}$) by the growth in that industry's output from the 2007 base year (*output* $gr_i$). Account is also taken of improvements in eco-efficiency/reductions in residuals over time. The rates of change in eco-efficiency (*chng ecoeff* $rt_{e,i}$) are set exogenously, and a user can change the values to suit the scenario being explored.

a. Energy Use – Diesel (gigajoules of oil equivalent)
b. Energy Use – Electricity (gigajoules of oil equivalent)
c. Energy Use – Geothermal (gigajoules of oil equivalent)
d. Energy Use – Petrol (gigajoules of oil equivalent)
e. Energy Use – Total (gigajoules of oil equivalent)
f. Energy-related CO2 emissions (tonnes)
g. Solid waste (tonnes).

## 7.4 Equations

### 7.4.1 Elements and Arrays within WRDEEM

A complete list of arrays and their elements is presented below. Because WRDEEM utilises input–output mathematics, it assumes that each industry produces only one homogenous commodity (i.e. Ind01 produces only Com01). A concordance matching the industry (*i*) notations to the WRDEEM industry codes and full names is provided in Appendix A. Also provided in this appendix are the concordances matching the environmental and socio-economic reporting variable notations (*e*, *emp*, *soce*) to the associated full names and a concordance matching the land use categories (*lucat*) notations to the full land-use category names.

| | | |
|---|---|---|
| Age | *a* | = 0–4 yrs, 5–9 yrs 10–14 yrs, 15–19 yrs, 20–24 yrs, 25–29 yrs, 30–34 yrs, 35–39 yrs, 40–44 yrs, 45– yrs, 50–54 yrs, 55–59 yrs, 60–64 yrs, 65–69 yrs, 70–74 yrs, 75–79 yrs, 80–85 yrs, 85 yrs and over |
| Commodity | *c* | = Com01, Com02, Com03, Com04, Com05, Com06, Com07, Com08, Com09, Com10, Com11, Com12, Com13, Com14, Com15, Com16, Com17, Com18, Com19, Com20, Com21, Com22, Com23, Com24, Com25, Com26, Com27, Com28, Com29, Com30, Com31, Com32, Com33, Com34, Com35, Com36, Com137, Com38, Com39, Com40, Com41, Com42, Com43, Com44, Com45, Com46, Com47, Com48 |
| Environment Reporting Variable | *e* | ERV01, ERV02, ERV03, ERV04, ERV05, ERV06, ERV07, ERV08, ERV09, ERV10, ERV11, ERV12, ERV13, ERV14, ERV15, ERV16, ERV17, ERV18, ERV19, ERV20, ERV21, ERV22, ERV23, ERV24, ERV25, ERV26, ERV27, ERV28, ERV29, ERV30, ERV31, ERV32, ERV33, ERV34, ERV35, ERV36, ERV37, ERV38, ERV39, ERV40, ERV41, ERV42, ERV43, ERV44, ERV45, ERV46, ERV47, ERV48, , ERV, ERV50, ERV51, ERV52, ERV53, ERV54, ERV55, ERV56, ERV57, ERV58, ERV59 |
| Employment Reporting Variable | *emp* | Emp01, Emp02, Emp03, Emp04, Emp05, Emp06, Emp07, Emp08, Emp09, Emp10, Emp11, Emp12, , Emp13, Emp14, Emp15, Emp16, Emp17, Emp18, Emp19, Emp20, Emp21, Emp22, Emp23, Emp24, Emp25, Emp26, Emp27, Emp28, Emp29, Emp30, Emp31, Emp32, Emp33, Emp34, , Emp35, Emp36, Emp37, Emp38, Emp39, Emp40, Emp41, Emp42, Emp43, Emp44, Emp45, Emp46, Emp47 |

| | | |
|---|---|---|
| Final Demand | *f* | = HhldCons, GFKF, IntRegExp, IntNatExp, ChngInv |
| Industry | *i* | = Ind01, Ind02, Ind03, Ind04, Ind05, Ind06, Ind07, Ind08, Ind09, Ind10, Ind11, Ind12, Ind13, Ind14, Ind15, Ind16, Ind17, Ind18, Ind19, Ind20, Ind21, Ind22, Ind23, Ind24, Ind25, Ind26, Ind27, Ind28, Ind29, Ind30, Ind31, Ind32, Ind33, Ind34, Ind35, Ind36, Ind37, Ind38, Ind39, Ind40, Ind41, Ind42, Ind43, Ind44, Ind45, Ind46, Ind47, Ind48 |
| Land Use Category | *lucat* | =LUCat01, LUCat02, LUCat03, LUCat04, LUCat06, LUCat06, LUCat07, LUCat08, LUCat09, LUCat10, LUCat11 |
| Sex | *s* | = male, female |
| Socio-Economic Reporting Variable | *soce* | = SocEcon01, SocEcon02, SocEcon03 |

### 7.4.2 Demand-Side Module

The demand-side estimates of annual output for a given industry *i* are calculated as:

| | |
|---|---|
| $output\ wo\ luc_i$ | $= \sum_c \left( leont\ coeff_{i,c} \times fd\ wo\ luc_c \right)$. As measured in $\$_{2007}$mil, |

where

| | |
|---|---|
| $leont\ coeff_{i,c}$ | =the Leontief inverse matrix coefficient for commodity *c*, industry *i*. |
| $fd\ wo\ luc_c$ | $= \sum_{f=1}^{n} ( final\ demand_{c,f} )$. The estimate of total annual final demand ($\$_{2007}$mil) for commodity *c* without taking account of potential constraints in the supply of land. |
| $final\ demand_{c,\ HhldCons}$ | $= init\ \ final\ demand_{c,HhldCons} \times hhld\ cons\ gr$. The annual value of commodity *c* sales to household consumption ($\$_{2007}$mil). |
| $final\ demand_{c,GFKF}$ | = an exogenous estimate of the annual sales of commodity *c* to gross fixed capital formation ($\$_{2007}$mil). |
| $final\ demand_{c,IntNatExp}$ | = an exogenous estimate of the annual sales of commodity *c* to international exports ($\$_{2007}$mil). |
| $final\ demand_{c,IntRegExp}$ | = an exogenous estimate of the annual sales of commodity *c* to interregional exports ($\$_{2007}$mil). |
| $final\ demand_{c,\ ChngInv}$ | =an exogenous estimate of the annual sales of commodity *c* to change in inventory stocks ($\$_{2007}$mil). |
| $pop\ avg\ equiv_{a,s}$ | $= population_{a,s} \times cons\ rel\ avg_{a,s}$. A quantification of the spending propensity of a particular age-sex cohort as measured in 2003 average person equivalents. |

*init pop avg equiv*$_{a,s}$ = *pop avg equiv*$_{a,s}$ for the 2007 base year. As measured in 2003 average person equivalents.

*population*$_{a,s}$ = Population projections by age, sex cohort, as measured in number of people. To be obtained from the University of Waikato's Population Model.

*cons rel avg*$_{a,s}$ = Age, sex cohort-specific consumption scalar defining the level of private and public household consumption relative to an average person (dimensionless).

*hhld cons gr* = $\left( \frac{\sum_{a,s} pop\ avg\ equiv_{a,s}}{\sum_{a,s} init\ \ pop\ avg\ equiv_{a,s}} \right)$ A growth scalar in household consumption from the 2007 base year (dimensionless).

*init final demand*$_{c,HhldCons}$ =annual household consumption of commodity *c* for the 2007 base year ($\$_{2007}$ mil).

### 7.4.3 Supply-Side Module

Taking into account the flow-on economic (forward) impacts of constraints in the supply of land for agricultural purposes, final estimates of output by industry ($\$_{2007}$mil) may be determined according to the equation:

*output w luc*$_i$ = $\sum_c \left( leont\ coeff_{i,c} \times fd\ w\,luc_c \right)$,

where

*fd w luc*$_c$ = *fd wo luc*$_c$ + *fd chng w luc*$_c$. The final estimate of total final demand for commodity *c* as measured in $\$_{2007}$mil.

*fd chng w luc*$_c$ = $\sum_i \left( ghosh_{i,c} \times diff\ \ in\,output_i \right)$. The change required ($\$_{2007}$mil) to the demand-side estimate of total final demand for commodity *c* to account for constraints in the supply of agricultural land.

*diff in output*$_i$ *= output w luc*$_i$ *– output wo luc*$_i$,. The difference in land-use estimates for each industry between that derived under the Land Use Change model and that derived from the Demand-Side Module. For non-agricultural industries (i.e. Ind05 and Ind07-Ind48), *diff in output*$_i$ is set to zero as account is only taken of potential constraints in agricultural land.

*ghosh*$_{i,c}$ = The estimated change in annual total final demand for commodity *c* ($\$_{2007}$mil) required to account for a one unit change in the output of industry *i*. These values are determined exogenous to the model and are based on 'forward multipliers' for the agricultural industries.

### 7.4.4 Reporting Module

For each industry category *i* WRDEEM reports 4 socio-economic indicators, an employment/ occupation indicator, and 7 environmental indicators. The method for deriving these indicators is as follows:

| | |
|---|---|
| $se\ report\ var_{soce,i}$ | $= init\ se\ report\ var_{soce,i}$ x $output\ gr_i$. The socio-economic reporting variable for industry *i* ($\$_{2007}$mil). |
| $employment_{emp,i}$ | $= init\ employment_{emp,i} \times output\ gr_i \times (1 - mf\ \ prod\ rt_i)^{(t)-2004}$ The total employment/occupation numbers in industry *i*. The unit of measurement varies according to the reporting variable with employment measured in either full-time-equivalent employees (FTEs), employment counts (ECs) or modified employment counts (MECs) and occupations measured in the number of people employed. |
| $env\ report\ var_{e,i}$ | $= init\ env\ report\ var_{e,i} \times output\ gr_i \times (1 - chng\ ecoeff\ \ rt_i)^{(t)-2004}$ The magnitude of the environmental reporting variable *e* for industry *i*, as measured by GJ of oil equivalents (in the case of delivered energy use), tonnes (in the case of energy-related $CO_2$ emissions and solid waste production) and kg (in the case of $N_2O$ and $CH_4$ emissions). |

where

| | |
|---|---|
| $init\ se\ report\ var_{soce,i}$ | $= se\ report\ var_{soce,i}$ for the 2007 base year as measured in $\$_{2007}$mil. |
| $init\ employment_{emp,i}$ | $= employment_{emp,i}$ for the 2007 base year as measured in FTEs, ECs, MECs or persons. |
| $init\ env\ report\ var_{e,i}$ | $= env\ report\ var_{e,i}$ for the 2007 base year as measured in GJ of oil equivalents (in the case of energy) or in tonnes (in the case of energy-related $CO_2$ emissions and solid waste production) and kg (in the case of $N_2O$ and $CH_4$ emissions). |
| $output\ gr_i$ | $= output\ w\,luc_i\ /\ init\ output\ w\,luc_i$. A scalar defining the level of output of industry *i* relative to the 2007 base year. |
| $init\ output\ w\ luc_i$ | = The value of output ($\$_{2007}$mil) for industry *i* in the 2007 base year. |
| $mf\ prod\ rt_i$ | = The annual rate of increase in output per employee industry *i*. In the sample model these productivities have been set with base values. |
| $chng\ ecoeff\ rt_{e,i}$ | = The annual rate of increase in eco-efficiency for energy use/emission *e* and industry *i*. |

Aggregated socio-economic and environmental indicators can also be determined:

| | |
|---|---|
| $tot\ se\ report\ var_{soce}$ | $= \left(\sum_i value\ added_{soce,i}\right) + hhld\ value\ added_{soce}$. The total estimate of a socio-economic reporting variable (value added, interregional imports or international imports) for the Waikato Region economy ($\$_{2007}$mi). |
| $tot\ employment_{emp}$ | $= \sum_i employment_{emp,i}$ . Total employment/occupation numbers in the Waikato Region economy as measured in FTEs, ECs, MECs or persons. |

*tot env report var*$_e$ = $\left(\sum_i env\ report\ val_{e,i}\right) + hhld\ env\ report\ value_e$ The total energy use/residuals for environmental indicator *e*. Measured in GJ of oil equivalents (in the case of delivered energy use), tonnes (in the case of energy-related $CO_2$ emissions and solid waste production) and kg (in the case of $N_2O$ and $CH_4$ emissions).

where

*hhld se report var*$_{soce}$ = *init hhld se report var*$_{soce}$ x *hhld cons gr*. The value added contribution of households ($\$_{2007}$mil).

*hhld env report var*$_e$ = *init hhld env report value*$_e$ *x hhld cons gr.* The total household energy use/energy related emissions for environmental indicator *e.* Measured in GJ of oil equivalents (in the case of delivered energy use), tonnes (in the case of energy-related $CO_2$ emissions and solid waste production) and kg (in the case of $N_2O$ and $CH_4$ emissions).

*init hhld se report var*$_{soce}$ = *hhld se report var*$_{soce}$ for the 2007 base year ($\$_{2007}$mil).

*init hhld env report var*$_e$ = *hhld envi report var*$_e$ for the 2007 base year.

## 7.5 Links

WRDEEM links with the Demography model and the Land Use Change model (Table 4).

**Table 4** Links between WRDEEM and other models

| Type | Model Component | Data Passed | Comments |
|---|---|---|---|
| Inputs | Land Use Change | Supply of land | Amount of land (ha) supplied to the supply-sidedule to calculate final economic activity (*ag lu w luc*$_i$) |
| | Demography | Population | Population data is passed to calculate labour force participation (%) |
| Outputs | Land Use Change | Demand for land | Amount of land demanded; calculated by multiplying the economic activity ($\$2007_{mln}$) x the land productivity index |

*Demand-Side*

Demand-side estimates of the land required by Waikato region industries are calculated as:

*lu wo luc*$_i$ = *output wo luc*$_i$ x *ind ecoeff*$_{i.}$ The land demanded (ha) by industry *i*.

where

*lu ecoeff*$_i$ = the land productivity of industry *i* as measured by the average area of land required per unit of output (ha per $\$_{2007}$mil). The land productivity estimates for other industries have, at this stage, been set as constant values defined according to the base year.

The demand estimates of land required by each industry according to the -industry classification (i.e. *lu wo* $luc_i$) are aggregated into the 12-industry classification used in the Land Use Change model (*lu wo* $luc_{lucat}$) according to the mapping set out in Appendix B.

*Supply Side*

As discussed earlier, any constraints on agricultural land as determined by the Land Use Change model are returned to the Supply-Side Module according to:

*diff in* $output_i$ = *output w* $luc_i$ – *output wo* $luc_i$,. The difference in land use estimates for each industry between that derived under the Land Use Change model and that derived from the Demand-Side Module. For non-agricultural industries (i.e. Ind05 and Ind07-Ind48), *diff in* $output_i$ is set to zero as account is only taken of potential constraints in agricultural land.

Final demand is then re-recalculated to account for flow-on economic (forward) impacts of land constraints as discussed above. Note that the difference can be positive or negative.

# 8 Water Quality – NIWA

## 8.1 Metadata

| | | |
|---|---|---|
| 1. | Name | **SPARROW - Spatially Referenced Regression on Watershed Attributes** |
| 2. | Organisation | NIWA (with U.S. Geological Survey) |
| 3. | Contact | Sandy Elliott |
| 4. | Spatial Resolution | Stream reach and sub-catchment<br>(typically 0.5 km and 0.5 $km^2$, respectively) |
| 5. | Temporal Resolution | Annual |
| 6. | Input Data | Rainfall (mm) (as grid)<br>Land Use (as grid) |
| 7. | Internal Data | Stream/lake/impoundment network (as shapefile)<br>Slope (as grid)<br>Soil Drainage Class (as grid)<br>Distribution of Point Sources (as shapefile)<br>Delivery Type – Drainage<br>Delivery Type – Rain<br>Land Use Source Coefficient – Nitrogen<br>Land Use Source Coefficient – Phosphorus<br>Land Use Drainage Exponent – Nitrogen<br>Land Use Drainage Exponent – Phosphorus<br>Land Use Rain Exponent – Nitrogen<br>Land Use Rain Exponent – Phosphorus<br>Point Source Load – Nitrogen<br>Point source Load – Phosphorus<br>Reservoir Decay – Nitrogen<br>Reservoir Decay – Phosphorus<br>Stream Attenuation – Low Flow – Nitrogen<br>Stream Attenuation – Low Flow – Phosphorus<br>Stream Attenuation – High Flow – Nitrogen<br>Stream Attenuation – High Flow – Phosphorus |
| 8. | Output Data | Mean Annual Load of Total Nitrogen by Stream reach<br>(mean kg N/year over a 5-year period)<br>Mean Annual Load of Total Phosphorus by Stream reach<br>(mean kg P/year over a 5-year period) |

## 8.2 Summary

SPARROW estimates mean annual loads over a 5-year period of nutrients from present and future distributions of point sources, climate, soil types, land slope, drainage characteristics, and land uses. It does not explicitly consider long-term lags attributable to groundwater storage and release. The New Zealand implementation of the SPARROW model has been developed in collaboration with the US Geological Survey and calibrated on Waikato regional data (Alexander et al. 2002) and on data from the nationwide National Rivers Water Quality Monitoring Network (Elliott et al. 2005) at a finer resolution.

## 8.3 Description

The SPARROW model accounts for "routing, accumulation, and decay", and infers contaminant losses. Its spatial surface has been implemented on NIWA's River Environment Classification database (Snelder et al. 2004), at 30-m grid resolution, on which stream/lake/reservoir locations were added. The resulting national model has nearly 600 000 stream reaches.

Data for concentrations of Total Nitrogen and Total Phosphorus collected from the 77 sites in NIWA's National River Water Quality Monitoring Network were combined with river flow information from those sites to estimate total annual loads. The model was calibrated against these data, i.e., by adjusting its coefficients to optimise the match with the calculated loads. In doing so, it used information on: (a) point sources of nutrients (from Regional Council data, consultancy reports, and informed estimations), (b) land use (combining data from AgriBase (AsureQuality) and the Land Cover Database 2 (Ministry for the Environment (2004)), and (c) mean stream flow using rainfall and evapotranspiration modelling.

The model's structure allows calibration not only of the contribution of point sources and land uses, but also land-to-water delivery variables (e.g., rain, drainage efficiency) and in-stream attenuation ("decay"). An implementation for the Waikato region has been reported (Alexander et al. 2002), and also for the whole nation (Elliott et al. 2005). For implementation in WISE, model parameters were re-calibrated for the Waikato region, taking into account stream reaches from the Waikato region as a whole and not just the Waikato River basin. Also, the WISE implementation relies on these pre-calibrated parameters; SPARROW coefficients within WISE are therefore static and are not dynamically recalculated/recalibrated during a model run.

SPARROW has two very desirable properties that give enhanced credence to its results. First, it is "data hungry": it demands and uses large quantities of environmental data of many types. Second, while statistical in nature (model coefficients are largely unconstrained and are optimised by the model fitting procedure during calibration), its coefficients are *physically interpretable*. For example, it produces settling rates for reservoirs and these can be checked for physical plausibility against other, local and independent settling studies.

Finally, SPARROW's output can calculate nutrient loads at any point on the landscape, and it can also calculate the fraction of the load delivered to any downstream point, highlighting the relative importance of all upstream sources. The key spatial elements of SPARROW are shown below (Figure 12).

Note that in calculating total N and P, the environmentally more harmful proportions of the load are disguised (dissolved reactive phosphorus, nitrate and ammonia) nevertheless the model gives a high level spatial picture of nutrient losses.

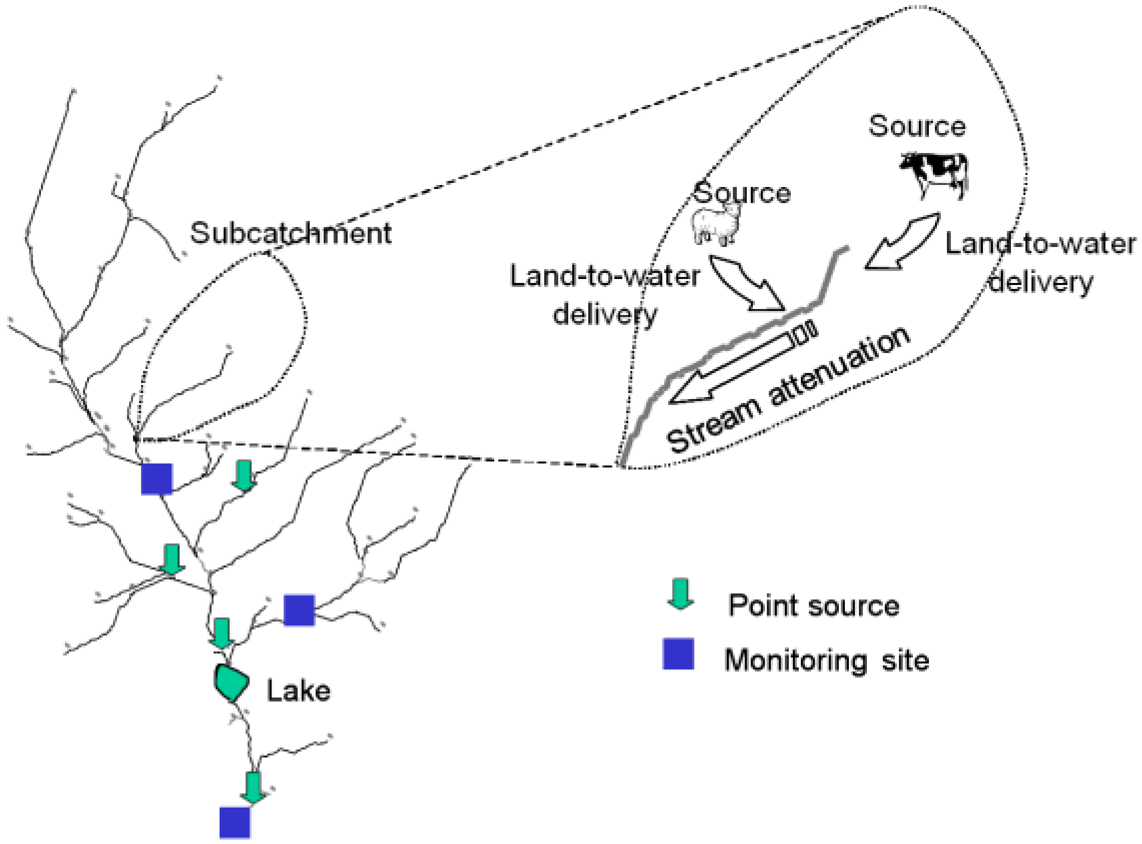



**Figure 12** Key spatial elements of the SPARROW model system.

## 8.4 Equations

### 8.4.1 Sources

The stream reach network is a dendritic system of reaches and nodes (Figure 12). Each reach has a single subcatchment associated with it. A reach may also have a lake associated with it. Data on a reach (e.g., length, flow) and its associated catchment characteristics (e.g., areas of different land-uses) are stored in a record in a table.[4] Sources within subcatchments that contribute nutrient loads to a reach include land uses and point sources. Contributions of an individual source (land use or point source) are calculated as follows:

$$S_{ij} = c_i A_{ij}$$

where

$S_{ij}$ = amount of source from land use class $i$ generated in subcatchment $j$ (kg/year)
$c_i$ = the source coefficient for land-use class $i$ (kg ha$^{-1}$ yr$^{-1}$)
$A_{ij}$ = the total area of land use class $i$ in subcatchment $j$ (ha).

