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CLUES Spatial DSS: From Farm-Scale Leaching Models to Regional Decision Support

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Abstract: Land-use in New Zealand poses risks to water quality in streams and lakes, yet there have previously been few tools used in New Zealand to predict the effects of land-use change at catchment to national scale. The CLUES spatial decision support system has been developed recently to assist with the assessment of land-use change on water quality, farm economics, and employment. The system incorporates a number of existing models from several research providers, ranging from models of leaching at the farm scale to national regression-based models. An early application of the model is the identification of catchments where the receiving surface waterbodies are at risk from nitrate sources. Several extensions of the system are underway to improve the usefulness for local decision-making. These include making the spatial resolution of land-use finer, adding mitigation and land management options, and increasing the number of environmental measures provided by the model, and linking these measures to a values framework. This will improve the utility of the model for integrated catchment management.

***Keywords**:* land use; water quality; decision support

1. INTRODUCTION

Land-use in New Zealand poses risks to water quality in streams and lakes [PCE 2004; MfE 2007a, b]. Although nutrient levels in New Zealand rivers are still low by international standards, there is concern about current and potential eutrophication in lakes, and the impacts of intensification of pastoral agriculture. While field-scale nutrient budgeting models are available, and detailed dynamic models have been applied to specific catchments, there have previously been few planning-level tools available in New Zealand to predict the effects of land-use change at catchment, regional or national scales. The CLUES (Catchment Land Use for Environmental Sustainability) project was initiated in 2003 by the Ministry of Agriculture and Forestry (MAF) and the Ministry for the Environment (MfE). The objective was to tie together a number of models into one GIS platform to facilitate assessments of the progressive effects of land use change on water quality in lakes, rivers, and coastal regions. An early application of CLUES was envisaged in the Sustainable Water Programme of Action, which wanted to identify catchments that are associated with waterbodies at risk of nitrate contamination, at the national level. At the same time as providing a national perspective, it was intended that CLUES would have sufficient spatial resolution so that predictions within particular regions or catchments of interest could be provided. In this sense, the model is dual-purpose. In addition, farm-economics components have been brought into CLUES to assess the immediate economic implications of land-use change.

The models currently implemented within the Catchment Land Use and Environmental Sustainability framework (CLUES) include predictions of nutrient and microbial flux in streams, and farm employment and economic factors as a function of land-use, climate, and soils. The first version of the system is now complete and has been distributed to national and regional land/water management agencies.

In this paper we describe the CLUES system, discuss ongoing developments, and discuss the applicability of the system to integrated catchment management planning.

2. DESCRIPTION OF THE SYSTEM

CLUES contains databases, a user interface, and graphical display, and models housed within ArcGIS (Figure 1). A national spatial database of all the spatial layers required for the model is provided, although the user may also import land-use layers. A graphical user interface is provided for the model, so that the user may easily identify the study area of interest, set up land-use scenarios interactively, and view results. Users with a knowledge of GIS may also make use of broader ArcGIS functionality to further manipulate the land-use and output displays.

The spatial framework of the model is built around the stream network and associated subcatchments of the REC national stream network. The network has approximately 500,000 stream reaches with subcatchments of 0.5km^2 area on average. The mixture of land-use within a subcatchment is specified, but not the locations of the land-uses within the subcatchment. This level of spatial resolution is suited to studies from the catchment scale to national scale, but not for paddock-scale management.

At present, the system provides predictions of the following measures:

- Total phosphorus (TP), total nitrogen (TN) and *E. coli* loads and yields for each stream reach, and loads generated from each subcatchment. A sediment component is in the process of being added.
- Gross domestic product arising directly from the farming, horticulture, and pine plantation land uses.
- Total employment for farms.
- Cash flow surplus – this is the output from the land use after farm working expenses have been deducted, but before interest, leases, wages of management, and capital expenditure.
- Leaching risk for nitrogen (on a relative scale from very low to very high) for the current land-use, displayed as a grid with 100 m resolution (a departure from the spatial framework described above).

CLUES draws on a number of models from a number of research providers to provide these predictions:

- SPASMO (Soil Plant Atmosphere System Model, HortResearch) [Rosen 2004]. This is a daily model of water and nutrient flux, and is used for prediction of nitrogen leaching from horticultural land-uses. Rather than run the daily SPASMO model within CLUES, a meta-model of mean annual leaching as a function of land-use, region, and rainfall was derived from a number of long-term SPASMO runs. This meta-model is implemented as a look-up table within CLUES.
- OVERSEER Nutrient Budget Model (AgResearch) – is a farm-scale nutrient loss model for various land uses (dairy, sheep/beef lowland, sheep/beef hill country, sheep/beef high country, and deer). It provides annual average estimates of nitrogen losses from these land uses, given information on rainfall, region, soil order, topography, and fertiliser applications. A simplified version of Overseer is

used in CLUES, driven by representative regional inputs (such as herd composition for a particular land-use) where necessary.