For point sources, $A$ is the amount of nutrients emitted (kg/year) and $c_i$ =1.

Because the subcatchments are a shapefile (vector) spatial layer whereas land use is a grid (raster) spatial data layer, a link table is used to calculate the total area of each land-use class

[4] In principle, this could be extended so that more than one ‘subcatchment’ can be associated with a particular reach.

in each subcatchment. The link table contains information about how much of each grid cell (x,y, hectares) occurs in each subcatchment *j* (Table 5).

**Table 5** Structure of the Water Quality – Land Use Change model link table

| Grid Cell | | Subcatchment ID | Area (hectares) |
|---|---|---|---|
| *X* Coordinate | *Y* Coordinate | | |
| | | | |
| | | | |
| | | | |

### 8.4.2 Source modification factors

The contribution from each source is modified by two factors, rainfall and drainage, using the following formula:

$$S'_{ij} = S_{ij} \prod_k \exp\left[-\alpha_{ik}\left(d_{jk} - \bar{d}_k\right)\right]$$

where

$S'_{ij}$ = nutrient discharge from source after modification (kg/year)

$\alpha_{ik}$ = modification exponent for land use class *i* for modification type *k* ($m^{-1}$ yr for rainfall, dimensionless for drainage class)

$d_{jk}$ = value of the delivery variable for modification type *k* in subcatchment *j* (m $yr^{-1}$ for rainfall, dimensionless for drainage class )

$\bar{d}_k$ = mean value of the delivery variable for modification type *k* across the entire modelled region (m $yr^{-1}$ for rainfall, dimensionless for drainage class).

### 8.4.3 Attenuation in stream reaches

Nutrient loads can decrease as a result of attenuation through a reach. This is calculated as follows:

$$F_{sj} = \exp(-k_{sj}L_j)$$

where

$F_{sj}$ = fraction of the stream *s* load carried through subcatchment j (%)

$k_{sj}$ = the stream (*s*) attenuation coefficient in subcatchment *j* ($km^{-1}$)

$L_j$ = the length of the reach in subcatchment *j* excluding any portion that lies within a lake (km).

For the WISE nitrogen model,

$$k_{sj} = aQ_j^{-b}$$

where

$a$ = proportionality constant ($km^{-1}(m^3\ s^{-1})^b$)

$Q_j$ = the mean annual flow of the reach in subcatchment *j* ($m^3\ s^{-1}$)

$b$ = flow exponent (dimensionless).

For the WISE phosphorus model, a stepwise function was used.

$$k_{sj} = \begin{cases} k_1 : & Q_j \le Q_1 \\ k_2 : & Q_j > Q_2 \end{cases}$$

Loads entering a reach from an upstream node have this attenuation applied. Loads entering from the catchment associated with the reach (the incremental catchment) have attenuation over only half of the reach.

### 8.4.4 Attenuation in lakes (reservoir decay)

In stream reaches with lake outlets, attenuation is applied to account for settling of nutrient loads within the lake. Lake attenuation is calculated as follows:

$$F_l = \frac{R_l}{k_l + R_l}$$

where

$F_l$ = fraction of the load carried through lake $l$ in reach $j$ (dimensionless)
$R_l$ = lake overflow rate (m $yr^{-1}$)
$k_l$ = effective settling velocity for lake $l$ (m $yr^{-1}$).

Also:

$$R_l = \frac{q_l}{A_l}$$

where $q_l$ is the flow rate out of the lake and $A_l$ is the plan area of the lake.

For reaches without lake outlets, the fraction carried is 1 (i.e. no loss).

For any reach, the lake fraction carried and the stream fraction carried are multiplied together to give the total fraction carried.

### 8.4.5 Routing method

Nutrient loads in stream reaches are accumulated along the dendritic network, i.e. from upstream to downstream. Mathematically, stream reaches are sorted according to a calculation order that ensures nutrient loads in upstream reaches are calculated first. The algorithm then loops through the list of reaches. For each reach it:

1. calculates the unmodified source from each land use $i$ or point source in local subcatchment $j$
2. modifies the source from each land use $i$ in local subcatchment $j$
3. sums all sources in local subcatchment $j$
4. adds the modified, attenuated load from the upstream subcatchment $j - 1$
5. attenuates the total source due to stream and/or lake (if applicable) in subcatchment $j$.

Mathematically those steps are:

$$S_{ij} = c_i A_{ij}$$
$$S'_{ij} = S_{ij} \prod_k \exp\left[-\alpha_{ik}\left(d_{jk} - \bar{d}_k\right)\right]$$
$$S'_j = \sum_i S'_{ij}$$
$$S'_j = S'_j + \sum_{\substack{upstream \\ reaches\, j-1}} S''_{j-1}$$
$$S''_j = (F_{sj} \times F_{lj}) \times S'_j$$

where $S''_j$ is the attenuated load at the downstream end of reach *j*.

There is also provision to divert a fraction of the load from a reach based on the location of flow diversions in the catchment. In that case, in Step 4 above, only a fraction of the load from the upstream node is carried into the reach of interest. The diversion fractions are provided as a fraction of the reach.

## 8.5 Links

The Water Quality model links with the Climate Change Scenarios and the Land Use Change model (Table 6).

**Table 6** Links between the Water Quality model and other models

| Type | Model Component | Data Passed | Comments |
|---|---|---|---|
| Inputs | Climate Change Scenarios | Rainfall | Weighted average of the 4 nearest 0.05° grid cell to each subcatchment |
| | Land Use Change | Land Use | Land use determines the source coefficient ($c_i$) via a look-up table<br>Land use determines the value of the rain exponent and drain exponent for N loading ($\alpha_{ik}$) |
| Outputs | None | | |

# 9 Zoning Tool – Waikato Regional Council

## 9.1 Metadata

| | | |
|---|---|---|
| 1. | Name of Model | **Zoning** |
| 2. | Organisation | Waikato Regional Council |
| 3. | Contact | Derek Phyn |
| 4. | Spatial Resolution | 200m (as grid layer) |
| 5. | Temporal Resolution | Annual |
| 6. | Input Data | 2006 Land Use (as grid)<br>Protected Areas Network (as grid)<br>District Reserves and Covenants (as grid)<br>Waikato Regional Council Flood and Erosion Control Land (as grid)<br>District Council Designations (as grid)<br>District Council Overlays (as grid)<br>District Council Zones (as grid)<br>Core Record System "Queens Chain" Land (as grid)<br>District Extent (as grid) |
| 7. | Internal Data | Zoning Status (categorical)<br>Zoning Parameters (numeric) |
| 8. | Output Data | Zoning (categorical, as grid)<br>Zoning (numerical, as grid) |

## 9.2 Summary

Zoning delineates areas with differing degrees for potential future land use development. It is an input into the Land Use Change model (Section 11). The Zoning Tool inspects sets of zoning maps compiled from various sources such as regional and district plans (Figure 13). Each zone in a map is called a category and has an explicit or inferred zoning status[5] that applies to at least one land use. Based on an order of precedence among categories specified by the user, the zoning tool annually determines the zoning status of the highest-ranking category for a land use in each grid cell. The zoning status is then translated to a user-specified numerical zoning score, from which a 200 × 200-m resolution grid layer is generated for supply to the Land Use Change model.

Zoning scores are not constrained but typically range from 0 (prohibited) to 1 (permitted). Zoning scores <1 impede future development by lowering the overall score for a land use at a particular location. Conversely, users can also specify zoning scores >1 to simulate the encouragement of future development, e.g., economic development zones.

[5] As defined by Section 77B of the Resource Management Act

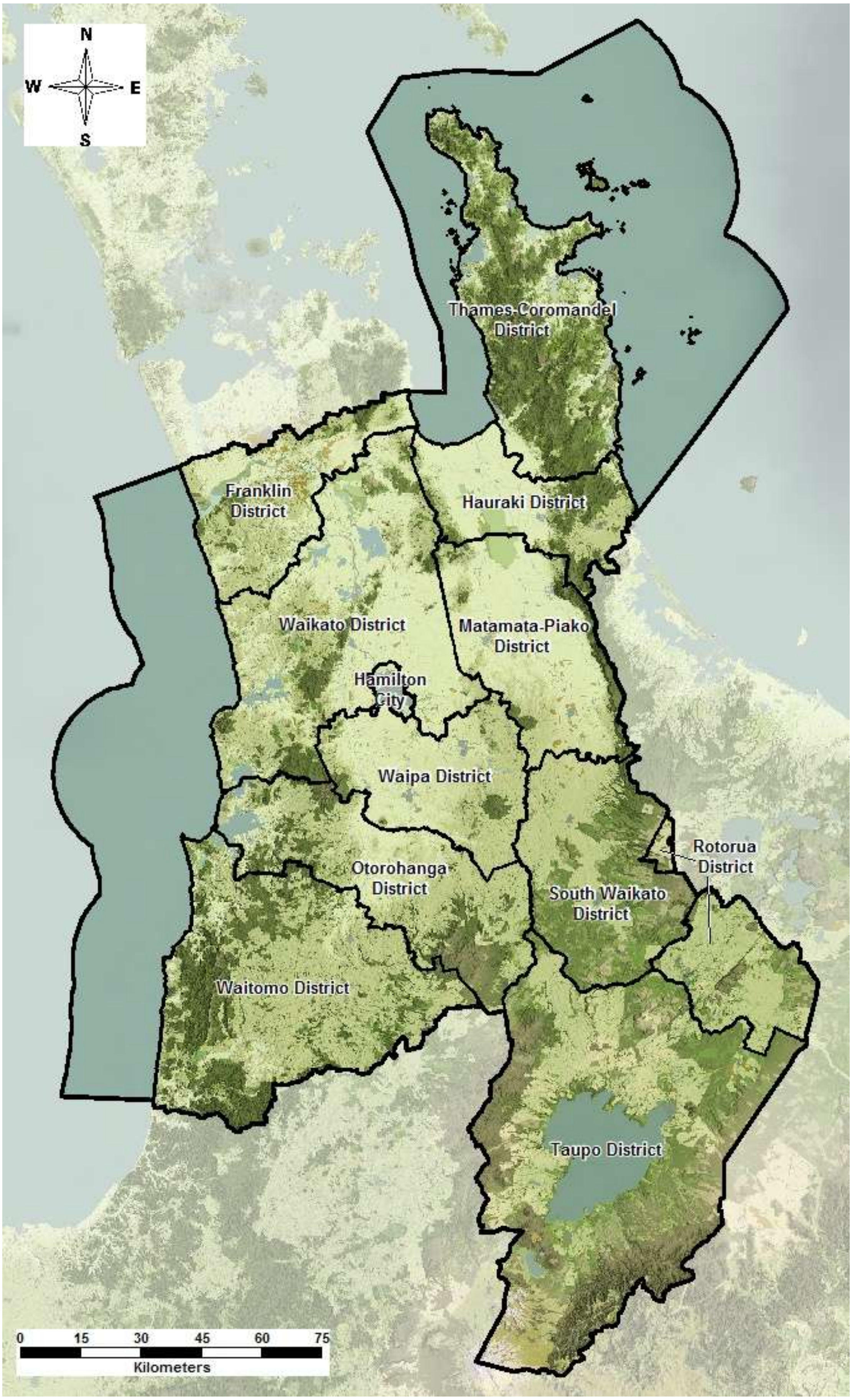
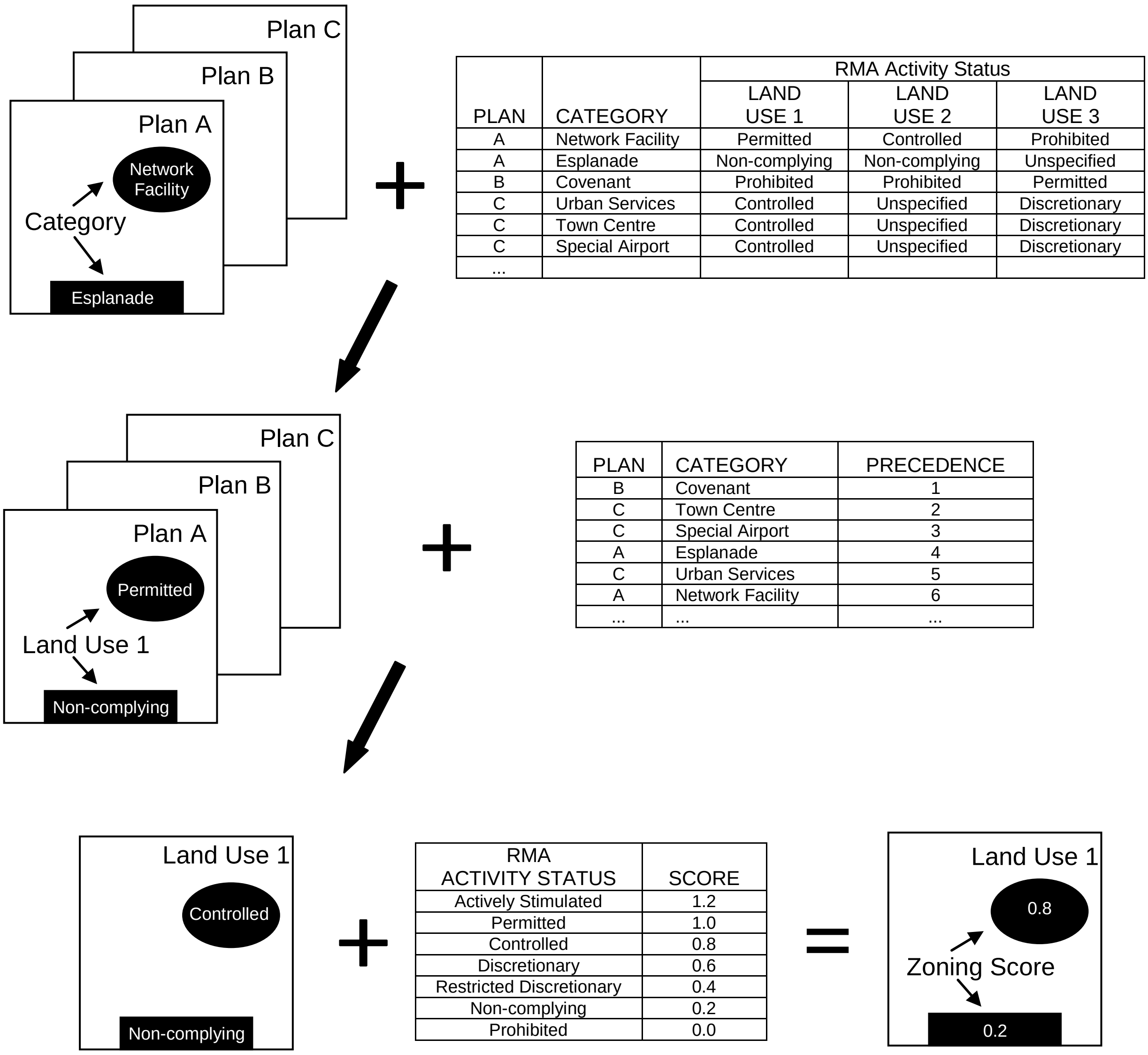



**Figure 13** Districts within the Waikato region as of September 2010.

## 9.3 Model Description

Under the Resource Management Act, regional and district councils identify activities that could cause adverse effects to the environment and develop rules to manage, mitigate, or in some cases, completely avoid those effects. The rules are codified in regional and district plans. In addition, other relevant zoning information can be found in other data sources such as non-statutory planning strategies or national datasets, e.g., protected areas in the conservation estate. The process involves translating the various rules and other statutory requirements into a comprehensible set of information for processing and use by WISE (Figure 13).




| PLAN | CATEGORY | RMA Activity Status: LAND USE 1 | LAND USE 2 | LAND USE 3 |
|---|---|---|---|---|
| A | Network Facility | Permitted | Controlled | Prohibited |
| A | Esplanade | Non-complying | Non-complying | Unspecified |
| B | Covenant | Prohibited | Prohibited | Permitted |
| C | Urban Services | Controlled | Unspecified | Discretionary |
| C | Town Centre | Controlled | Unspecified | Discretionary |
| C | Special Airport | Controlled | Unspecified | Discretionary |
| ... | | | | |

| PLAN | CATEGORY | PRECEDENCE |
|---|---|---|
| B | Covenant | 1 |
| C | Town Centre | 2 |
| C | Special Airport | 3 |
| A | Esplanade | 4 |
| C | Urban Services | 5 |
| A | Network Facility | 6 |
| ... | ... | ... |

| RMA ACTIVITY STATUS | SCORE |
|---|---|
| Actively Stimulated | 1.2 |
| Permitted | 1.0 |
| Controlled | 0.8 |
| Discretionary | 0.6 |
| Restricted Discretionary | 0.4 |
| Non-complying | 0.2 |
| Prohibited | 0.0 |

**Figure 14** Process followed to delineate and evaluate zoning scores.

First, a series of maps are generated that correspond to different plans or strategies (simply "plans" hereafter). The plan maps contain one or more categories showing various elements in the plan. Frequent examples from district and city plans include zones (in a more restricted sense than used here), designations, and overlays. Others include flood hazard areas, protected areas such as conservation estate of covenants, air noise boundaries, etc. For WISE 1.3, several national, regional, and local information sources were used to compile zoning information (Table 7).

**Table 7** Data sources used to compile zoning information in WISE

| Data Source | Extent | Reference |
|---|---|---|
| Land Cover Database Version 2 | National | Thompson et al. 2003 |
| District Valuation Roll | Region | Waikato Regional Council |
| Protected Areas Network (PAN-NZ) Database | National | Rutledge et al. 2008 |
| CRS Property and District Reserve data | Region | Waikato Regional Council |
| Territorial Authority (TA) District Plans[6] | District | District Councils |
| TA Default Rules[7] | District | District Plans |

Second, an assessment was undertaken to determine the appropriate activity status for each land use within a zone. Under section 77B of the Resource Management Act activities fall into one of six activity statuses, which vary in their implications for interpretation and application of rules used to develop the zoning layers (Table 8).

Rules vary among districts in accordance with plan for a district. To develop zoning layers for WISE, an independent review (Environmental Management Services Limited 2009) was undertaken of each district plan for the 12 districts within the Waikato region. The purpose of the review was to determine the most likely activity status for each land use within each TA based on an interpretation of the rules, zones, overlays, policy areas or designations contained within each district plan. As the RMA regulates *activities* and not *land use* per se, each land use could have a range of associated activities with varying activity types. In determining the overall activity status for a particular land use, a permissive approach was taken such that the least restrictive activity type was applied to each combination of zoning and land use. However, the resolution of the land-use model (200 × 200-m grid cells) often meant that the most permissive activity type was not assigned for those land uses having a very small spatial extent (such as home occupations).

The review produced a set of 12 land use-zoning matrices (as Excel spreadsheets), one for each city/district council, which identified the RMA activity status for each combination of zoning and land use (Figure 15). Waikato Regional Council modified a small number of activity statuses after the review was finished. All changes and the reason for the change were recorded in the zoning spreadsheet (Environment Waikato 2010). The matrices provided the basis to develop sets of zoning status rules that were applied as outlined in Table 8 above for generating zoning grid layers.

When considering the city/district plans collectively it became clear that each plan has a distinct format and approach to its policies and the underlying rule structure. Notwithstanding this, the basis for rule structures is generally either activity-based or effects-based, and the approach to determining activity type either restrictive or permissive (Table 9). In the matrix, plans with an activity-based approach were easier to assess as the types of land use activities described in the matrix could more easily be associated with the activities outlined in the plan.

[6] As of September 2010 the Waikato region encompassed 12 districts in whole or in part. The new Auckland Region formally took effect on 01 November 2010, at which point the portion of the former Franklin district in the Waikato region became part of the Waikato district.

[7] Where no higher ranked category occurred in the precedence order a default activity status was assigned to a cell. This includes parts of districts outside the Waikato regional administrative boundary but within the boundary of the area included in the Hydrology model analysis.

**Table 8** Activity status as defined under Section 77B of the RMA

| Activity Status | Definition |
|---|---|
| Permitted | If an activity is described in this Act, regulations, or a plan or proposed plan as a permitted activity, a resource consent is not required for the activity if it complies with the standards, terms, or conditions, if any, specified in the plan or proposed plan. |
| Controlled | If an activity is described in this Act, regulations, or a plan or proposed plan as a controlled activity,—<br>(a) a resource consent is required for the activity; and unless it has insufficient information to determine whether or not the activity is a controlled activity; and<br>the consent authority must grant the resource consent, unless it has insufficient information to determine whether or not the activity is a controlled activity; and<br>(b) the consent authority must specify in the plan or proposed plan matters over which it has reserved control; and<br>(c) the consent authority's power to impose conditions on the resource consent is restricted to the matters that have been specified under paragraph (b); and<br>(d) the activity must comply with the standards, terms, or conditions, if any, specified in the plan or proposed plan. |
| Restricted Discretionary | If an activity is described in this Act, regulations, or a plan or proposed plan as a restricted discretionary activity,—<br>(a) a resource consent is required for the activity; and<br>(b) the consent authority must specify in the plan or proposed plan matters to which it has restricted its discretion; and<br>(c) the consent authority's powers to decline a resource consent and to impose conditions are restricted to matters that have been specified under paragraph (b); and<br>(d) the activity must comply with the standards, terms, or conditions, if any, specified in the plan or proposed plan. |
| Discretionary | If an activity is described in this Act, regulations, or a plan or<br>proposed plan as a discretionary activity,—<br>(a) a resource consent is required for the activity; and<br>(b) the consent authority may grant the resource consent with or without conditions or decline the resource consent; and<br>(c) the activity must comply with the standards, terms, or conditions, if any, specified in the plan or proposed plan. |
| Non-Complying | If an activity is described in this Act, regulations, or a plan or<br>proposed plan as a non-complying activity,—<br>(a) a resource consent is required for the activity; and<br>(b) the consent authority may grant the resource consent with or without conditions or decline the resource consent. |
| Prohibited | If an activity is described in this Act, regulations, or a plan as a prohibited activity, no application may be made for that activity and a resource consent must not be granted for it. |

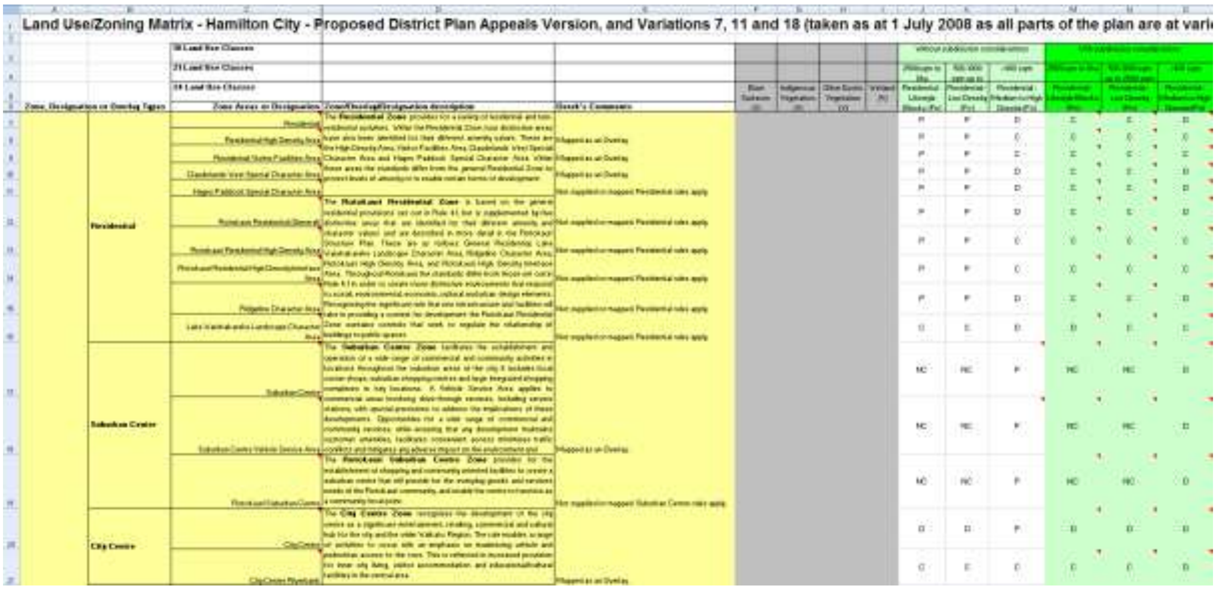



**Figure 15** Screenshot of the zoning matrix for Hamilton City Council.

Waikato Regional Council also had to assign default activity status (categorical and numerical) to areas occurring outside the regional administrative boundary but partly within the hydrologically modelled area (Table 9).

Effects-based plans were more difficult to assess, as some assumptions were required about each potential land use and the types of effect it might have. In this case, the resulting matrices tended to have many Permitted activity statuses for permissive plans and many Discretionary or Non-Complying activity statuses for restrictive plans. In some cases the details of a consent application for a specific land use proposal may alter the result.

The effect of subdivision rules was also considered in relation to the residential land uses. Subdivision rules, in the main, focus on physical aspects of the land being subdivided, although a few plans differentiated subdivision status to some extent on the basis of land use. Net lot area was a strong driver for subdivision rules and results in impacting the activity status of the residential land uses in the matrix, and, in 75% of the plans, also results in some instances of activities becoming considerably more restricted.

Other controls that apply to land-use change or development have not been reflected in the matrices or in corresponding spatial data. These include activities on the surface of water and other tools such as bylaws and structure plans. Restrictions in district plans on indigenous vegetation clearance and regional council controls with relevance to wetland clearance and the Taupo Variation apply to a limited extent.

Based on a review of the regional plan, the 12 district plans, and a number of other statutory plans and designation (e.g., protected areas), a total of 238 unique overlays, designations, etc., (generally referred to as zones here) applied across the region at varying locations. Not every zone applied to every land use. Collectively approximately 2500–3000 rules were assigned to these zones across the Waikato region in some way. Not every rule has been included. Many were not considered legislatively or spatially significant; others were too complex to assess or map. In some instances the rules were known but spatial data were lacking.

**Table 9** Default activity status for city and district councils included in the WISE model. For those areas occurring within the hydrologically modelled area but not within Waikato region administrative boundaries, a default zoning status was assigned

| District | Rule Structure Basis | Nature of Rules | Default Activity Status |
|---|---|---|---|
| Hamilton City | Activity | Restrictive | Non-complying (0.2) |
| Waikato | Effects | Permissive | Permitted (1.0) |
| Waipa | Activity | Permissive (predominantly) | Permitted (1.0) |
| Matamata-Piako | Activity | Restrictive | Non-complying (0.2) |
| Franklin (in part) | Activity (predominantly) | Restrictive | Non-complying (0.2) |
| South Waikato | Activity | Restrictive | Non-complying (0.2) |
| Taupo (in part) | Effects | Permissive | Permitted (1.0) |
| Thames-Coromandel | Activity | Prescriptive | Non-complying (0.2) |
| Hauraki | Activity | Restrictive | Non-complying (0.2) |
| Rotorua (in part) | Activity | Restrictive | Non-complying (0.2) |
| Otorohanga | Effects | Permissive | Permitted (1.0) |
| Waitomo (in part) | Effects | Permissive | Permitted (1.0) |
| Manukau City (in part) | Not assessed | Not assessed | Non-complying (0.2) |
| Marine Region | Not assessed | Not assessed | Prohibited (0) |
| New Plymouth (in part) | Not assessed | Not assessed | Permitted (1.0) |
| Ruapehu (in part) | Not assessed | Not assessed | Non-complying (0.2) |
| Western Bay of Plenty (in part) | Not assessed | Not assessed | Non-complying (0.2) |
| Whakatane | Not assessed | Not assessed | Discretionary (0.4) |

Further investigation might conclude some zones have greater significance on land-use change than initially thought. If all data were available and all rules were thoroughly assessed and mapped, there could potentially be 300–400 zones to consider, or as many as twice the number currently implemented.

A full copy of the planning review (Environmental Management Systems Limited 2009) and the zoning methodology are available from Waikato Regional Council (EW Documents 1589639 and 1391838).

Third the underlying spatial zoning data is imported from GIS into the zoning tool of WISE as a series of “categories” under plans. Categories are then compared to one another based on a precedence order specified by the user (Table 10). A “zoning status” (the same thing as “activity status” but named differently in the WISE model) is then assigned to those categories of relevance to each land use function. The resulting zoning maps, one for each land use function, indicate the zoning status of a grid cell for a particular land use or set of land uses.

Finally categorical zoning statuses are transformed into numerical values for use in the Land Use Change model (Table 11). The minimum value is 0 (Prohibited). Increasing values indicate more permissive zoning, with a value of 1 indicating a “permitted” activity status.

Values over 1 are also possible, which indicates areas where particular land uses are actively stimulated.

Currently a simple method of assigning zoning has been applied to the existing extent of indigenous vegetation (restricted discretionary region-wide) and wetland (discretionary region-wide) as at 2006. This could be made more complex but would involve consideration of at least a dozen additional rules. Currently zoning statuses assigned to these two categories only apply to rural land uses. Urban land uses usually have even more restrictive zoning applied to them in areas where indigenous vegetation and wetlands typically occur, although there are a few exceptions.

Below are examples of the resulting categorical zoning maps for the land uses "Dairy Farming" and "Residential – Low Density" as at 2030 (Figure 16).

## 9.4 Equations

Zoning does not involve equations per se, other than the translation of categorical activity status into a numeric zoning score. See Section 11.4.4. for more information.

## 9.5 Links to other models

Zoning links with the Land Use Change model (Table 10).

**Table 10** Links between Zoning and other models

| Type | Model | Data Passed | Method |
|---|---|---|---|
| Inputs | None | | |
| Outputs | Land Use Change | Zoning Score | Grid layer of numeric values used as a factor in the calculation of transition potentials for each land use function at each time step |

**Table 11** Order of precedence of categories within WISE

| Order | Rule, Designation, Overlay, etc. | Interpretation | Categorical Activity Type | Numerical Activity Type |
|---|---|---|---|---|
| 1 | Existing land use as at 2006 | Where a land use already occurs at 2006, assume "permitted" activity type | Permitted | 1 |
| 2 | PAN-NZ | All land-use functions assumed "prohibited" as location is legally protected | Prohibited | 0 |
| 3 | District Reserves & Covenants | All land-use functions | Prohibited | 0 |
| | | Except | | |
| | | Community Services on District Reserves | Permitted | 1 |
| 4 | EW Land | All land-use functions | Prohibited | 0 |
| | | Except | | |
| | | Dairy Farming | Permitted | 1 |
| | | Sheep, Beef & Deer Farming | Permitted | 1 |
| 5 | TA Designations | All land-use functions | Prohibited | 0 |
| | | Except | | |
| | | Community Services on Public Facilities or Proposed Public Facilities | Permitted | 1 |
| 6 | Internationally or Nationally Significant Natural Areas Overlay | All rural land-use functions | Discretionary | 0.4 |
| 7 | Existing Indigenous Vegetation Land Use as at 2006 | All land-use functions | Restricted Discretionary | 0.6 |
| 8 | Existing Wetland Land Use as at 2006 | All land-use functions | Discretionary | 0.4 |
| 9 | TA Overlays or Policy Areas | Zoning status determined by Land Use-Zoning Matrix (see Section 9.3.1 below) | Varies | Varies |
| 10 | TA Zones | Zoning status determined by Land Use-Zoning Matrix (see Section 9.3.1 below) | Varies | Varies |
| 11 | CRS Queens Chain Land | All land-use functions | Prohibited | 0 |
| 12 | TA Default | Zoning status determined by default rules (see Table 12 below) | Varies | Varies |

**Table 12** Categories and default values for activity types in the zoning model

| Category | Value |
|---|---|
| Actively stimulated | 1.2 |
| Permitted | 1 |
| Controlled | 0.8 |
| Discretionary | 0.6 |
| Restricted discretionary | 0.4 |
| Non-complying | 0.2 |
| Prohibited | 0 |

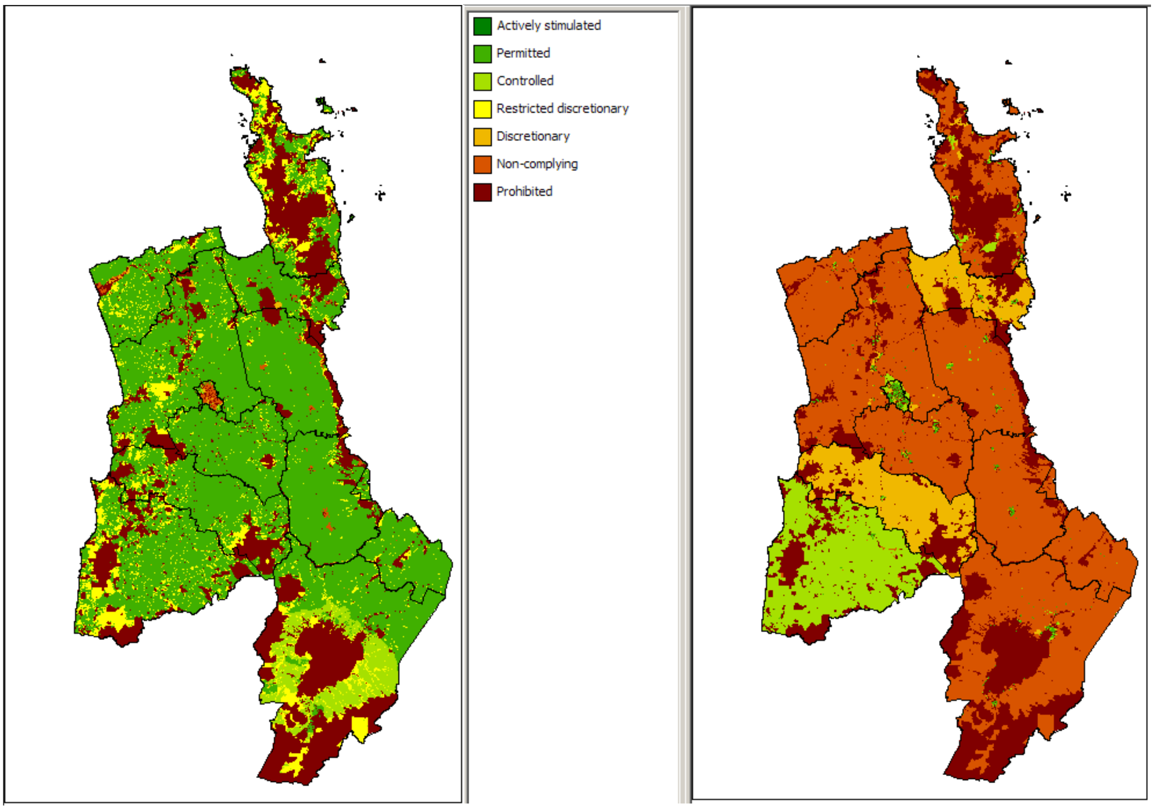



**Figure 16** Examples of categorical zoning grid layers for Dairy Farming (left) and Residential – Low Density (right) land uses as at 2030.

# 10 Whole of Waikato (WOW) Population Model – NIDEA

## 10.1 Metadata

| | | |
|---|---|---|
| 1) | Name | **WOW (Whole of Waikato) Population Model** |
| 2) | Organisation | National Institute of Demographic and Economic Analysis |
| 3) | Contact | Michael Cameron and Jacques Poot |
| 4) | Spatial Resolution | District |
| 5) | Temporal Resolution | Annual |
| 6) | Input Data | Fertility Lever (% change)<br>Mortality Lever (% change)<br>Net Migration (persons per district, time series) |
| 7) | Internal Data | 2006 Population × 1-year age/gender cohort (persons per district)<br>Fertility rate × 1-year female age cohort, and masculinity ratio (per district)<br>Survivorship rate × 1-year age/ gender cohort (per district)<br>Net migration rate × 1-year age/gender cohort (per district) for each district |
| 8) | Output Data | Population × 1-year age/gender cohort (persons per district)<br>Births × 1-year age/gender cohort (persons per district)<br>Deaths × 1-year age/gender cohort (persons per district)<br>Net migration × 1-year age/gender cohort (persons per district) |

## 10.2 Summary

The WOW (Whole of Waikato) population model generates possible future populations, referred to as population projections, starting from a given base population and assumptions about the demographic processes of fertility, mortality and migration. The methodology used is broadly that of the standard cohort-component model that is also widely used by other agencies, including Statistics New Zealand and RIKS.

The general approach used for population projections in WISE is adapted from Cameron et al. (2007). The current population (base population) is first defined, and then assumptions are made about demographic changes to this population, using the cohort component model (Figure 17). This is a stock-flow model that is based on the following fundamental "accounting identity" of population growth:

$$P_{i,t+1} = P_{i,t} + B_{i,t} - D_{i,t} + I_{i,t} - O_{i,t}$$

where

$P_{i,t+1}$ = usually resident population in district *i* at the *end* of year *t*

$P_{i,t}$ = usually resident population in area *i* at the *beginning* of year *t*

$B_{i,t}$ = births to mothers residing in area *i during* year *t*

$D_{i,t}$ = deaths of residents of area *i during* year *t*

$I_{i,t}$ = inward migration from other regions and from overseas into region *i during* year *t*

$O_{i,t}$ = outward migration of residents from area *i* to other regions or to overseas *during* year *t.*

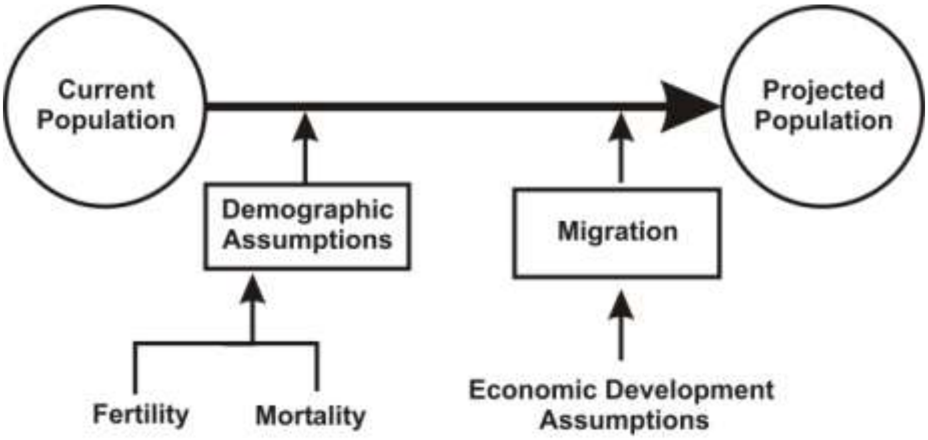



**Figure 17** Whole of Waikato (WOW) Population Model.

Starting with a given base year population, the population one year later is then calculated with the equation above. This defines the base population of the following year. This procedure is repeated for each year through to the end of the projection period. This is done for both genders. Separate assumptions are used for each of the demographic "drivers". Births are derived by multiplying age specific fertility rates by the numbers of women of childbearing age (13–). Deaths are derived by multiplying age- and gender-specific survivorship rates by the numbers of people of each age and gender. Age- and gender-specific net migration is derived by multiplying age- and gender-specific net migration rates by the numbers of people of each age and gender.

The combination of demographic change assumptions, when applied to the current population, allows the calculation of possible future populations. Such calculations are referred to as population *projections* rather than population *forecasts*, because they depend on sets of assumptions and no explicit assessment is made of the relatively likelihood of the assumptions being correct in the future. Varying the assumptions across projections simply permits a sensitivity analysis that provides a relatively broad range of possible outcomes.

The key innovations that differentiate the WOW population model from the cohort component models in use by Statistics New Zealand and others are:

a. Use of age- and gender-specific net migration rates rather than total migration in the determination of migration flows[8]

b. Simultaneous modelling of all districts in the Waikato, including net migration flows in each district.

## 10.3 Description

The WOW population model runs both within WISE and independently, using Vensim simulation software (Ventana Systems 2008). All internal data used in the model (base population, net migration rates, fertility rates, and survivorship rates) are contained in a Microsoft Excel spreadsheet that WISE accesses to obtain the data necessary for a simulation.

As noted above, the model requires age- and gender-specific data inputs, as follows:

(i) Base population data by single-year-of-age and gender, for all territorial local authorities (TLAs, e.g., districts and cities) completely or partly occurring in the Waikato region, for the beginning of the first year of the projection period (currently 30 June 2006);

(ii) Fertility rates by single-year-of age for all females aged 13–, for each TLA in the Waikato region, for all years of the projection period (currently 2006–2061);

(iii) Survivorship rates by single-year-of-age and gender, for each TLA in the Waikato region, for all years of the projection period (currently 2006–2061);

(iv) Net migration rates by single-year-of-age and gender, for each TLA in the Waikato region, for all years of the projection period (2006–2061).

These data inputs have been derived by NIDEA from Statistics New Zealand data and supplementary data provided under contract by Monitoring and Evaluation Research Associates (MERA) Ltd. Data inputs are contained in a single Microsoft Excel spreadsheet across multiple worksheets and called by the WISE as needed.

[8] This methodology has already been applied to the development of population projections for the Thames-Coromandel District Council area and other Waikato sub-regions. A description of the differences between this methodology and that applied by Statistics New Zealand is included in Cameron and Poot (2011).