- TBL (Triple Bottom Line, Harris Consulting) [Woods et al. 2006] - estimates economic output from different land use types (pasture, horticulture, forestry and cropping), in terms of Cash Farm Surplus (CFS), Total GDP and Total Employment. The calculations are based on the MAF Farm Monitoring models.
- Ensus (Landcare Research) - provides maps of nitrate leaching potential. This is used as an adjunct to interpretation of CLUES results. It is based on studies of nitrogen losses at national and regional scales [Parfitt et al. 2006].
- SPARROW (USGS, NIWA) [Smith et al. 1997, Elliott et al. 2005] – is used for the *E. coli* model, and to assess diffuse sources of nutrients not provided by the OVERSEER or SPASMO models. SPARROW also provides the spatial framework for accumulation and routing of loads, and it includes provisions for loss processes in streams and lakes or reservoirs. The extra source terms and decay parameters are determined by calibration to national and regional water quality data.

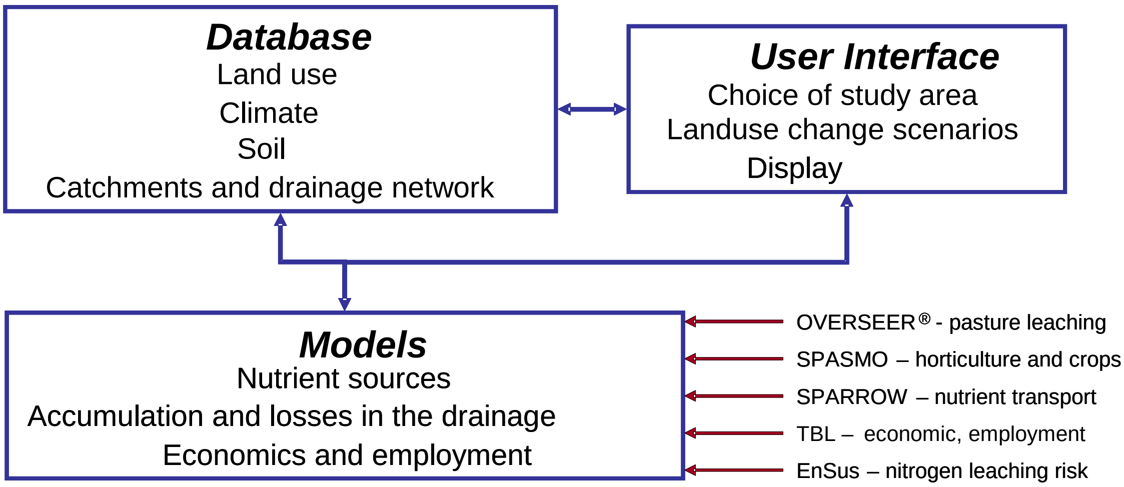

Figure 1. Schematic representation of the CLUES model.

The user interface is written within ESRI ArcGIS, but a custom control panel is used rather than the conventional ArcGIS toolbars, to make the system more appealing to users with little GIS background (Figure 2). The interface manages the reach selection, run control and scenario management, output display, land-use modification, and data or map export. Users familiar with GIS can also use the complete set of ArcGIS features to manipulate the land-use and mapping. The system allows the user to draw polygons of new land-uses, which enables a quick examination of the effect of land-use change. For more advanced uses, land-use can be modified externally and then imported (for example, to specify a fractional conversion of land-use or to make the changes dependent upon other factors such as slope).

Results can be displayed as maps in a variety of forms (Figure 3), or as tabular output and summaries. A tutorial manual is now available from NIWA [Semadeni-Davies et al. 2007]. Values of interest, such as the nutrient load or farm profit can be displayed either as local values associated with a subcatchment or as values accumulated in the upstream catchment.