## 10.4 Equations

### 10.4.1 General Formulae

WOW uses three sets of equations to generate population projections. The general formulae for deriving the population at each year-of-age and each gender are as follows:

$$P_{agl}^{t+1} = \begin{cases} a = 0 : P_{0gl}^{t+1} = \frac{1}{2}(B_{gl}^{t} + N_{-1gl}^{t}) \times S_{-1gl}^{t} + \frac{1}{2}(B_{gl}^{t} + N_{-1gl}^{t}) \\ 1 \le a \le 99 : P_{agl}^{t+1} = (P_{(a-1)gl}^{t} + \frac{1}{2}N_{(a-1)gl}^{t}) \times S_{(a-1)gl}^{t} + \frac{1}{2}N_{(a-1)gl}^{t} \\ a = 100 : P_{100gl}^{t+1} = (P_{99gl}^{t} + \frac{1}{2}N_{99gl}^{t}) \times S_{99gl}^{t} + \frac{1}{2}N_{99gl}^{t} + \\ \qquad (P_{100gl}^{t} + \frac{1}{2}N_{100gl}^{t}) \times S_{100gl}^{t} + \frac{1}{2}N_{100gl}^{t} \end{cases}$$

where

| | | |
|---|---|---|
| $P_{agl}^{t+1}$ | = | population of age $a$ and gender $g$ in location $l$ at time $t$+1 (with $t$ measured in years); |
| $P_{(a-1)gl}^{t}$ | = | population of age $a$-1 and gender $g$ in location $l$ at time $t$; |
| $B_{gl}^{t}$ | = | number of births of gender $g$ in location $l$ between time $t$ and time $t$+1; |
| $N_{(a-1)gl}^{t}$ | = | net migration of people of age $a$ and gender $g$ to/from location $l$ between time $t$ and time $t$+1; a positive number represents more people moving into $l$ than moving out, while a negative number represents more people moving out of $l$ than in; |
| $S_{(a-1)gl}^{t}$ | = | survivorship rate for people of gender $g$ in location $l$ and age $a$-1 at time $t$, who survive to age $a$ at time $t$+1; |
| $a$ | = | age subscripts ranging from of –1 to 100 with –1 representing births during the previous twelve months; 0 representing those of age 0; 1 … representing those of age 1 …; 100 representing those aged 100 or over; |
| $g$ | = | gender subscripts, with 1 representing male and 2 representing female; |
| $l$ | = | subscripts ranging from 1 to 12, with each number representing one of the TLAs in the Waikato region. |

The main additional assumption implicit in this formula is that migration, births, and deaths are all evenly spaced throughout the year. This allows half of the migrants and half of the births to be subject to the full year's survivorship rate. It should also be emphasised that the age group represented by $a$=100 is actually all people of gender $g$ in location $l$ aged 100 or over.

### 10.4.2 Births

Births are calculated using the following formula:

$$B_{gl}^{t} = \begin{cases} g = 1: B_{gl}^{t} = G_{l}^{t} \times \sum_{a=13}^{49} (F_{al}^{t} \times (P_{a2l}^{t} + \frac{1}{2} N_{a2l}^{t}))\,(males) \\ g = 2: B_{gl}^{t} = (1 - G_{l}^{t}) \times \sum_{a=13}^{49} (F_{al}^{t} \times (P_{a2l}^{t} + \frac{1}{2} N_{a2l}^{t}))\,(females) \end{cases}$$

where $G_l^t$ is the fraction of births between time *t* and time *t*+1 that are male (the masculinity ratio of births) in location (TLA) *l*; and $F_{al}^t$ is the fertility rate for women of age *a* in location (TLA) *l* between time *t* and time *t*+1, and other terms remain as defined above.

These formulae contain two additional implicit assumptions. First, gender bias in births between male and female children is assumed to be constant both across time and among TLAs at 105.5 male children for every 100 female children or G = 0.513. This is consistent with the experience of New Zealand over the past several decades. Second, only women between the ages of 13 and  are assumed to have children, as women outside that age range have very few children.

### 10.4.3 Net Migration

Net migration for each year-of-age and each gender is calculated using the following formula:

$$N_{agl}^{t} = \begin{cases} a = -1: (M_{-1gl}^{t} \times B_{gl}^{t}) \\ a \geq 0: (M_{agl}^{t} \times P_{agl}^{t}) \end{cases}$$

where

$M_{aglj}^{t}$ = migration rate of people of age *a* and gender *g* to/from location *l* between time *t* and time *t*+1.

### 10.4.4 External Factors

Fertility rates, survivorship rates, and net migration rates in the WOW population model can be altered via the External Drivers to test the effect of different assumptions regarding future population trends. Each factor adjusts the baseline rates as indicated by the following formulae:

$$F_{al}^{t} = f_{al}^{t} \times (1 + \frac{k_{al}^{f}}{100})$$

$$S_{agl}^{t} = 1 - (1 - s_{agl}^{t}) \times (1 + \frac{k_{agl}^{s}}{100})$$

$$M_{agl}^{t} = \begin{cases} m_{agl}^{t} \geq 0: M_{agl}^{t} = m_{agl}^{t} \times (1 + \frac{k_{agl}^{m}}{100}) \\ m_{agl}^{t} < 0: M_{agl}^{t} = m_{agl}^{t} \times (1 - \frac{k_{agl}^{m}}{100}) \end{cases}$$

where:

$f_{al}^{t}$ is the baseline fertility rate for women of age *a* in location *l* between time *t* and time *t*+1 estimated from data;

$k_{al}^{f}$ is the fertility parameter that can vary between -5 and +5, resulting in an adjustment of up to plus or minus 5%;

$s_{agl}^{t}$ is the baseline survivorship rate for people of age *a* and gender *g* in location *l* between time *t* and time *t*+1 estimated from data;

$k_{agl}^{s}$ is the mortality parameter which can vary between -2 and +2, resulting in an adjustment of up to plus or minus 2%;

$m_{agl}^{t}$ is the baseline net migration rate of people of age *a* and gender *g* to/from location *l* between time *t* and time *t*+1 estimated from data;

$k_{agl}^{m}$ is the migration parameter that can vary between -50 and +50, resulting in an adjustment of up to plus or minus 50%.

Given the large number of parameters that could be modified (e.g., 407 fertility rates, 2244 mortality rates, net-migration rates), a simplification was implemented to allow flexibility without overwhelming the user with an unmanageable number of parameters to adjust and check. For fertility and mortality, the same external factor is applied to all rates across age and (for mortality) genders or

Fertility: $k_{al}^{f} = k_{13l}^{f} = k_{14l}^{f} = \ldots = k_{49l}^{f} = k^{f}$

Mortality: $k_{agl}^{s} = k_{-1,1,l}^{s} = k_{-1,2,l}^{s} = \ldots = k_{100,2,l}^{s} = k^{s}$

Net-migration can be adjusted by district for each year of the simulation. In other words, a time series of net-migration factors can be applied for each district over the entire simulation run. Changes to net-migration are apportioned among the age/sex cohort classes as follows:

Net-migration: $k_{agl}^{m} = k_{-1,1,l}^{m} = k_{-1,2,l}^{m} = \ldots = k_{100,2,l}^{m} = k_{l}^{m}$

Alternatives to this policy lever scheme are also possible. The optimal design can be adapted as a result of on-going use and application of the WISE system.

## 10.5 Links

WOW links with the Land Use Change model and WRDEEM as indicated in Table 13.

**Table 13** Links between Zoning and other models

| Type | Model | Data Passed | Comments |
|---|---|---|---|
| Inputs | None | | |
| Outputs | Land Use Change | Population | Population determines the demand for land (ha) for each of the three residential land-use classes as explained below |
| | WRDEEM | Population | Population is used to calculate labour force participation rates |

Population from WOW determines demand for land for the three residential land use categories (Lifestyle Blocks, Low Density, Medium-High Density) in the Land Use Change model. Population is converted into demand for residential land as follows:

$$L_{cl} = \frac{P_l \times r_{cl}}{d_{cl}}$$

where

$L_{cj}$ = demand for residential land of class *c* in district *l* (hectares)

$P_j$ = total population in district *l* (persons)

$r_{cl}$ = fraction of population preferring residential land use class *c* (unitless) in district *l*, as specified by the user

$d_{cl}$ = average density of residential land use class *c* in district *l* (persons/hectare).

Note that $r_{cl}$ and $d_{cl}$ are specified by the user and can change over the course of a simulation (i.e. they are specified as time lines). By definition the three ratios $r_{cl}$ (one for each residential land use class) should sum to a value that is less than or equal to one in all districts, i.e.

$$\sum_{c=1}^{3} r_{cl} \leq 1$$

# 11 Land Use Change – RIKS

## 11.1 Metadata

| | | |
|---|---|---|
| 1) | Name | **Cellular Automata Dynamic Land Use Change** |
| 2) | Organisation | RIKS |
| 3) | Contact | Hedwig van Delden |
| 4) | Spatial Resolution | 200 m (as grid) |
| 5) | Temporal Resolution | Annual |
| 6) | Input Data | Land Use (as grid)<br>Land Use Suitability (as grid)<br>Zoning (as grid)<br>Accessibility Network (as shapefiles)<br>Industry Land Use Demand (hectares, WRDEEM)<br>Residential Land Use Demand (hectares, WOW) |
| 7) | Internal Data | Local Influence Matrix<br>Accessibility Parameters |
| 8) | Output Data | Land Use (as grid)<br>Transition Potential (as grid) |

## 11.2 Summary

The Land Use Change model dynamically simulates land-use change by evaluating 1) demand for different land uses as a function of drivers of economic activities and demographic trends, and 2) a suite of four factors: accessibility, neighbourhood influence, suitability, and zoning. At each time step, WRDEEM (Section 7) and WOW (Section 10) present a demand for land in hectares to the Land Use Change model. The model then allocates land-use change based on analysis of the four factors until demands have been met or there is no more available land to allocate.

## 11.3 Description

### 11.3.1 Generic Constrained Cellular Automata Model

Cellular automata (CA) get their name from the fact that they consist of *cells* – like the cells on a checkerboard – and that cell states may evolve according to a simple transition rule, the *automaton*. A conventional cellular automaton consists of:

- a *Euclidean space* divided into an array of identical cells. For geographical applications a 2 or 3-dimensional array is most practical
- a cell *neighbourhood*. For flow and diffusion processes the 4 (*Von Neumann* neighbourhood) or 8 (*Moore* neighbourhood) adjacent cells are sufficient, but for most socio-economic processes larger neighbourhoods are required
- a set of discrete *cell states*
- a set of *transition rules,* which determine the state of a cell as a function of the states of cell itself and in relation to the state of cells in a specified neighbourhood around the cell of interest

- *discrete time steps*, with all cell states updated simultaneously.

Until recently, CA models raised only limited interest in the geographical community despite the fact that Tobler (1979) referred to them as "*geographical models*". Originally, they were developed to provide a computationally efficient technique for investigating the general nature of dynamic systems. Recent applications, however, have been directed at representing geographical systems more realistically, both in terms of the processes modelled and the geographical detail. These advances have been accompanied by an increase in the complexity of the models and in the effort to build more realistic models (Couclelis 1997). A concise overview of the application of CA models in land-use modelling and spatial planning can be found in Engelen et al. (1999).

RIKS have developed a generic constrained cellular automata model and applied it to urban (White & Engelen, 1993, 1994, 1997; White et al. 1997) and regional (Engelen et al. 1993, 1995, 1996, 1997, 2000, 2002a) cases.

In this section, we will consistently use the following notation:

*LU* The set of all land uses. An element of this set – a land use – will be referred to by the letter *f*.

*t* Time index of a variable. All dynamic variables have a time index that is written in superscript to the left of the variable, for example, ${}^{t}Z$ .

*c* A cell on the a grid (map) with coordinates *x* (row) and *y* (column). Sets or variables that are defined for each cell on the map are preceded by a set of brackets within which the specific cell is indicated – for example, $f\left(c\right)$ is the land use function occupying cell *c*.

Other notation will be introduced when appropriate.

### 11.3.2 The cell space

The cell space consists of a 2-dimensional rectangular grid of square cells each representing an area ranging from 50 × 50 m to 1000 × 1000 m in resolution. Grid extent and shape varies according to the requirements of the application, but is typically less than 1000 × 1000 cells. WISE uses a 200 × 200-m grid cell size. Grid extent may be larger (i.e. more rows and/or columns), but at the cost of longer run times. The same applies to the resolution of the model: it is technically possible to increase the resolution of the CA model, but this would geometrically increase the number of cells in the neighbourhood of interest for a specified distance, thus considerably increasing execution time. Moreover, before increasing the resolution of the CA model, it is essential to analyse whether this would lead to any better results. It would be inefficient to decrease the size of the cells beyond the typical physical entities, the blocks or plots of land, that are the subject of the location decisions of the spatial agents determining the use of the land. Very often also, the data will not be available or will become unreliable at high resolutions so that the processes modelled are laden with uncertainty. Thus, a higher spatial resolution might give a false impression of more detail and information, but could result in less realistic and/or less accurate spatial dynamics.

### 11.3.3 The cell neighbourhood

The cell neighbourhood is defined as the circular region around the cell out to a radius of eight cells. The neighbourhood thus contains 196 cells (Figure 18) arranged in 30 discrete distance zones forming concentric circles. We indicate the collection of cells that form the neighbourhood of a cell *c* by $D\left(c\right)$. The distance between cells *a* and *b*, $d\left(a,b\right)$, is given by

$\sqrt{X^2+Y^2}$, where $X$ and $Y$ represent the horizontal and vertical distance between the cells, respectively (Table 14).

**Table 14** Distances and distance-numbers in the cell neighbourhood

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Concentric circle | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| Distance (in cells) | 0 | 1 | 1.41 | 2 | 2.24 | 2.83 | 3 | 3.16 | 3.61 | 4 |
| Concentric circle | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| Distance (in cells) | 4.12 | 4.24 | 4.47 | 5 | 5.10 | 5.39 | 5.66 | 5.83 | 6 | 6.08 |
| Concentric circle | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| Distance (in cells) | 6.32 | 6.40 | 6.71 | 7 | 7.07 | 7.21 | 7.28 | 7.62 | 7.81 | 8 |

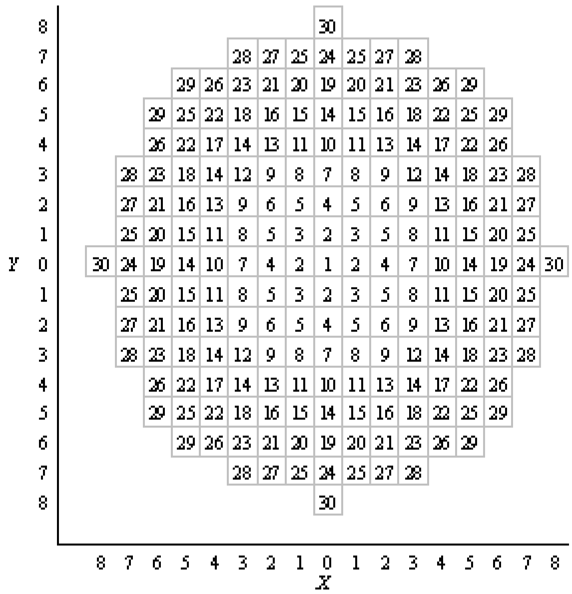



**Figure 18** All cells in the neighbourhood are in exactly one concentric circle. The index of the circle depends on the distance of the circle's cells to the centre of the neighbourhood (circle 1).

The neighbourhood radius varies depending upon grid resolution. For WISE the land use model operates on a 200 × 200-m grid, so that the neighbourhood radius is 1600 m. This distance delimits an area that is similar to what residents and entrepreneurs commonly perceive to be their neighbourhood. It should thus be sufficient to allow the CA transition rules to capture local-scale spatial processes. The neighbourhood moves as the cell of interest (cell 1 in Figure 18) changes.

### 11.3.4 Cell States

Cell states represent the dominant land use in each cell. A distinction is made among dynamic elements, called *land-use functions* and *land-use vacant states*, and static elements, called *land-use features* (Table 15). Land-use features will not change as the result of micro-scale dynamics. They do not change location, but influence the dynamics of the land-use functions and land-use vacant states and thus affect the general allocation process. Increasing the number of states in the CA will increase – in theory at least – the number of possible state transitions of each cell, and defining transition rules will become more complicated. Again, it requires special attention on behalf of the model developer to keep this complexity within limits. It is useful to distinguish between land uses if and only if these land uses behave differently in space. If, however, their spatial dynamic is very similar, then land uses can just as well be combined into a single land-use function.

**Table 15** Types of land-use classes within the Land Use Change model

| Land Use Type | Dynamics at Regional Level | Dynamics at Local Level | Type of Microdynamics | Examples |
|---|---|---|---|---|
| Function | Yes<br>Demand for land from WRDEEM for industry uses and from WOW for residential uses. | Yes<br>CA Model allocates land use until demands met (if possible) | Active | Residential – Low Density<br>Community Services<br>Forestry<br>Manufacturing |
| Vacant | No | Yes<br>CA Model allocates land if possible based on other factors | Passive | Indigenous vegetation<br>Wetlands |
| Feature | No | No | Static<br>Does not change during the simulation | Marine<br>Urban Parks |

### 11.3.5 Neighbourhood Effects

A fundamental idea underpinning a CA model is that the state of a cell at any time depends on the states of the cells within its neighbourhood. Thus, a neighbourhood effect must be calculated for each of the land use function states to which the cell could be converted. In our models, the neighbourhood effect represents the attraction (positive) and repulsion (negative) effects of the various land uses and land covers within the neighbourhood (Figure 19).

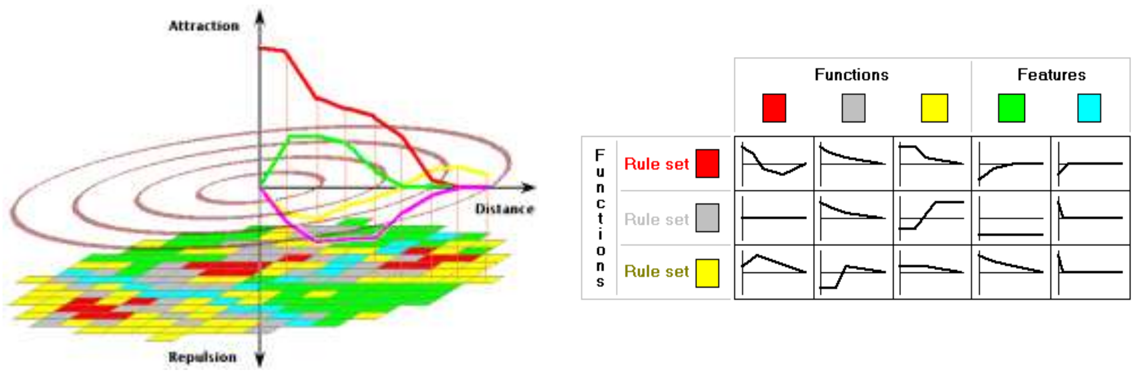



**Figure 19** For the calculation of the neighbourhood effect, a circular neighbourhood consisting of 196 cells is applied (left). For each land use function, the transition rule is a weighted sum of distance functions calculated relative to all other land use functions and features (right).

In general, cells that are more distant in the neighbourhood will have a smaller effect. Thus each cell in a neighbourhood will receive a weight according to its state and its distance from the central cell.

An example of an influence function for the influence of one land use on another land use is shown in Figure 20. At every distance in the CA neighbourhood the neighbourhood influence function could be specified. This has the advantage of enabling the definition of very complex functions. However, its disadvantage is the large number of parameters that could be defined, which could significantly complicate the calibration process. To overcome largely this difficulty, the influence functions are transformed to splines defined by only several points. For these splines, the following properties should hold:

- The inertia value is always given on the vertical axis, that is, at distance 0. Thus, the first point is (***a*** on Figure 20)
- The second point must be located at distance 1 (***b*** on Figure 20)
- The last point of the spline should have value 0, such that for all distances larger than *d*, the function value is 0 (***c*** on Figure 20)
- There can also be points between the second and the last point (***d*** and ***e*** on Figure 20), although increasing the number of points increases complexity again.

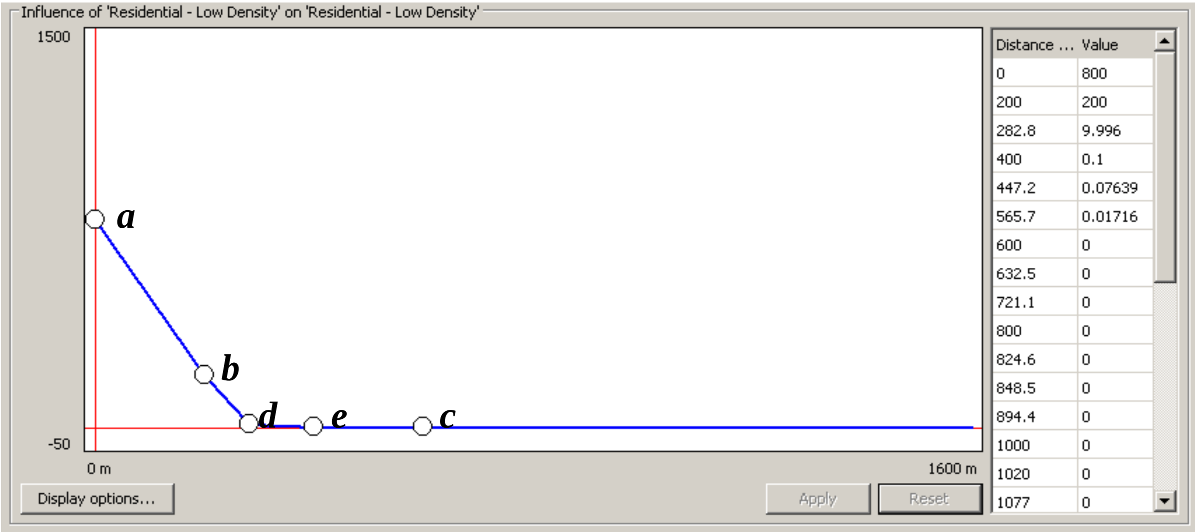



**Figure 20** Example of the neighbourhood function for Influence of Residential – Low Density on Residential – Low Density in WISE.

### 11.3.6 Transition Rules

The goal of the CA model is to simulate the dynamic behaviour of land-use change by allocating one cell state (land use) to each cell on the map. The allocation is performed on the basis of an algorithm that evaluates a vector of values – one value for each possible cell state (land use), known as transition potentials. In WISE, transition potentials are determined on the basis of four factors:

- Accessibility
- Neighbourhood influence
- Suitability
- Zoning

For land-use functions, the CA model allocates cells to a land use and attempts to meet the external demand from WRDEEM (industrial uses) and WOW (residential uses). In this case the transition potentials are a function of all four factors.

For land-use vacant states, the CA model allocates cells to a vacant land use if, and only if, there is available suitable land that is not demanded by land-use functions. Most often the total area of land-use vacant states decreases over time as demand for land-use functions increases. In the default case, the transition potential is only a function of suitability, although a user could choose to include other factors in the calculation of the transition potential.

For land-use features, no changes occur, although features can influence other land uses via neighbourhood influence or accessibility.

### 11.3.7 Land Use Change Model Spatial Data Layers

The following sections describe the spatial data layers used in the Land Use Change model: land use, suitability and accessibility. Zoning, which also influences land-use change, was previously described in Section 8.

#### *11.3.7.1 Land Use*

The choice of land-use classes and the type of micro-scale dynamics was critical to the overall functioning of WISE. The number of land-use classes affects the speed of the simulation, as does the grid cell resolution. More land-use classes (the maximum is currently 32 classes) would cause WISE to run more slowly. Finer resolution would also result in slower model simulations.

Table 16 shows both the total and active (i.e. cells containing either land, freshwater or marine within Waikato regional boundaries) number of grid cells for the Waikato region at various spatial resolutions.

**Table 16** Summary statistics for varying grid cell resolutions for the Waikato region. Total cell count = the total number of cells in the full extent, i.e. # rows x # columns. Active cell count = total cells bounded by the Waikato region coastline and interregional boundaries, i.e. all cells containing land or freshwater within Waikato region boundaries

| Cell Size | # of Rows | # of Cols | Total Cell Count | Active Cell Count |
|---|---|---|---|---|
| 25 | 12 832 | 6 636 | 85 153 152 | 39 280 154 |
| 100 | 3 208 | 1 659 | 5 322 072 | 2 455 148 |
| 250 | 1 283 | 664 | 851 912 | 392 802 |
| 500 | 642 | 332 | 213 144 | 98 188 |

The choice between number of land-use classes and spatial resolution depends on the intended use of WISE. If intend*ed primarily for in-house use to evaluate policy strategies or resource management issues,* for example, WISE could have a relatively high number of classes and/or finer spatial resolution, as overall execution time would not be a critical consideration. If intended to support community consultation processes where overall speed of execution was critical to effective engagement, WISE would generally have fewer land use classes and/or a coarser resolution.

Following consultation among Waikato Regional Council staff and project team members, a 200 × 200-m spatial resolution and 25 classes (Table 16) were chosen to represent land use within WISE. The choice represented a compromise that provided a sufficient level of spatial and classification detail while still allowing for model simulation run-times that were fast enough for possible use in interactive sessions with stakeholders or communities. For example, the current version of WISE (1.3), including all modules, requires approximately five minutes to run a single simulation on a relatively new laptop running an Intel i5 processor with 5 GB of RAM

Table 17 lists the 25 land-use classes for WISE. Of those classes, 4 are vacant states, 14 are functions, and seven are features. *Land Outside the Study Area* and *Marine Outside the Study Area* are also listed and shown in the land-use map to provide spatial context. Of the 14 land-use functions, 3 are residential land uses with demand determined by the WOW model, while the remaining 11 land-use functions are non-residential (e.g., commercial, dairy farming) land uses with demand determined by WRDEEM.

The choice of land-use type is not fixed. Land uses can be re-assigned to a new type. For example, aquaculture is currently a feature that reflects both its highly limited nature currently in the Waikato region and lack of supporting models in WISE 1.3. If aquaculture becomes more pervasive and subject to market conditions similar to other primary production uses (dairying, forestry), modelling it dynamically as a land-use function may make more sense.

Similarly, carbon credit markets could generate enough demand for regeneration of native forest to consider treating indigenous vegetation as a function rather than a vacant state. That would also require adjustments in WRDEEM to account for those new markets.

Appendix C lists the input data layers used to develop the land-use classification and briefly outlines the process used to generate the land-use layer. Waikato Regional Council holds the database and associated algorithms needed to generate the land-use layer. Note that not all input data layers may be publically available.

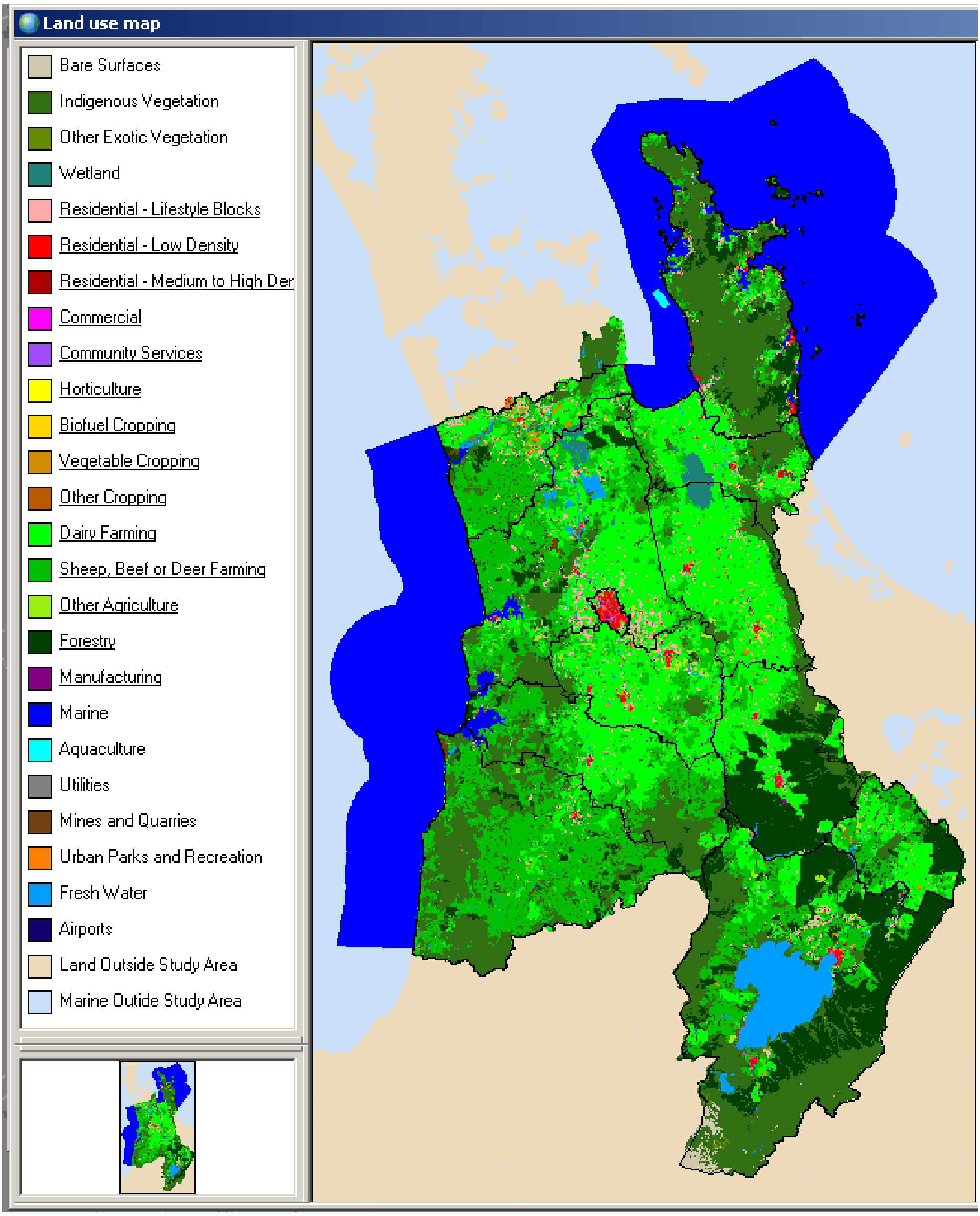



**Figure 21** Land-use map for 2006, the start year for simulations in WISE Version 1.3.

**Table 17** Land-use classes for the Land Use Change model in WISE 1.3

| Cell Value | Type | Class | Code | Description | Examples | Rationale |
|---|---|---|---|---|---|---|
| 0 | Vacant | Bare Surfaces | BSF | Sand, unvegetated sand dunes, bare rock, ice and snow, large unvegetated erosion scars and alluvial flats, permanent exposed soil not related to Mine or Quarry activities | Beaches and sand dunes on the Coromandel and West Coast, The Volcanoes of Tongariro National Park. | Covers significant parts of Waikato coastline and around mountains. Is a passively dynamic land use of natural causes |
| 1 | | Indigenous Vegetation | IDV | Predominantly native vegetation such as indigenous forest, shrubland, tussock and mangroves | Indigenous forests, mānuka/kanuka, flaxland, fernland, etc. | “Native bush” is an iconic part of the NZ landscape; also indigenous forest has second highest coverage in Waikato region |
| 2 | | Other Exotic Vegetation | OEV | Predominantly exotic/non-native vegetation not intentionally planted for production of timber products | Wilding pines, willows, deciduous hardwoods, gorse, blackberry, heather, matagouri? | Allows for areas where non-natives exist or can colonise after management for economic gain stops (similar to abandonment in other RIKS models but that concept does not fit as well in NZ) |
| 3 | | Wetland | WLD | Permanent saline or freshwater wetlands and their associated non-woody vegetation | Whangamarino; Torehape; Kopuatai; Some estuarine margins. | Although officially protected, inclusion as vacant state allows for possibility of further loss or restoration, both of which occur; difficulty with resolution as many wetlands may fall below the resolution of the model |
| 4 | Function | Residential – Lifestyle Blocks | RLB | Very low density, detached, private, single-family dwellings on lots >0.25 ha but usually no larger than 8 ha; usually located in peri-urban or rural areas | Developments around Matangi, Tamahere, River Road north of Hamilton and NW of Cambridge. | For the Waikato, 2 classes (low/high) for depicting lifestyle/periurban vs. urban situations would likely suffice; 3 classes are recommended for easier transferability to other regions, such as Auckland or Wellington, where 3 classes better capture the range of densities available or allows for more |
| 5 | | Residential – Low Density | RLW | Areas with 5–25 dwellings per hectare, typically dominated by detached, single-family dwellings or duplexes; lot sizes typically from 500–1000$^2$ m but can be up to 2500$^2$ m | This is typical New Zealand residential development (i.e. "the Kiwi quarter acre dream") built mostly prior to 2000. | |

| Cell Value | Type | Class | Code | Description | Examples | Rationale |
|---|---|---|---|---|---|---|
| 6 | | Residential – Medium to High Density | RMH | Areas with >25 dwellings per hectare, typically dominated by multi-unit buildings like townhouses, apartment complexes, or high-rises | Sherwood Vale in Hamilton (along Ruakura Road); new developments north of Hamilton; apartment blocks | scrutiny of intensification |
| 7 | | Commercial | CML | Wholesale and Retail Trade, Accommodation/Restaurants/Cafes, most communication services, Finance/Insurance and Property Services; Services to Agriculture; Hunting and Trapping | The Base, any CBD or shopping centre in Hamilton or other city/town | A key land use class in terms of its influence on other urban land uses. Typically is the centre of any urban area |
| 8 | | Community Services | CMS | Government Administration and Defence; Education; Public Safety; Health Services; Public Film, Video, Radio and Television services; Libraries, Museums, Arts and services to the Arts | Waikato District Hospital, Waikeria Prison (Buildings), Hamilton Boys High School, Police Station | A key land use in the service of urban areas. Typically borders commercial and is actively dynamic in expanding urban areas |
| 9 | | Horticulture | HOR | Production of fruits, nuts, seeds and flowers and other ornamental plants; includes nurseries and viticulture | Vilagrads and Mystery Creek Vineyards; Sunfruit Orchards | Pastoral based production is the dominant land use in the Waikato Region, followed by forestry. Cropping and horticulture generally make up a smaller part of the region although they can be significant in terms of their effects on land and water. Biofuel cropping is included to allow for expansion in future scenarios |
| 10 | | Biofuel Cropping | CPB | Production of plants for energy supply | Rape seed, Jatropha, Beets, Sorghum, Coppice plantations, maize? (see issues), etc. | |
| 11 | | Vegetable Cropping | CPV | Production of plants and roots for the purpose of vegetables for human consumption. Typically involves heavy soil disturbance as part of succession cropping | Land around Pukekohe | |
| 12 | | Other Cropping | CPO | Production of other crops such silage, barely, maize, wheat, tobacco, hops; fungi. Usually involve less disturbance of the soil and rotated on an annual basis | Various rural locations around the region | |
| 13 | | Dairy Farming | DFM | Land used for the pastoral production of dairy milk or for support of that land use | Most of Waikato's low-lying pastoral landscape | |
| 14 | | Sheep, Beef or Deer Farming | SBD | Pastoral production of sheep and/or beef and/or deer | Predominantly hill country farming such as commonly found around Te Kuiti | |

| Cell Value | Type | Class | Code | Description | Examples | Rationale |
|---|---|---|---|---|---|---|
| 15 | | Other Agriculture | OAG | Other agricultural activities such as beekeeping, horse, pig, poultry mixed livestock and other livestock farming | Equine industry around Cambridge; Goats, Pigs, Chickens, Ostriches, Alpaca | |
| 16 | | Forestry | FTY | Land used for the growth and harvesting of wood, primarily Radiata Pine but also may include other exotic or indigenous species | Kaingaroa or Kinleith Forest. Various smaller private forestry blocks on farmland | |
| 17 | | Manufacturing | MFG | Production and storage of goods such as wood/paper, textiles, clothing, footwear, foods, beverages, petroleum, coal, chemicals, metals and non-metals, machinery, equipment and furniture; Printing and publishing | Kinleith Pulp and Paper Mill; Dairy Factories; Urban industrial areas | A key land use in terms of its interactions with primary production land uses and the urban land uses serving the manufacturing area |
| 18 | Feature | Marine | MAR | Estuarine and open coastal water out to the 12NM regional boundary | West Coast, Firth of Thames, Coast around Coromandel Peninsula, Raglan Harbour, Whangamata Estuary | A significant part of the Waikato region generally deemed static but could change to a vacant state if aquaculture became a function. Has neighbourhood influences on some land uses |
| 19 | | Aquaculture | AQC | Production and cultivation of aquatic animals and plants; both salt and fresh water | Mussel farms off Thames coast. Huka prawn park | A developing industry in the Waikato Region. Difficult to model as a function at this stage due to a lack of information but could be changed to a function in later versions |
| 20 | | Utilities | UTL | Infrastructure for generation, transmission, distribution, storage, treatment or manufacture of electricity, gas, water supply and wastewater treatment. Also includes large infrastructure associated with transportation but not airports | Huntly Power Station, Karapiro Dam, Hamilton Wastewater Plant, Wairakei Geothermal Power Plant, Frankton Railway Station | Critical in keeping the built human environment although tends to have only minor interactions with neighbouring land uses |
| 21 | | Mines and Quarries | MAQ | Mining and quarrying operations and their solid waste products. Includes coal, oil and gas extraction and exploration activities | Huntly Coal Mine, Waihi Gold Mine; various sand & gravel quarries | Covers significant parts of the Waikato Region. A key employer |

| Cell Value | Type | Class | Code | Description | Examples | Rationale |
|---|---|---|---|---|---|---|
| 22 | | Urban Parks and Recreation | URP | Areas set aside for recreation, leisure activities, or aesthetic enjoyment; includes Parks and Gardens, Sports Fields and facilities, Gambling and Other Recreation services. Excludes conservation estate land such as National or State Forest Parks | Claudelands Park, Cambridge Town Belt, Hamilton Gardens, Waikato University grounds, Waikato Stadium, Te Rapa Racetrack | Has strong impacts on urban land use dymanics |
| 23 | | Fresh Water | FRS | Permanent fresh water bodies including lakes, reservoirs, dams and ponds over 4 ha and rivers wider than 200 m | Lake Taupo, Lake Karapiro, various smaller lakes and ponds 4ha minimum | Covers significant parts of the region and has some interaction with some neighbouring land uses |
| 24 | | Airports | APT | Large airports used for domestic or international flights and their directly associated structures and buildings. Excludes small rural airports and airstrips used only for recreational or primary industry purposes | Hamilton, Taupo and Thames Airports | Critical in servicing large urban areas. Has immediate interactions with some neighbouring land uses |
| 25 | | Land Outside Study Area | | | | |
| 26 | | Marine Outside Study Area | | | | |

### *11.3.7.2 Suitability*

Suitability estimates the potential of a given location to support a particular land use. For WISE this means: how suitable is each 200 × 200-m grid cell for each land-use function or vacant state? Suitability is evaluated on a scale from 0 (= completely unsuitable) to 10 (= most suitable) in increments of one. For WISE, a suitability of 0 means a land use cannot occur at that location. In that regard, a suitability of 0 has the same effect as prohibited zoning, i.e. a land use is “not allowed” in such places.

Suitability layers were generated for each land-use function and vacant state by combining relevant input layers using sets of rules generated via a review by experts with considerable experience in sustainable land management (A. Hewitt and T. Webb, Landcare Research, pers. comms). The rules consisted primarily of graphical functions that depicted relationships between critical factors on the horizontal axis and suitability from 0 to 10 on the vertical axis. Figure 22 shows an example of such relationships for the land uses Arable Cropping and Biofuels. The specific factors represented are fields for various soil attributes found in the National Soils Database.

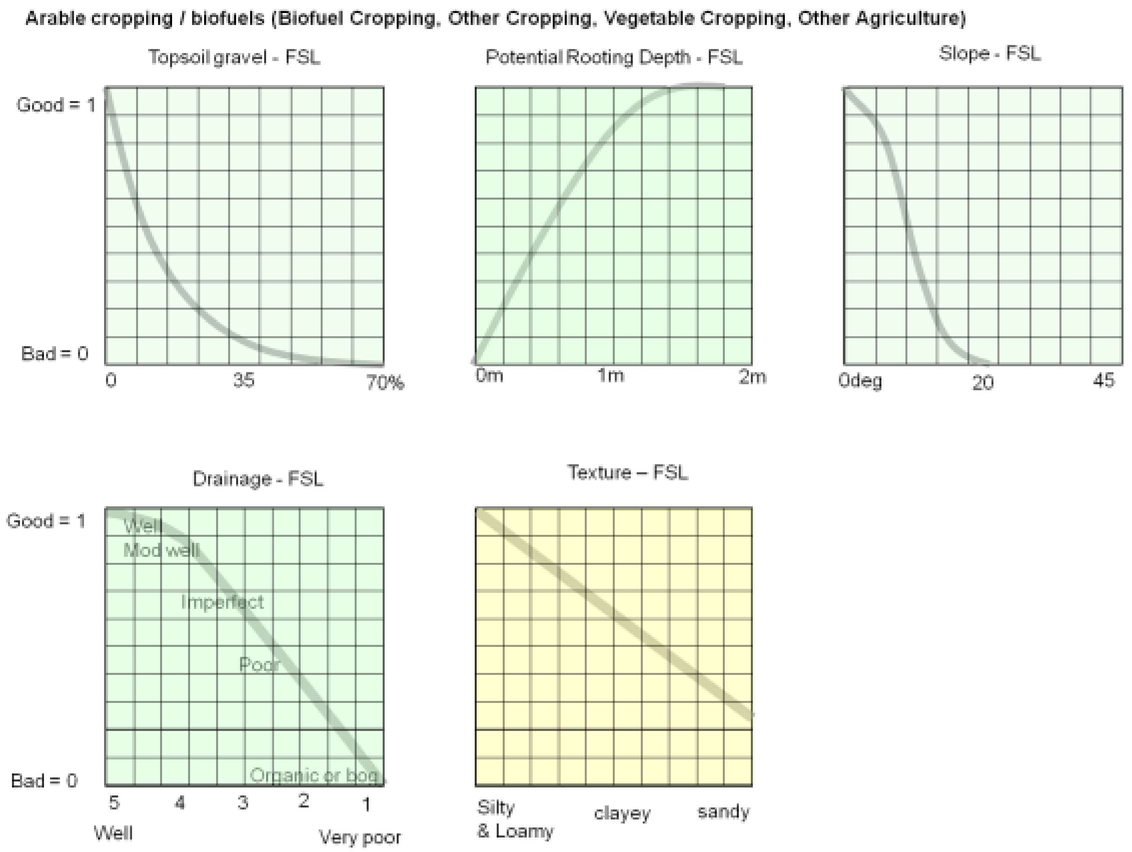



**Figure 22** Relationships between key factors and suitability for arable cropping and biofuels. FSL = Fundamental Soil Layers.

Suitability factors can be combined in various ways to generate an overall score, such as arithmetic mean, geometric mean, limiting factors where overall suitability scores reflect the minimum score of the lowest factor, or even more complex relationships. For WISE all suitability maps were generated using a geometric mean as follows:

$$S_{i,xy} = \sqrt[N]{s_{1,xy} \times s_{2,xy} \times s_{3,xy} \times \ldots \times s_{n,xy}}$$

where

| | | |
|---|---|---|
| $S_{i,xy}$ | = | total suitability score for land use *i* at location *x*,*y* |
| $s_{i,xy}$ | = | suitability score for factor *n* at location *x*,*y* |
| $N$ | = | count of all factors. |

Values for the geometric mean vary from 0 to 10. If any one factor score = 0, then total suitability = 0. If all factor scores = 10, then total suitability = 10. Intermediate scores vary depending on individual factor scores and the total number of factors. For example, consider the following two cases:

Case 1: $s_{i,xy}$ = {10,10,5} = 7.9

Case 2: $s_{i,xy}$ = {10,10,10,10,10,5} = 8.9

Overall, suitability scores depended on all three considerations: selected factors, characterisation of relationships, and rules for combining factors. There is no definitive method for defining and characterising suitability. Instead different combinations of attributes, weightings, combinations and methods can be explored to evaluate the impact of different representations of suitability within WISE. Different suitability maps can be generated independently of WISE or the baseline suitability maps provided with WISE can be modified via use of tools within WISE to suit user requirements.