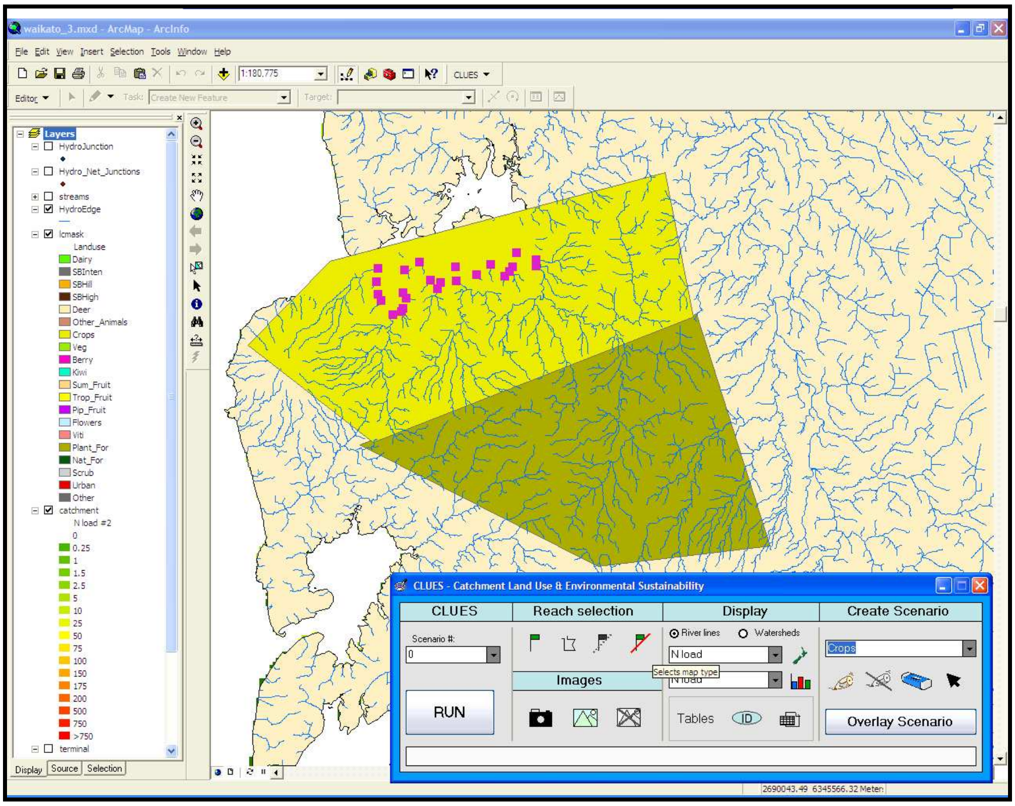

Figure 2. Tool-panel and interactive modification of land-uses

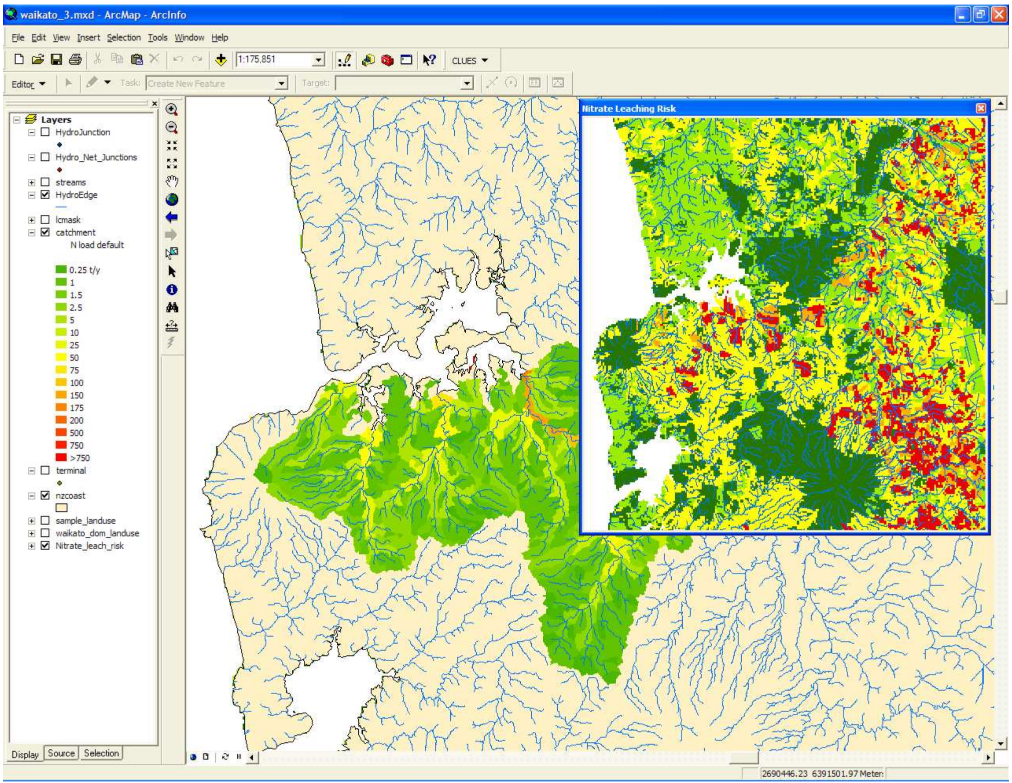

Figure 3. Example map of model predictions. The subcatchments are coloured according to the nutrient load in the associated stream reaches. An accompanying more detailed map of nitrogen leaching risk for the current land-use is also shown.

5. APPLICATIONS AND FUTURE DEVELOPMENTS

The CLUES concept has been embraced by regional and national level agencies, with funding for ongoing development and dissemination. As an example of the support, improved access to national databases on land-use has been provided by MAF. Now that the first version of CLUES is available, various management applications are emerging, and these are driving further development and refinement of the system to make it more suited to these applications.

5.1 Identification of sensitive and at risk catchments

Action 2.2 of the Sustainable Water Programme of Action calls for identification of catchments that are "sensitive and at risk from rural and urban diffuse discharges" [MfE, 2006], and this is a current early application of CLUES. Also, the pastoral agriculture industry are interested in identifying catchments that are sensitive to the effects of dairy land-use, and are co-funding this application of CLUES. The sector seeks to identify locations where dairying is an issue in relation to water quality, so that the scope of the problem can be quantified and mitigation measures targeted and prioritised. This has some parallels to identification of Nitrate Vulnerable Zones in the UK under the EU Nitrates Directive.

At the most basic level, this involves identifying subcatchments with relatively high nutrient yields, and the proportion of the load attributable to dairying – that is, traditional 'hot-spot' identification. This is straightforward to achieve with the current CLUES system. A modification of this approach is to consider the delivered yield or load, that is, the yield or load after delivery to major waterbodies after nutrient attenuation. This 'delivered yield' can be calculated in the CLUES system as the attenuation in streams is modelled, and this will be provided in future versions of CLUES.

An alternative stance on this problem is to identify waterbodies that exceed some threshold concentration. We are using CLUES to determine flow-weighted concentrations in lakes and streams, and comparing this with guidelines for eutrophication or concentration guidelines in streams. By this process, the most-impacted streams and lakes, and their associated catchments, are being identified. Within these catchments, the predominant hot-spots can also be identified.

'Catchment sensitivity' also suggests some consideration of the sensitivity of the receiving environment to increases in nutrient loads. This has several facets. Are the receiving water bodies currently limited by nitrogen or phosphorus? What is the value of the receiving environment, taking into account the use of the water body, uniqueness or representativeness, or contribution to biodiversity? Is the water body already impaired or reaching some threshold in terms of nutrient loading? Work by other agencies to identify waters of national importance (WONI) could feed into this process.

Finally, catchment sensitivity also can be interpreted as the change in state of the receiving water body in response to some anticipated future change in land-use – either an incremental unit change or some future pre-determined land-use scenario. While land-use can certainly be altered in the model, methods to express the results in terms of this forcing-response relationship are not yet developed.

5.2 Modifications for regional applications

The Regional Councils who are interested in application of CLUES have identified that the concentrations of contaminants in streams are in some cases more important than the loads. This is partly due to water quality criteria being expressed in terms of concentrations (which in turn are related to nutrient responses of stream periphyton, bathing suitability criteria for E. coli). This has spurred further research relating loads to concentrations (based on examination of national water quality databases), which will be incorporated into CLUES. Regional Councils are also interested in versions of CLUES with parameters optimised for their particular region; at present, some parameters are available only from a national-level calibration. Hence, some projects to develop more locally-applicable versions of the model are underway.

5.3 Linking to mitigation and land management

At present, the system does not take mitigation measures into account – it is restricted to consideration of changes in land-use. This limits the ability of the model to identify the benefits of modifications to land management. Hence, mitigation measures are being added to CLUES. For similar reasons, the ability to add more information on management, such as intensification of grazing or modification of fertilise application rates is also being added.

In an effort to link regional-scale planning approaches to farm-scale land management action, we are investigating the means to drive CLUES with the farm or property as a level of spatial unit, hence providing linking between scales. This also provides opportunities to improve the predictions by driving the nutrient modules with more accurate farm-specific data (at present, a range of representative farm types and associated parameters are used, which has been identified as limiting the predictive capabilities for specific small catchment applications). This poses challenges in terms of obtaining and managing the spatial data.

5.4 Linking to values to enhance usefulness for integrated catchment management

At present, CLUES is targeted mostly to assessment of land-use change on water quality, with an additional consideration of economic and employment considerations. This stems from the drivers for the initial development of the system. For use in integrated catchment management, however, it is necessary to consider a wider range of environmental measures.