Suitability maps were generated using the same process as that use for land use as described in Appendix C. Figure 23 shows an example suitability map for the "Other Cropping" land use.

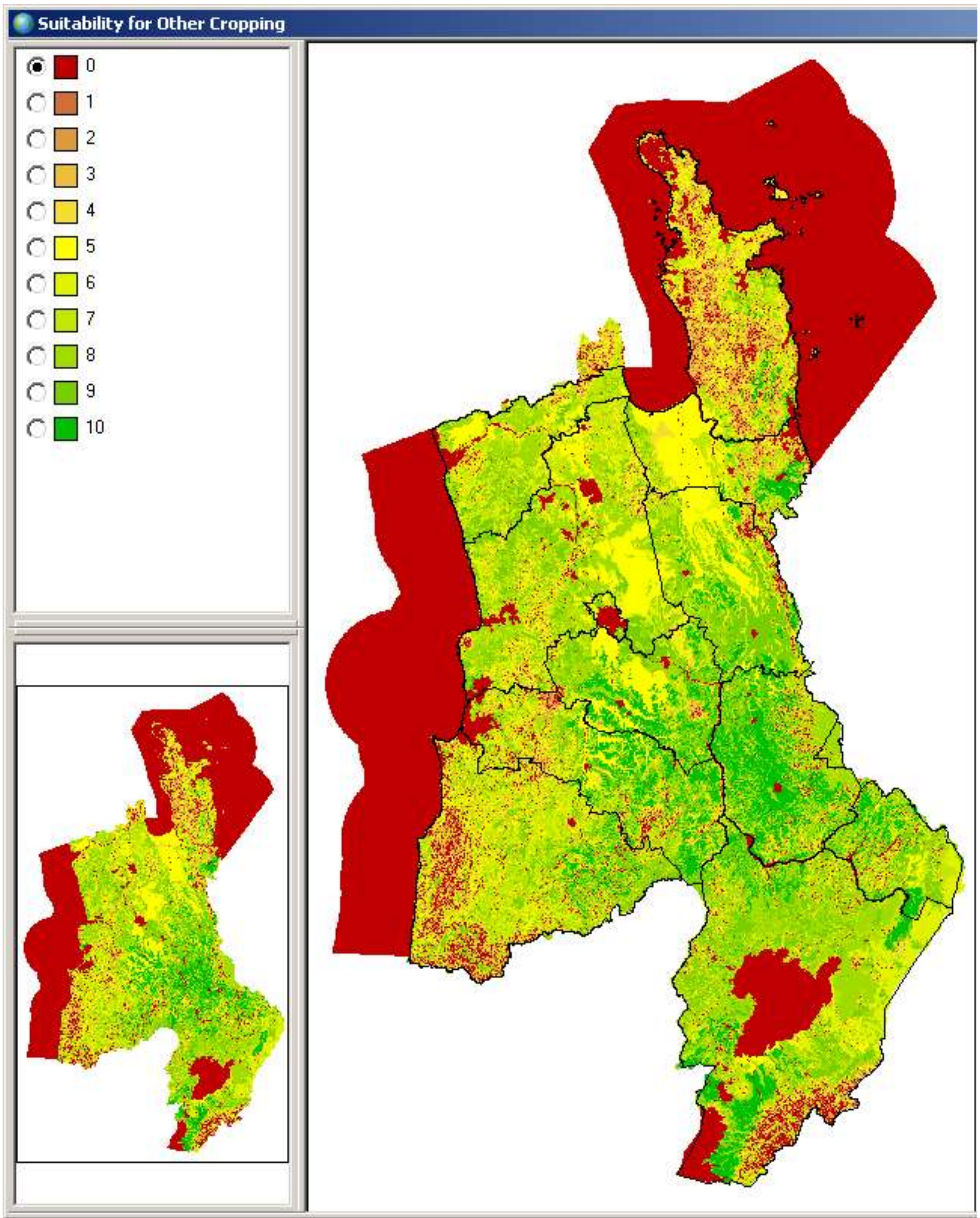



**Figure 23** Example of suitability map for Other Cropping land use.

### *11.3.7.3 Accessibility*

Accessibility layers vary depending upon the relevance of features to different land uses. WISE 1.3 includes accessibility layers for three types of features:

- Transport networks (highways, roads, and railways)
- Major processing facilities
    - Dairy processing plants
    - Timber production plants
    - Abattoirs

- Central business districts and shopping centres
    - Waikato
    - Auckland
    - Tauranga.

Appendix C contains the list of input data layers that provided the basis for the accessibility spatial data layers in the Land Use Change model.

## 11.4 Equations

### 11.4.1 Accessibility

Accessibility measures the effect of the nearness and importance of different types of transport networks – such as local roads, highways, railroads or stations on the possible future occurrence of each land-use function at a certain location. Accessibility in WISE for each land-use function is a composite measure of four types of accessibility:

- local accessibility
- implicit accessibility
- explicit accessibility
- zonal accessibility

Users can alter accessibility by adding or removing layers (usually infrastructure) of interest or by modifying the parameter values defining the accessibility relationships.

#### *11.4.1.1 Local Accessibility*

Local accessibility reflects the extent to which the need for a transportation network for a land use can be fulfilled. The network consists of a number of network layers made up of (a) nodes, such as schools or stations, and (b) links, such as roads or railways. Local accessibility is first determined individually for each node or link type and, thereafter, combined into one value for each land use and each cell.

For each land use, the local accessibility for a certain node or link can be either decreasing or increasing over distance, indicated by a positive or negative value for the distance decay parameter, respectively. A positive value indicates the land use needs to be located close to that node or link, whereas a negative value indicates the land use needs to be located away from the node or link. The functional form of this effect is hyperbolic with respect to the distance, where the distance decay parameter determines the rate of the increase or decrease (Figure 24). Note that the local accessibility per link type lies in the range [0, 1].

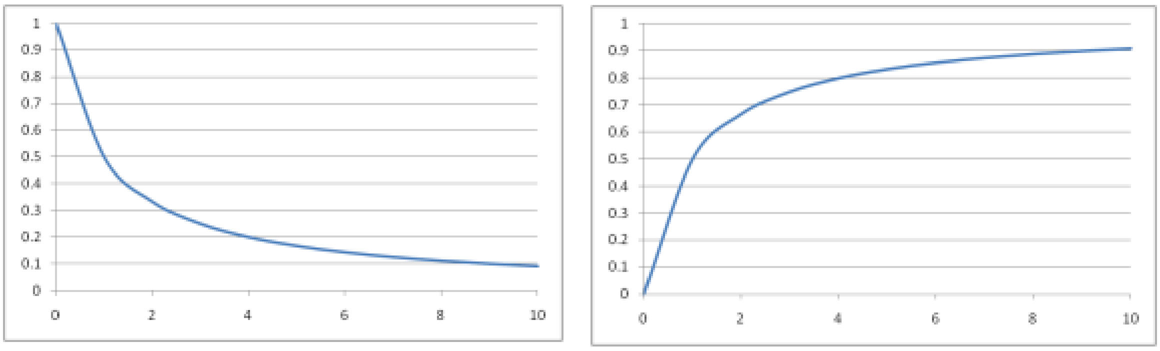
The *local accessibility* of cell *c* to node or link *s* for land use *f* is calculated as:

$$
{}^{t}LA_{s,f,c} = \begin{cases} \dfrac{a_{s,f}}{D_{s,c} + a_{s,f}} & \text{if } a_{s,f} > 0 \\ 0 & \text{if } a_{s,f} = 0 \\ 1 - \dfrac{|a_{s,f}|}{D_{s,c} + |a_{s,f}|} & \text{otherwise} \end{cases}
$$

where

${}^{t}D_{s,c}$ = the distance in cells between cell $c$ and the nearest cell that is intersected by a node or link $s$ at time $t$

$a_{s,f}$ = the accessibility distance decay parameter of node or link $s$ for land use $f$.




(a) (b)

**Figure 24** Effect of proximity to the network as a combined function of distance and the distance decay parameter. (a) $a_{s,f}$ = 1 (positive distance decay factor) means that a cell is more suitable for land use $f$ if that cell is closer to the node or link of interest; (b) $a_{s,f}$ = -1 (negative distance decay factor) means that a cell is more suitable for land use $f$ if that cell is farther from the node or link of interest.

The local accessibility of all nodes and links with negative distance decays is calculated as:

$$
{}^{t}LA^{neg}_{f,c} = \prod_{s \in S^{-}_{f}} w_{s,f} \cdot {}^{t}LA_{s,f,c}
$$

$$
w^{neg}_{f} = \prod_{s \in S^{-}_{f}} w_{s,f}
$$

where

${}^{t}LA^{neg}_{f,c}$ = the total negative local accessibility of cell $c$ for land use $f$ at time $t$

$w_{s,f}$ = the relative weight of the proximity to the different networks on the total local accessibility

$S_f^-$ = the set of all nodes and links with a negative distance decay parameter for land use *f*

${}^{t}LA_{s,f,c}$ = the local accessibility of cell *c* to node or link *s* for land use *f*

$w_f^{neg}$ = the total weight of the local accessibilities with a negative distance decay parameter.

The total local accessibility of cell *c* for land use is calculated as:

$$ {}^{t}LA_{f,c} = \frac{1-\left(1-w_f^{neg}\cdot {}^{t}LA_{f,c}^{neg}\right)\cdot \prod_{s\in S_f^+}\left(1-w_{s,f}\cdot {}^{t}LA_{s,f,c}\right)}{1-\left(1-w_f^{neg}\right)\cdot \prod_{s\in S_f^+}\left(1-w_{s,f}\right)} $$

where

| | | |
|---|---|---|
| ${}^{t}LA_{f,c}$ | = | total local accessibility for cell *c* with land use *f* at time *t* |
| $w_f^{neg}$ | = | the total weight of the local accessibilities with a negative distance decay parameter |
| ${}^{t}LA_{f,c}^{neg}$ | = | the total negative local accessibility of cell *c* for land use *f* at time *t* |
| $S_f^+$ | = | the set of all nodes and links with a postive distance decay parameter for land use *f* |
| $w_{s,f}$ | = | the relative weight of the proximity to the different networks on the total local (what??) |
| ${}^{t}LA_{s,f,c}$ | = | the local accessibility of cell *c* to node or link *s* for land use *f*. |

### *11.4.1.2 Implicit Accessibility*

Implicit accessibility reflects the fact that when an area is occupied by an urban land use, measures will be taken to assure its accessibility, even if it does not appear so on the network map, e.g., provision of new roads in a subdivision. This is significant because as the cellular automata model changes the land use map, it does not change the network map accordingly.

Implicit accessibility takes one of two possible values for each land-use class: one for urbanised areas and one for non-urbanised areas. A cell is urbanised if its current land use class is flagged as a ‘built-up area’. These flags are, therefore, parameters of the accessibility model block.

The implicit accessibility is determined as:

$$ {}^{t}IA_{f,c} = \begin{cases} Urb_f & \text{if } {}^{t}f(c)\in LU_U \\ NUrb_f & \text{otherwise} \end{cases} $$

where

| | | |
|---|---|---|
| ${}^{t}IA_{f,c}$ | = | implicit accessibility for land use *f* of a cell *c* |
| $Urb_f$ | = | implicit accessibility for land use *f* of a cell *c* that is occupied by a built-up (urban) land use |
| $NUrb_f$ | = | implicit accessibility for land use f of a cell c that is occupied by a non-built-up (non-urban) land use |
| $LU_U$ | = | the set of built-up (urbanised) land uses. |

In WISE the implicit accessibility for built-up land uses is 1.

#### 11.4.1.3 Explicit Accessibility

When determining the distance from a cell to the nearest node or link, some land uses cannot be crossed. Therefore the distance cannot be measured in a straight line. In this case, the explicit suitability is set to 0.

On the other hand, some land uses that are impassable for other land uses are actually passable for the same land use, e.g., a military land use. In this case, explicit suitability is set to equal to the implicit suitability of the land use in question. More formally:

$$ {}^{t}EA_{f,c} = \begin{cases} {}^{t}IA_{f,c} & \text{if } {}^{t}f(c) = f \\ 0 & \text{otherwise} \end{cases} $$

where

| | | |
|---|---|---|
| ${}^{t}EA_{f,c}$ | = | explicit accessibility of cell *c* for land use *f* at time *t* |
| ${}^{t}IA_{f,c}$ | = | implicit accessibility of cell *c* for land use *f* at time *t* |
| ${}^{t}f(c)$ | = | land use occupied by cell *c* at time *t*. |

#### 11.4.1.4 Zonal accessibility

Zonal accessibility in WISE 1.3 is simply included as a (static) parameter that specifies the multiplication factor for each land use function in each district. These values are used to account for accessibility influences from outside the Waikato region (mainly the attraction of Auckland).

#### 11.4.1.5 Total Accessibility

Local, implicit, and explicit suitability are combined to produce a total accessibility score ranging from 0 to 1 for each land use in each cell. If current land use in a cell is classified as impassable land, then total accessibility = explicit accessibility. Otherwise, the total accessibility equals the product of local accessibility × implicit accessibility.

The total accessibility () is defined as:

$$ {}^{t}A_{f,c} = \begin{cases} {}^{t}EA_{f,c} & \text{if } {}^{t}f(c) \in LU_I \\ {}^{t}ZA_{f,z_c} \cdot {}^{t}LA_{f,c} \cdot {}^{t}IA_{f,c} & \text{otherwise} \end{cases} $$

where

| | | |
|---|---|---|
| ${}^{t}A_{f,c}$ | = | total accessibility of cell *c* for land use *f* at time *t* |
| ${}^{t}EA_{f,c}$ | = | explicit accessibility of cell *c* for land use *f* at time *t* |
| ${}^{t}f(c)$ | = | land use occupied by cell *c* at time *t* |
| $LU_I$ | = | the set of impassable land uses, |
| ${}^{t}ZA_{f,c}$ | = | the zonal accessibility of cell *c* for land use *f*. |
| ${}^{t}LA_{f,c}$ | = | the local accessibility of cell *c* for land use *f* |

$^{t}IA_{f,c}$ = the implicit accessibility of cell *c* for land use *f*.

Table 18 below lists the full set of inputs, parameters, and outputs in the accessibility model block.

**Table 18** Accessibility model block inputs, parameters and outputs

| Name | GUI | Type | Description | Source |
|---|---|---|---|---|
| - | Network maps | Input | The network layers that consist of nodes and links of different types, representing the transport network. | Data |
| $^{t}D_{s,c}$ | Distance to road | Input | The distance from a cell to the nearest link segment of a certain link type. | Data |
| - | Built-up area | Parameter | True/false parameter per land use, specifying if the land use is urbanised or not. | User specified |
| $Urb_f$ | Implicit accessibility of built-up area | Parameter | The implicit accessibility for a land use on a built-up area. | User specified |
| $NUrb_f$ | Implicit accessibility of non-built-up area | Parameter | The implicit accessibility for a land use on a non-built-up area. | User specified |
| - | Impassable | Parameter | True/false parameter per land use, specifying if the land use is impassable for other land uses or not. | User specified |
| $w_{s,f}$ | Relative importance | Parameter | The relative weight of the local accessibility for a certain link type and land use in the total local accessibility for that land use. | User specified |
| $a_{s,f}$ | Distance decay | Parameter | The rate at which the local accessibility for a certain link type and land use decreases – for positive values – or increases – for negative values – over distance. | User specified |
| $^{t}A_{f,c}$ | Accessibility map | Output | The map that contains the accessibility value for each cell. | Sent to the transition potential model block |

## 11.4.2 Neighbourhood Influence

As described above, neighbourhood influence assesses the composition of land use in an 8-cell radius neighbourhood around the cell of interest. Users assign weights to neighbouring cells using influence relationships as discussed earlier (Figure 19). Each land use in the neighbourhood has a possible influence on the future occurrence on land use in the cell of interest. Influences are accumulated to produce the neighbourhood effect in each cell for each land-use function, as follows:

$$^{t}R_{f,c} = \sum w_{f,f'}(d(a,b))$$

where

| | | |
|---|---|---|
| ${}^{t}R_{f,c}$ | = | The neighbourhood effect on cell *c* with land use state *f* at time *t* |
| $w_{f,f'}(d)$ | = | The influence function, expressing the strength of the influence of a cell with land use *f'* on land use *f* for each distance *d* in the CA neighbourhood. |
| $d(a,b)$ | = | The Euclidian distance between cell *a* and cell *b* |

**Table 19** Neighbourhood influence inputs, parameters, and outputs

| Name | GUI | Type | Description | Comments |
|---|---|---|---|---|
| ${}^{t}f(c)$ | Land use map | Input | The map that contains the land use that occupies each cell. | Data source |
| $w_{f,f'}(d)$ | Rules - Influence table | Parameter | The spline that determines the influence of a land use on another land use for each distance in the neighbourhood. | User specified |
| ${}^{t}R_{f,c}$ | - | Output | A map for each land use function containing the neighbourhood effect for that land use for each cell. | Input to the transition potential model block |

### 11.4.3 Suitability

Suitability quantifies the effect that particular factors have on the occurrence of land uses at different locations. In WISE, suitability is pre-determined by users and usually remains fixed for the duration of a simulation. However, users can edit suitability maps within GEONAMICA on-the-fly by pausing a simulation run, editing the map (or maps), and restarting the simulation.

**Table 20** Suitability outputs

| Name | GUI | Type | Description | Comments |
|---|---|---|---|---|
| $S_{f,c}$ | *Suitability maps* | Output | A map for each land use containing the suitability of each cell for that land use | Sent to the transition model block |

### *11.4.4 Zoning*

Zoning models the influence of policy and planning on the land-use allocation process. As discussed in Section 8, users create categorical zoning maps based on interpretations of various rules, zones, designations, etc., from regional plans, district plans, or other relevant sources. The zones show the RMA activity status of a cell for a particular land use. The Land Use Change model evaluates the overall zoning score for each land-use function *f* at each cell *c* at each time step *t* by looping through zones that apply to that particular land-use function following the precedence rules set by the user. It then converts the resulting categorical zoning values into numerical zoning values according to the zoning state values assigned by users, e.g., permitted = 1, discretionary = 0.8, etc. More formally, let:

| | |
|---|---|
| $P$ | the set of all plans |
| $R$ | the set of all categories in all plans |
| $F$ | the set of all land-use functions |
| $Z$ | the set of all activity status values. |

.

Each plan $p \in P$ is represented by a zoning map $Z_p$ that shows the location of all categories $r$ within that plan. Each cell $c$ in map $Z_p$ can have only one category, i.e. no overlaps are allowed. Where categories do not apply, cells have the value 'no data.' For each zone in a plan $p$, a binary map $B_r$ is created indicating where that category occurs in the plan.

As outlined in the zoning model discussion, users specify several other parameters for each category $r$ in a plan $p$:

| | | |
|---|---|---|
| $T_r^{start}$ | = | start year of zone |
| $T_r^{end}$ | = | end year of zone |
| $S_{f,r}$ | = | activity status for land-use function $f$ in category $r$ |
| $O_r$ | = | the precedence order for category $r \in R$ . |

For $r \neq r'$, if $O_r < O_{r'}$ then category $r$ takes precedence over zone $r'$.

The result of the algorithm will be a time series of zoning maps for each land-use function that indicate for each cell the resulting activity status. Formally, let

$^tZ_{f,c}$ = the activity status of land-use function $f$ in cell $c$ at time $t$.

Categorical zoning maps must be converted to numerical zoning maps for use in the calculation of the total transition potential. The Land Use Change Model converts the activity status into the numerical zoning score assigned by the user in the Land Use Change Model. In addition, the model also considers the de facto land-use function. For this purpose we define a matrix that shows on which existing land use a potential land-use function is allowed to develop. Formally let:

$DF_{l,f} \in \{0,1\}$ the De Facto status of land use function $f$ on land use $l$, indicating if land use function $f$ is always allowed to develop in areas where land use $l$ occurs,

$V_{f,s}$ the value that needs to be assigned to zoning status $s \in S$ for land use function $f \in F$ and

$^tZV_{f,c} \in [0,\infty)$ the value used for zoning in the calculation of the total potential for land use function $f \in F$ in cell $c$ at time $t$.

**Table 21** Zoning algorithm for determining precedence among zones

| Logic Statement | Comment |
|---|---|
| **Let** $t$ denote the current simulation time | |
| Initialise $^tZ_{f,c}$ = 'unspecified' for all cells $c$ and for all land-use functions $f \in F$ | Set zoning for all cells as 'unspecified' |
| **For** each class $r$ ordered by $O_r$ descending | |
| **If** $T_r^{start} \leq t \leq T_r^{end}$ | |
| **For** each $f \in F$ | |

```
            If ZS_{f,r} ≠ 'unspecified'
                For each c for which B_{r,c} = 1
                    Z_{f,c} = ZS_{f,r}
                End for
            End if
        End for
    End if
End for
```

**Table 22** Zoning inputs, parameters, and outputs

| Name | GUI | Type | Description |
|---|---|---|---|
| $Z_p$ | Zoning plan | Input | A categorical map that spatially delineates zones in a plan. Zones are specified in an associated legend file |
| $\mathbf{T}_z^{start}$ | Start time | Input | The start time of zone *z* |
| $\mathbf{T}_z^{end}$ | End time | Input | The end time of category *z* |
| ${}^tZ_{f,c,z}$ | Categorical zoning status | Input | Categorical zoning status for land use *f* at grid cell *c* within zone *z* |
| $\mathbf{O}_r$ | Zone precedence | | The precedence order of zone *z* |
| $DF_{l,f}$ | De Facto zoning | | The de facto status of land-use function f on land use l, indicating if land-use function f is always allowed to develop in areas where land use l occurs |
| $V_{f,s}$ | Zoning status value | | The numerical zoning value for land use function *f* with activity status *s* |
| $Z_{f,s}$ | Zoning maps | | A map for each land-use function *f* that denotes the activity status *s* |
| ${}^tZV_{f,c}$ | Numerical zoning maps | | A map for each land-use function f that denotes the numerical zoning value used in the transition potential calculation for cell *c* |

### 11.4.5 Land-use Change

Land-use change is updated based on an analysis of the transition potentials calculated for each cell with either a land-use function or a vacant state. Land-use features do not change and therefore are not modelled. The Land Use Change model aims to meet any external demands for land-use functions as determined by the WRDEEM and WOW models. Vacant states will be allocated after the required number of cells has been allocated to all land-use functions.

This land-use change procedure can be understood most easily by considering the land-use functions as agents that want to occupy a certain number of cells in the region and by considering the cells in each region as agents that want to be occupied by a land use that has the highest transition potential in that cell. The algorithm attempts to satisfy those conditions such that the accumulated transition potential of the cells occupied by each land-use function is maximised. In that regard, the allocation algorithm (Table 23) yields an equilibrium outcome in which no land use can find a cell that it can occupy, meaning the currently allocated land use has a lower transition potential value in that cell, while vacating another cell and, thereby, increases its accumulated transition potential. At the same time, no cell can find a land use that is willing to vacate another cell and occupy this cell, thus increasing its accumulated transition potential, thereby increasing the transition potential in this cell.

The equilibrium state is found by an iterative procedure, in which the land-use function that has the highest transition potential in an unallocated cell in the region is allocated to that cell, as long as more cells need to be allocated to that land-use function. Thereafter, the vacant land use with the highest transition potential is allocated to each unallocated cell.

**Table 23** Algorithm for allocating land use based on calculated transition potentials

```
for each region
    allocate the current land use to all cells occupied by a land-use feature
        while some cells have to be allocated to some land-use function
            select the land use function for which we still need to allocate more cells that has
            the highest total potential value in an unallocated cell
            allocate the land use to that cell
        end while
        while not all cells have been allocated a land use
            select the vacant land use with the highest potential in an unallocated cell
            allocate the land use to that cell
        end while
end for
```

The default calculation determining transition potential in WISE 1.3 is:

$${}^{t}T_{f,c} = I_{f,c} \times S_{f,c}$$ for land-use vacant states

$${}^{t}T_{f,c} = (1-c) \times {}^{t}N_{f,c} \times {}^{t}A_{f,c} \times S_{f,c} \times {}^{t}Z_{f,c}$$ for land-use functions if ${}^{t}R_{f,c} \geq 0$

$${}^{t}T_{f,c} = (1-c) \times {}^{t}N_{f,c} \times \left(2 - {}^{t}A_{f,c} \times S_{f,c} \times {}^{t}Z_{f,c}\right)$$ for land-use functions if ${}^{t}R_{f,c} < 0$

where

| | | |
|---|---|---|
| ${}^{t}T_{f,c}$ | = | transition potential for cell *c* for land use *f* at time *t* |
| $I_{f,c}$ | = | inertia/conversion effect of the current land use in cell *c* for land use *f* |
| $S_{f,c}$ | = | suitability score for cell *c* for land use *f* |
| ${}^{t}N_{f,c}$ | = | neighbourhood influence score for cell *c* for land use *f* at time *t* |
| ${}^{t}A_{f,c}$ | = | total accessibility score for cell *c* for land use *f* at time *t* |
| ${}^{t}Z_{f,c}$ | = | zoning score for cell *c* for land use *f* at time *t* |
| *c* | = | random coefficient set by the user. |

Users may change the algorithms as desired to explore different combinations or weightings of factors (Table 24). The default value for the random coefficient *c* is 0.5.

**Table 24** Land use model inputs, parameters, and outputs

| Name | GUI | Type | Description | Source |
|---|---|---|---|---|
| - | Land-use map | Input | The land-use map at the start of the simulation | Data |
| ${}^{t}P_{f,c}$ | Transition potential maps | Input | The transition potential for each land use and each cell | Calculated internally |

| | | | | |
|---|---|---|---|---|
| ${}^{t}N_{f,i}$ | Regional demands | Input | The number of cells that need to be allocated to each land use function in each region | WRDEEM (industrial land uses) and WOW (residential land uses) |
| ${}^{t}f(c)$ | Land-use map | Output | The land use that currently occupies each cell in the map | Land Use Change model |

### 11.4.6 Monte Carlo functionality

The land use model has the functionality to perform a Monte Carlo analysis. This means that the integrated model will be run from start to finish a specified number of times and the frequency with which each land use occurs on each location of the map at the end of a run will be counted. In this way, the stochastic nature of the land use change model can be presented much better than with the outcome of a single run. The basic result of a Monte Carlo analysis in WISE will be a set of maps indicating the probability (between 0 and 1) of occurrence of each land use function.

For a useful presentation of the analysis output, these maps need to be combined with each other and with information from the initial land use map. E.g. to display the probability of urbanisation the user can sum the probability of occurrence of each urban land use class, depict this against a background of existing (natural) land use classes taken from the initial land use map, and overlay the existing urban land use from the initial land use map (in order to distinguish between existing and new urban areas). Other overlays, such as the road network or district boundaries may be desired as well.

## 11.5 Links

The Land Use Change model links with the Hydrology, Water Quality, Demography, WRDEEM, and Terrestrial Biodiversity (Table 25).

**Table 25** Links between the Land Use Change model and other models

| Type | Model | Data Passed | Comments |
|---|---|---|---|
| Inputs | WRDEEM | Economic activity | Economic activity determines the amount of land demanded by multiplying economic activity ($\$mil_{2007}$) x the land productivity index |
| | Demography | Population | Population determines the demand for land (ha) for each of the three residential land use categories |
| Outputs | Hydrology | Land Use | Land use determines the canopy capacity $w_{cm}$ (mm) via a look-up table |
| | Water Quality | Land Use | Land use determines the source coefficient ($c_i$) via a look-up table<br>Land use determines the value of the rain exponent and drain exponent for N loading ( $\alpha_{ik}$ ) |

| | | |
|---|---|---|
| WRDEEM | Land Use | Amount of land (ha) supplied to WRDEEM |
| Terrestrial Biodiversity | Land Use | Land use is passed to the Terrestrial Biodiversity model, where it is reclassified as either native or non-native cover |

# 12 Terrestrial Biodiversity – Landcare Research

## 12.1 Metadata

| | | |
|---|---|---|
| 1) | Name of Model | Terrestrial Biodiversity |
| 2) | Organisation | Landcare Research |
| 3) | Contact | Robbie Price |
| 4) | Spatial Resolution | 100m (as grid) |
| 5) | Temporal Resolution | Annual |
| 6) | Input Data | Land Use (categorical grid) |
| 7) | Internal Data | Legally Protected Areas (binary grid)<br>Land Environments of New Zealand Level II (categorical grid)<br>Link Table: Land Use to Land Cover |
| 8) | Output Data | Threatened Environments (categorical grid) |

## 12.2 Summary

The Terrestrial Biodiversity model assesses the representativeness of native ecosystems in the Waikato region. It performs a combinatorial analysis to identify unique combinations of land environments (Leathwick et al. 2003a, b), legally protected areas (Rutledge et al. 2008), and land cover (Thompson et al. 2003). That analysis in turn provides information on ecosystem condition, assessed as % remaining native cover, and protection, expressed as % of each Level II land environment in the Waikato region. Percentages of remaining native cover and/or legal protection are then transformed into one of six threat categories following Walker et al. (2008).

## 12.3 Description

The New Zealand Biodiversity Strategy broadly calls for actions to halt the decline of indigenous biodiversity throughout New Zealand (MfE & DOC 2000). Specifically, the Strategy promotes two major goals for indigenous biodiversity:

- Maintain and restore the full range of remaining natural habitats and ecosystems to a healthy functioning state, enhance critically scarce habitats, and sustain the more modified ecosystems in production and urban environments
- Maintain and restore viable populations of all indigenous species and subspecies across their natural range, and maintain their genetic diversity.

Because the full state of biodiversity across all of New Zealand is not – or never will be – fully known, we rely on indicators to help assess our progress in achieving such goals (Lee et al. 2004).

The Terrestrial Biodiversity model combines information on all land cover including vegetation state with information from two other primary data sources to produce an indicator of ecosystem representativeness. The two data sources are land environments that serve as surrogates for ecosystems and habitats (Land Environments of New Zealand or LENZ) (Leathwick et al. 2003a, 2003b) and a database of legally protected areas (Protected Areas Network of New Zealand or PAN-NZ) (Rutledge et al. 2008) (Table 26).

**Table 26** Spatial data layers used in the biodiversity model to analyse ecosystem representativeness

| Layer | Source | Classes | Description |
|---|---|---|---|
| Land Use | Land Use Change Model | Native (1) | Bare Ground<br>Indigenous Vegetation<br>Water<br>Wetlands |
| | | Exotic (0) | All other land use classes |
| Land Environments of New Zealand (LENZ) Level II Version 1.0 | Ministry for the Environment | 1–100 | Layer depicting areas with similar environmental conditions across New Zealand based on a combination of climate, landform, and soil conditions |
| Protected Areas Network of New Zealand (PAN-NZ) | Landcare Research<br>(compilation of other data sources) | Protected (1) | Legally protected areas based on polygon coverage:<br>• Conservation Estate (DOC managed)<br>• Queen Elizabeth II National Trust Covenants<br>• Nga Whenua Rahui Covenants<br>• Nature Heritage Fund Covenants<br>• Regional Parks |
| | | Not Protected (0) | All other land |

The model overlays information on native ecosystem condition generated by the Land Use Change model with LENZ and PAN-NZ to generate a new spatial data layer whose values consist of a reference to a look-up table containing all unique combinations of vegetation state, LENZ environments, and protected areas. Based on the results of the combinatorial analysis, the model then assigns each environment to 1 of 5 threat categories (Walker et al. 2006) or, conversely, no threat category based on the level of remaining native vegetation or amount of legal protection (Table 27).

**Table 27** LENZ environments threat categories, and defining criteria

| Category | Criteria | |
|---|---|---|
| | Vegetation - Native | Legal Protection |
| Acutely Threatened | <10% | 0-100% |
| Chronically Threatened | 10–20% | 0-100% |
| At Risk | 20–30% | 0-100% |
| Critically Underprotected | >30% | <10% |
| Underprotected | >30% | 10-20% |
| No Threat Category | >30% | >20% |

## 12.4 Equations

Ecosystem representativeness calculates the percentage of native land cover remaining in a land environment that is legally protected. The formula used is as follows:

$$R_{LE_i} = \left( \frac{a_{NLC}}{A} \right)_{LE_i}$$

where

| | | |
|---|---|---|
| $R$ | = | percent of protected native land cover remaining versus total area within the Waikato region |
| $LE_i$ | = | land environment $i$ (1 to 100) |
| $a_{NLC}$ | = | area of native land cover remaining within the Waikato region in land environment $i$ |
| $A$ | = | total area within the Waikato region of land environment $i$. |

## 12.5 Links

The Terrestrial Biodiversity links to the Land Use Change model (Table 28).

**Table 28** Links between terrestrial biodiversity and other models within WISE

| Type | Model Component | Data Passed | Comments |
|---|---|---|---|
| Inputs | Land Use Change | Land Use | Land-use change classes are reclassified into Native and Non-native categories as outlined above. |
| Outputs | None | | |

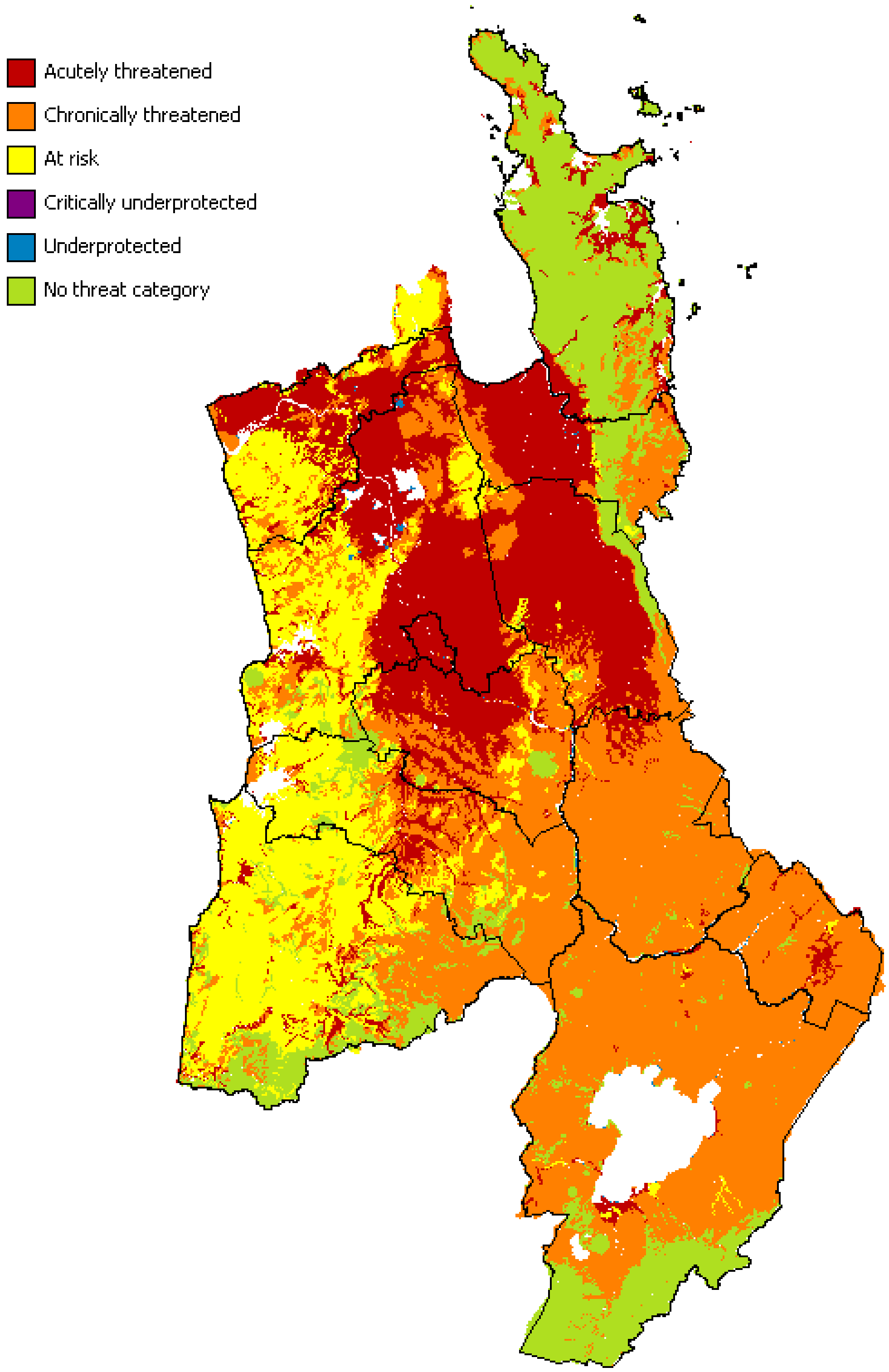



**Figure 25** Distribution of threatened environments in the Waikato region at the start of the WISE simulation period.

# 13 Future Development

This report documents WISE Version 1.3 as of January 2013. During WISE development, a list of suggested improvements and enhancements were compiled based on conversations among project team members, between project team members and various end-users including Waikato Regional Council staff, and based on targeted feedback from participants in end-user workshops held in November 2008 and November 2009 (Huser et al. 2009; van Delden et al. 2010). Some of those suggestions were incorporated into WISE Version 1.1 (Zoning Tool, various improvements to the graphical user interface or GUI). Further enhancements have been made in WISE Version 1.2 (changes to the integration of hydrology, economic and land use models) and WISE Version 1.3 (updated district boundaries, improved calibration of the land use model, addition of Monte Carlo tool and enhancements to the scenario manager).

Table 29 contains a compiled list of suggested improvements and enhancements for WISE that have yet to be incorporated. Improvements and enhancements were categorised into one of four types:

- *GUI Enhancement* – make changes to the GUI to improve the user experience
- *Indicators* – incorporate new indicators for exploring existing data or combining data in new ways to yield additional information
- *Model Enhancement* – make changes, additions, or enhancements to an existing model within WISE to add new analysis capabilities
- *New Link* – add new links between models to incorporate new interactions, help explore new questions, and improve understanding of feedbacks and trade-offs
- *Training, Development and Support* – put in place processes to help end-users use and apply WISE
- *Update* – incorporate updated data
- *Usability* – modify WISE to improve ease-of-use.

As part of its long-term Council Community Plan 2009–2019, Waikato Regional Council has committed funds for the maintenance, enhancement and upgrading of WISE over the next 10 years. Waikato Regional Council is currently exploring various options for improving and enhancing WISE based on the recommendations received.

**Table 29** Suggested improvements and enhancements for WISE in priority order

| Category | Model(s) Affected | Description |
|---|---|---|
| GUI Enhancement | WISE | Allow the user to hover the mouse pointer over, or select, the arrow links in the model system diagram to bring up a window that provides an overview of the relationships between the associated models |
| Training, Development and Support | WISE | Ensure availability of relevant experts for consultation when required when WISE is in use at Waikato Regional Council |
| Enhanced Model | WISE | Use a district boundary layer that shows the district boundaries for those parts of the model that is outside the Waikato political region |
| Training, Development and Support | WISE | Plan and implement the installation of WISE on the internet such that external users can access and experts can maintain their models dynamically |
| New Link | Land Use Change<br>WOW<br>WRDEEM | Employment & demography not directly linked, i.e. creation of new jobs does not influence population in a district |
| New Link | Land Use Change<br>WRDEEM | LUC model does not explicitly distribute jobs per grid cell, i.e. you would assume a mean # of jobs per cell |
| Model Enhancement | Land Use Change | Control land-use intensity e.g., dairying. Stocking rate per hectare. Dairy industry – 5 classes. Relationship to Sparrow – could we adjust the nutrient loadings from Dairy? How “fair” would that be? |
| GUI Enhancement | WISE | Need titles in the relevant map windows, otherwise ti is difficult to know what is being displayed |
| GUI Enhancement | WISE | Too hard to distinguish between INPUT/OUTPUT in various windows because it is same font/size as all other text |
| Usability | Water Quality | Makes Lake Taupo Looks really odd |
| Update | Water Quality | How to update point source info in the model? |
| Usability | Water Quality | How to access reach data? |
| New Link | Hydrology<br>Water Quality | Two models not currently linked. Potential inconsistency between them |
| New Link | WOW<br>WRDEEM | No ability to change consumption parameters by age class |
| Indicators | WISE | Integrated graphs? |
| Model Enhancement | Land Use Change | Hard to make a new land use |
| Model Enhancement | Water Quality | Add mitigation parameters to allow exploration of improved management practices |
| Usability | Land Use Change | Not easy to create polygons for changing zoning, suitability, etc. |
| Model Enhancement | Land Use Change | (Regional boundary effects on land use model (e.g., accessibility, suitability) – can this be improved? |

| Category | Model(s) Affected | Description |
|---|---|---|
| Indicators | WISE | Produce reports that include: 1) summary of baseline, 2) changed assumptions, 3) Use unique identifier for all outputs (i.e. label all results, maps, etc.) |
| Indicators | WISE | Combine all results together in a composite view, e.g., as a spider diagram |
| Indicators | WISE | Result outputs – can graphs depict trends over time? |
| Model Enhancement | WRDEEM | Energy use: convert oil equivalents into $CO_2$ equivalents |
| Model Enhancement | Land Use Change | Neighbourhood Rules: potential to include cultural perspectives |
| New Link | Hydrology<br>Land Use Change | New link to model how changes in hydrology affect land-use suitability |
| New Link | Hydrology<br>Land Use Change | New link to model water allocation |
| Usability | Land Use Change | Use italics for land use features |
| GUI Enhancement | Land Use Change | Hovering over a term with a mouse displays the definition of the term |
| New Link | WOW<br>WRDEEM | Include link from WRDEEM to WOW that allows employment availability to influence population. |
| Model Enhancement | Land Use Change | Include a factor reflecting 'ease of transition' |
| Model Enhancement | WRDEEM | Restrict productivity not only through exports as the policy lever but also: 1) total area (or %), 2) intensity (e.g., stocking rate), 3) N-cap, 4) water use/allocation, 5) land productivity |
| Indicators | WISE | Show historical data (i.e. before 2006 which is the start year of the simulation) to help the user see past trends |
| Model Enhancement | Land Use Change | Consents' permission status does not reflect entire story. Some permitted/controlled activities require mitigation measures |
| New Link | Land Use Change<br>WRDEEM | Can land allocation be restricted by district? |
| Model Enhancement | Land Use Change | Include land tenure, e.g. iwi/Maori land |
| Usability | WRDEEM | In addition to the international export, interregional export, and gross fixed capital formation drivers, household consumption by sector needs to be included as a driver. This would enable the user to test out changes in domestic consumption. Currently, household consumption is driven purely by demographic change |
| Indicators | WDREEM | Add an indicator for inter-regional imports |
| Usability | Water Quality | Link the lake outlet loads to a shapefile of lake polygons. This would a) clean up the look of the reaches diagram and b) let people find the lake outlet loading easily |

| Category | Model(s) Affected | Description |
|---|---|---|
| Model Enhancement | Water Quality | Incorporate a temporal lag in response of stream loads to catchment change arising from lags in groundwater, soils, lakes |
| Usability | Water Quality | Add the capability to identify the load values through the map interface |
| Indicators | Water Quality | Add an indicator(s) that show when nutrient loads exceed a defined threshold |
| GUI Enhancement | Water Quality | Improve the stream network map to show the actual course of stream flow in a reach and not just straight lines |
| New Link | Water Quality | There are no links from water quality to economics or land use (such as constraints around Taupo) at present. This could be modified (for example, driver for land use change reduced if downstream loads or concentrations exceed targets). Also, could specify cost of mitigations/reductions and feed this into economics |
| New Link | Water Quality | The flow rates are not fed into the water quality model. This is not a major concern as the sensitivity of attenuation to flow is not large, and flow rates will probably not change drastically. But for the sake of completeness this could be added. To achieve this, we would have to accumulate flows in the network (just provided as a grid at present), and link the reach flows fed into the water quality model. We would need to check that the flows thus obtained for the current land use are compatible with the values used in calibration of the model |
| Update | Zoning | Incorporate Hauraki Zoning Data |
| Enhanced Model | Land Use Change | Improve accessibility evaluation by including other possible links and nodes such as rivers, schools, major utilities, train stations, regional bus stops, on-ramps, minor town CBDs and a separate Auckland node |
| GUI Enhancement | WISE | In Parameters – Demography – Residential Land Use Demand, list inputs & outputs in units of ‘people/hectare’ rather than ‘people/cell’ |
| GUI Enhancement | WISE | Display of numbers in the Policy Interface is inconsistent: standardise on showing 2 decimal places, then having access to the full number when you click on any box. |