A systematic assessment of values and suitable environmental metrics has recently been developed by AgResearch. In this approach, sustainability value domains were first established (Table 1) [Small 2008]. Each of the value domains has been broken into a number of 'value objects', such as water quality. Indicators and measures for each of these value objects have been identified for international, national, regional, catchment, and farm scales. This has resulted in an extensive list of measures relevant to integrated catchment management. Some of these measures are included in CLUES, while others are would be difficult to include and are likely to remain outside CLUES. This list is being prioritised, with the aim of establishing relations between land-use and values to add to CLUES, or else to relate the current outputs of CLUES to some sort of aggregated values score.

A few water values can be assessed fairly directly from water quality variables predicted by CLUES (e.g., E coli concentrations as indicators of suitability for contact recreation). However, the links between most waterways values (e.g., clear water, native fish biodiversity, safe for swimming, healthy recreational fishery, healthy ecosystem) and levels of N and P predicted by CLUES are typically less straight-forward. This is because the effects of nutrient concentrations or loads on values are conditional upon the local context set by habitat factors, such as presence of riparian shade (high shade prevent nuisance algal growth regardless of nutrient levels), flow regime (highly variable flows can also control plant growth), and lake flushing rates (that influence time for algal bloom development), stratification patterns and history of enrichment. Other biotic factors, such as presence of exotic plant and fish species, also influence how nutrient levels/loads affect water values. This context-dependency of nutrient-water values suggests that the CLUES output will need to feed into other locally tuned models to link directly to common values defined in community consultation processes, for the purpose of integrated management of small catchments. For example, locally-focused holistic models of land use links to waterway values are being developed as Bayesian Network models (initially for Bog Burn catchment in Southland). CLUES output could inform /provide input to such models in various ways.

5.5 Other developments

There are also several future developments which would improve the usefulness of the model for catchment management, including: allowing for temporal progression of land-use rather than a constant future scenario, which introduces possibilities for linking with land-use evolution models and also prediction of transient responses to land-use change; incorporation of a groundwater component, which is limiting the applicability of the system in some parts of the country; including the effects of land-use change on water resources (such as hydrological statistics); adding a greenhouse gas emissions component (building on the capabilities of OVERSEER); adding uncertainty metrics to the predictions; and providing predictions of biotic impacts in addition to biophysical and economic variables.

Table 1. Sustainability value domains and value objects, from Small [2008].

Sustainability value domains	*Environment*	*Economy*	*Quality of life*	*Culture and identity*	*Participation and equity*
Value objects	Air	Productivity	Safety and security	Identity	Equity
	Land and soil	Prosperity	Health	Culture and heritage	Civic participation
	Water	Employment	Quality of work life		Treaty of Waitangi
	Landscape	Infrastructure	Knowledge and skills		Political/social trust
	Biodiversity	Tourism	Recreation and leisure		Human rights
	Biosecurity		Social connectedness		International treaties
	Kaitiakitanga/ stewardship		Housing		

5.6 Comments on the process of model development

Some of the modifications and improvements discussed above were identified in early round-table meetings of the programme guidance committee, but were not implemented at that time so that efforts could be focused on making the system operational. Other modification needs have become clear following demonstrations of early prototypes. The provision of a second phase of funding, support from regional and national authorities, and a collaborative approach by the researchers has enabled these modifications, which will ultimately make the system more useful for integrated land/water management. There are several elements that have contributed to the success of this project. First, there is a key central-government agency driving the process, with accompanying funding. This not only lends a weighting of government approval to the model, but also encourages the collective engagement of a number of research providers, who might otherwise find it more difficult to collaborate. The involvement of Regional Councils at user-group meetings, as prototype testers, and as funders has supported the programme. Such councils are at a stage where they seem to be receptive to the application of models to catchment planning, whereas this may not have been the case a decade ago. This funding is continuing, which allows the model to continue to be maintained and improved. The CLUES system also serves as a means for various organisations involved in farm-scale modelling to up-scale their models, thus providing a wider range of use of their models. Despite these positive signs, the use of CLUES for actual applications is in its infancy, and the long-term utility and hence viability of the system remains to be confirmed.

6. CONCLUSIONS

The initial national-level impetus to assess the effects of land-use change on water quality has led to the successful development of a spatial decision support system that brings together a range of models with a common national-scale driving datasets and spatial framework. Application of the system to regional and catchment management has highlighted the need for extensions to the system, including refining the spatial resolution, including mitigation measures, and linking to a values framework. Ongoing support of national and regional agencies is crucial in making the system more relevant to integrated decision support.

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