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# Appendix A WRDEEM Concordance Notations

## A.1 Concordance Relating Industry Notations to WRDEEM Industries

| Notation Name *i* | ARDEEM Industry Code | ARDEEM Industry Name |
|---|---|---|
| Ind01 | 1 | Horticulture and fruit growing |
| Ind02 | 2 | Livestock and cropping farming |
| Ind03 | 3 | Dairy cattle farming |
| Ind04 | 4 | Other farming |
| Ind05 | 5 | Services to agriculture, hunting and trapping |
| Ind06 | 6 | Forestry and logging |
| Ind07 | 7 | Fishing |
| Ind08 | 8 | Mining and quarrying |
| Ind09 | 9 | Oil and gas exploration and extraction |
| Ind10 | 10 | Meat and meat product manufacturing |
| Ind11 | 11 | Dairy product manufacturing |
| Ind12 | 12 | Other food manufacturing |
| Ind13 | 13 | Beverage, malt and tobacco manufacturing |
| Ind14 | 14 | Textile and apparel manufacturing |
| Ind15 | 15 | Wood product manufacturing |
| Ind16 | 16 | Paper and paper product manufacturing |
| Ind17 | 17 | Printing , publishing and recorded media |
| Ind18 | 18 | Petroleum and industrial chemical manufacturing |
| Ind19 | 19 | Rubber, plastic and other chemical product manufacturing |
| Ind20 | 20 | Non-metallic mineral product manufacturing |
| Ind21 | 21 | Basic metal manufacturing |
| Ind22 | 22 | Structural, sheet, and fabricated metal product manufacturing |
| Ind23 | 23 | Transport equipment manufacturing |
| Ind24 | 24 | Machinery and equipment manufacturing |
| Ind25 | 25 | Furniture and other manufacturing |
| Ind26 | 26 | Electricity generation and supply |
| Ind27 | 27 | Gas supply |
| Ind28 | 28 | Water supply |
| Ind29 | 29 | Construction |
| Ind30 | 30 | Wholesale trade |
| Ind31 | 31 | Retail trade |
| Ind32 | 32 | Accommodation, restaurants and bars |
| Ind33 | 33 | Road transport |
| Ind34 | 34 | Water and rail transport |
| Ind35 | 35 | Air transport, services to transport and storage |
| Ind36 | 36 | Communication services |
| Ind37 | 37 | Finance |
| Ind38 | 38 | Insurance |
| Ind39 | 39 | Services to finance and investment |
| Ind40 | 40 | Real estate |
| Ind41 | 41 | Ownership of owner-occupied dwellings |
| Ind42 | 42 | Business services |
| Ind43 | 43 | Central government administration, defence, public order and safety services |
| Ind44 | 44 | Local government administration services and civil defence |
| Ind45 | 45 | Education |
| Ind46 | 46 | Health and community services |
| Ind47 | 47 | Cultural and recreational services |
| Ind48 | 48 | Personal and other community services |

## A.2 Concordance Relating Aggregated Industry Notations to Aggregated Industry Names

| Notation Name *lucat* | Land Use Category Name |
|---|---|
| LUCat01 | Vegetable Production/Market Gardening and Horticulture |
| LUCat02 | Sheep/Beef/Deer |
| LUCat03 | Cropland/Cropping |
| LUCat04 | Dairy Farming |
| LUCat05 | Commercial |
| LUCat06 | Forestry/Planted- Exotic |
| LUCat07 | Mines and quarries |
| LUCat08 | Industry/Manufacturing |
| LUCat09 | Utilities |
| LUCat10 | Air transport |
| LUCat11 | Community Services |

## A.3 Concordance Relating Socio-Economic Reporting Variable Notations to Full Socio-Economic Indicator Name

| Notation Name *soce* | Socio-Economic Reporting Variable Name |
|---|---|
| SocEcon01 | Value Added |
| SocEcon02 | International Imports by Importing Sector |
| SocEcon03 | Interregional Imports by Importing Sector |

## A.4 Concordance Relating Employment Reporting Variable Notations to Full Employment Indicator Name

| Notation Name *emp* | Socio-Economic Reporting Variable Name |
|---|---|
| Emp01 | Employment (FTE) |
| Emp02 | Employment (EC) |
| Emp03 | Employment (MEC) |
| Emp04 | Occupation - Chief Executives, General Managers and Legislators |
| Emp05 | Occupation - Farmers and Farm Managers |
| Emp06 | Occupation - Specialist Managers |
| Emp07 | Occupation - Hospitality, Retail and Service Managers |
| Emp08 | Occupation - Arts and Media Professionals |
| Emp09 | Occupation - Business, Human Resource and Marketing Professionals |
| Emp10 | Occupation - Design, Engineering, Science and Transport Professionals |
| Emp11 | Occupation - Education Professionals |
| Emp12 | Occupation - Health Professionals |
| Emp13 | Occupation - ICT Professionals |
| Emp14 | Occupation - Legal, Social and Welfare Professionals |
| Emp15 | Occupation - Engineering, ICT and Science Technicians |
| Emp16 | Occupation - Automotive and Engineering Trades Workers |
| Emp17 | Occupation - Construction Trades Workers |
| Emp18 | Occupation - Electrotechnology and Telecommunications Trades Workers |
| Emp19 | Occupation - Food Trades Workers |
| Emp20 | Occupation - Skilled Animal and Horticultural Workers |
| Emp21 | Occupation - Other Technicians and Trades Workers |
| Emp22 | Occupation - Health and Welfare Support Workers |
| Emp23 | Occupation - Carers and Aides |
| Emp24 | Occupation - Hospitality Workers |
| Emp25 | Occupation - Protective Service Workers |
| Emp26 | Occupation - Sports and Personal Service Workers |
| Emp27 | Occupation - Office Managers and Program Administrators |
| Emp28 | Occupation - Personal Assistants and Secretaries |
| Emp29 | Occupation - General Clerical Workers |
| Emp30 | Occupation - Inquiry Clerks and Receptionists |
| Emp31 | Occupation - Numerical Clerks |
| Emp32 | Occupation - Clerical and Office Support Workers |
| Emp33 | Occupation - Other Clerical and Administrative Workers |
| Emp34 | Occupation - Sales Representatives and Agents |
| Emp35 | Occupation - Sales Assistants and Salespersons |
| Emp36 | Occupation - Sales Support Workers |
| Emp37 | Occupation - Machine and Stationary Plant Operators |
| Emp38 | Occupation - Mobile Plant Operators |
| Emp39 | Occupation - Road and Rail Drivers |
| Emp40 | Occupation - Storepersons |
| Emp41 | Occupation - Cleaners and Laundry Workers |
| Emp42 | Occupation - Construction and Mining Labourers |
| Emp43 | Occupation - Factory Process Workers |
| Emp44 | Occupation - Farm, Forestry and Garden Workers |
| Emp45 | Occupation - Food Preparation Assistants |
| Emp46 | Occupation - Other Labourers |
| Emp47 | Occupation - Not Elsewhere Included |

## A.5 Concordance Relating Environmental Reporting Variable Notations to Full Environmental Indicator Name

| Notation Name e | Environmental Reporting Variable Name |
|---|---|
| ERV01 | Energy - Aviation Fuel |
| ERV02 | Energy - Black Liquor |
| ERV03 | Energy - Coal |
| ERV04 | Energy - Diesel |
| ERV05 | Energy - Electricity |
| ERV06 | Energy - Fuel Oil |
| ERV07 | Energy - Geothermal |
| ERV08 | Energy - LPG |
| ERV09 | Energy - Natural Gas |
| ERV10 | Energy - Petrol |
| ERV11 | Energy - Wood |
| ERV12 | Energy - Total |
| ERV13 | Energy Related Carbon Dioxide - Aviation Fuel |
| ERV14 | Energy Related Carbon Dioxide - Black Liquor |
| ERV15 | Energy Related Carbon Dioxide - Coal |
| ERV16 | Energy Related Carbon Dioxide - Diesel |
| ERV17 | Energy Related Carbon Dioxide - Electricity |
| ERV18 | Energy Related Carbon Dioxide - Fuel Oil |
| ERV19 | Energy Related Carbon Dioxide - Geothermal |
| ERV20 | Energy Related Carbon Dioxide - LPG |
| ERV21 | Energy Related Carbon Dioxide - Natural Gas |
| ERV22 | Energy Related Carbon Dioxide - Petrol |
| ERV23 | Energy Related Carbon Dioxide - Wood |
| ERV24 | Energy Related Carbon Dioxide - Total |
| ERV25 | Energy Related N2O - Aviation Fuel |
| ERV26 | Energy Related N2O - Black Liquor |
| ERV27 | Energy Related N2O - Coal |
| ERV28 | Energy Related N2O - Diesel |
| ERV29 | Energy Related N2O - Electricity |
| ERV30 | Energy Related N2O - Fuel Oil |
| ERV31 | Energy Related N2O - Geothermal |
| ERV32 | Energy Related N2O - LPG |
| ERV33 | Energy Related N2O - Natural Gas |
| ERV34 | Energy Related N2O - Petrol |
| ERV35 | Energy Related N2O - Wood |
| ERV36 | Energy Related N2O - Total |
| ERV37 | Energy Related CH4 - Aviation Fuel |
| ERV38 | Energy Related CH4 - Black Liquor |
| ERV39 | Energy Related CH4 - Coal |
| ERV40 | Energy Related CH4 - Diesel |
| ERV41 | Energy Related CH4 - Electricity |
| ERV42 | Energy Related CH4 - Fuel Oil |
| ERV43 | Energy Related CH4 - Geothermal |
| ERV44 | Energy Related CH4 - LPG |
| ERV45 | Energy Related CH4 - Natural Gas |
| ERV46 | Energy Related CH4 - Petrol |
| ERV47 | Energy Related CH4 - Wood |
| ERV48 | Energy Related CH4 - Total |
| ERV49 | Solid Waste - Landfill - Construction and demolition waste |
| ERV50 | Solid Waste - Landfill - Metal |
| ERV51 | Solid Waste - Landfill - Glass |
| ERV52 | Solid Waste - Landfill - Plastic |
| ERV53 | Solid Waste - Landfill - Paper |
| ERV54 | Solid Waste - Landfill - Potentially hazardous |
| ERV55 | Solid Waste - Landfill - Organic matter - kitchen and garden waste |
| ERV56 | Solid Waste - Landfill - Other |
| ERV57 | Solid Waste - Landfill - Total |
| ERV58 | Solid Waste - Cleanfill - Construction and demolition waste |
| ERV59 | Solid Waste - Total |

# Appendix B Process for Translating Land Use by Industry ($lu\ wo\ luc_i$) to Land Use by Aggregated Industry ($luc\ wo\ luc_{lucat}$) in WRDEEM

| Notation Name *lucat* | Land Use Category Name | Equivalent Land Use |
|---|---|---|
| LUCat01 | Vegetable Production/Market Gardening and Horticulture | $lu\ wo\ luc_{Ind01}$ |
| LUCat02 | Sheep/Beef/Deer | $(lu\ wo\ luc_{Ind02} + lu\ wo\ luc_{Ind04}) \times (1 - lu\ split\ crop)$ |
| LUCat03 | Cropland/Cropping | $(lu\ wo\ luc_{Ind02} + lu\ wo\ luc_{Ind04}) \times lu\ split\ crop$ |
| LUCat04 | Dairy Farming | $lu\ wo\ luc_{Ind03}$ |
| LUCat05 | Commercial | $lu\ wo\ luc_{Ind05} + lu\ wo\ luc_{Ind30} + lu\ wo\ luc_{Ind31} + lu\ wo\ luc_{Ind32} + lu\ wo\ luc_{Ind36} + lu\ wo\ luc_{Ind37} + lu\ wo\ luc_{Ind38} + lu\ wo\ luc_{Ind39} + lu\ wo\ luc_{Ind40} + lu\ wo\ luc_{Ind42} + lu\ wo\ luc_{Ind48}$ |
| LUCat06 | Forestry/Planted- Exotic | $lu\ wo\ luc_{Ind06}$ |
| LUCat07 | Mines and quarries | $lu\ wo\ luc_{Ind08} + lu\ wo\ luc_{Ind09}$ |
| LUCat08 | Industry/Manufacturing | $lu\ wo\ luc_{Ind10} + lu\ wo\ luc_{Ind11} + lu\ wo\ luc_{Ind12} + lu\ wo\ luc_{Ind13} + lu\ wo\ luc_{Ind14} + lu\ wo\ luc_{Ind15} + lu\ wo\ luc_{Ind16} + lu\ wo\ luc_{Ind17} + lu\ wo\ luc_{Ind18} + lu\ wo\ luc_{Ind19} + lu\ wo\ luc_{Ind20} + lu\ wo\ luc_{Ind21} + lu\ wo\ luc_{Ind22} + lu\ wo\ luc_{Ind23} + lu\ wo\ luc_{Ind24} + lu\ wo\ luc_{Ind25} + lu\ wo\ luc_{Ind29}$ |
| LUCat09 | Utilities | $lu\ wo\ luc_{Ind26} + lu\ wo\ luc_{Ind27} + lu\ wo\ luc_{Ind28}$ |
| LUCat10 | Air transport | $lu\ wo\ luc_{Ind35}$ |
| LUCat11 | Community Services | $lu\ wo\ luc_{Ind43} + lu\ wo\ luc_{Ind44} + lu\ wo\ luc_{Ind45} + lu\ wo\ luc_{Ind46} + lu\ wo\ luc_{Ind47}$ |

Where *lu split crop* is the fraction of the total land used by the Livestock and Cropping Industry which is used just for the purposes of cropping. This fraction is likely to be determined from data for the base year.

# Appendix C Technical Process for Generating Spatial Data Layers Used in the Land Use Change Model

To generate the spatial data layers (land use, suitability, zoning) required for the Land Use Change model in WISE, substantial research was required that included

1. formulating the land-use classification
2. compiling and/or developing appropriate input data sets
3. devising appropriate rules and algorithms for combining input data sets
4. developing an effective, efficient, and repeatable process to generate the output data layers.

Earlier sections of this report describing the Zoning and Land Use Change models outlined #1–3 above. This appendix outlines #4, which represents a new process that was specifically developed for the Creating Futures project to generate the land use, suitability and zoning data layers. The same process was followed for each set of data layers, the only difference being the input data layers and the rules used to combine them.

Given the volume of information involved, the full set of rules, algorithms, Avenue scripts, etc., will not be repeated here. Only the overall process and input data layers will be outlined. For those interested in inspecting and trialling the process independently, Waikato Regional Council intends to make this information publicly available.

Successful execution of the process would require

- Microsoft Access database software
- ArcView 3.2 software
- Above average knowledge of MS Access, ArcView Avenue and Visual Basic scripting.

Figure 26 below outlines the process followed. Input data layers were collected and centrally stored on a workstation at Landcare Research. A Microsoft Access database was developed that linked input data layers to output data layers via a series of rules. Separate database and scripts were maintained for land use, suitability and zoning.

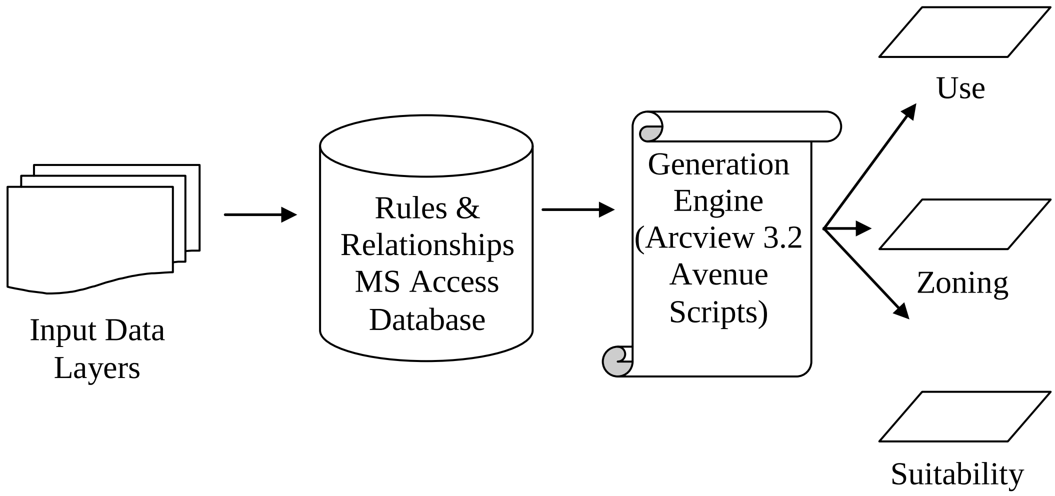


**Figure 26** Process used to generate spatial data layers for the Land-Use Change model in WISE.

Rules stored in the database were passed to a series of custom-built ArcView 3.2 Avenue scripts for processing of the data. The scripts produced a series of 200 × 200-m ESRI grid layers clipped to the area of interest. Additional processing via additional Avenue scripts called GDAL commands to convert the ESRI grid layers into IRDRISI grid layers (.rst files) needed for use by WISE.

Land-use Classification Input Data Layers

| Database | Year |
|---|---|
| Land Cover Database Version 2 | 2001/2 |
| Environment Waikato Valuation Database | 2008 |
| Environment Waikato Road Verges | 2006 |
| Environment Waikato Railway Corridors | 2006 |
| Topomap Airports | 2000 |
| Department of Conservation Conservation Estate Map | 2006 |
| Environment Waikato Aquaculture | 2008 |
| Statistics New Zealand Territorial Authority Boundaries | 2006 |
| Environment Waikato Land Use Map Errors Override | 2009 |
| Environment Waikato Land Use Mapping Manual Corrections | 2009 |

Suitability Input Data Layers

| Database | Year |
|---|---|
| Fundamental Soils Layers | 2008 |
| Land Environments of New Zealand Underlying Data Version 1.0 | 2003 |
| New Zealand Erosion Model | 2008 |
| Landcare Research Climate Layers 2002 | 2002 |
| WISE Land Use Layer Version 1.0.7 | 2009 |
| Land Cover Database Version 2 | 2001/2 |

Accessibility Input Data Layers

| Database | Year |
|---|---|
| Improved New Zealand Road Centrelines | 2008 |
| GIS_ALL.CRS_RAILWAY* | 2003 |
| GIS_ALL.AUTHORISATIONS_2006* | 2006 |
| GIS_ALL.AUTHORISATIONS_2009* | 2009 |
| GIS_ALL.CRS_PROPERTY_WHOLE_REGION_2009* | 2002 |
| PLANNED_ROAD_CONSTRUCTION_LINE* | 2007 |
| GIS_PHOTOS.WRAPS07_5K_By_GRID* | 2007 |
| GIS_ALL.AUTHORISATIONS* | 2009 |
| TA Designation Data* | 2009 |
| Yellow Pages and Google Searches | 2009 |

*From the EW Corporate or Internal Data Set

Zoning Input Data Layers

| Database | Year |
|---|---|
| Landcare Research Existing Land Use Grid | 2006 |
| Landcare Research Protected Areas Network | 2008 |
| Environment Waikato (WRC) Flood and Erosion Control Land | 2009 |
| Environment Waikato District Covenants & Reserves | 2008 |
| Hamilton City Council Designations | 2008 |
| Hamilton City Council Overlays | 2008 |
| Hamilton City Council Zones | 2008 |
| Waikato District Council Designations | 2008 |
| Waikato District Council Overlays | 2008 |
| Waikato District Council Zones | 2008 |
| South Waikato District Council Designations | 2008 |
| South Waikato District Council Zones | 2008 |
| Waipa District Council Designations | 2008 |
| Waipa District Council Overlays | 2008 |
| Waipa District Council Zones | 2008 |
| Matamata-Piako District Council Designations | 2009 |
| Matamata-Piako District Council Overlays | 2009 |
| Matamata-Piako District Council Zones | 2009 |
| Franklin District Council Designations | 2008 |
| Franklin District Council Overlays | 2008 |
| Franklin District Council Zones | 2008 |
| Taupo District Council Designations | 2008 |
| Taupo District Council Overlays | 2008 |
| Taupo District Council Zones | 2008 |
| Rotorua District Council Designations | 2008 |
| Rotorua District Council Zones | 2008 |
| Thames-Coromandel District Council Designations | 2009 |
| Thames-Coromandel District Council Overlays | 2009 |
| Thames-Coromandel District Council Zones | 2009 |
| Otorohanga District Council Designations | 2006 |
| Otorohanga District Council Overlays | 2006 |
| Otorohanga District Council Zones | 2006 |
| Waitomo District Council Overlays | 2009 |
| Waitomo District Council Zones | 2009 |
| Hauraki District Council Designations | 2010 |
| Hauraki District Council Overlays | 2010 |
| Hauraki District Council Zones | 2010 |
| Environment Waikato Queens Chain | 2008 |
| Territorial Authority Default Data Layer | 2010 |