HOW CLUES CAN HELP IN MANAGING CATCHMENT NUTRIENT LIMITS

A Semadeni-Davies, S Elliott and U Shankar

National Institute of Water and Atmospheric Research, NIWA.
Private Bag 99940, Auckland 1149, New Zealand
Email: annette.davies@niwa.co.nz

Abstract

The National Policy Statement for Freshwater Management (NPS-FM) heralds a shift from effects-based to limits-based water management whereby catchment-scale objectives are set, and limits to water use to achieve those objectives are determined. The Ministry for the Environment (MfE 2013a) outlined a set of proposed reforms to aid implementation of the NPS-FM. These are grouped under three key actions areas: planning as a community; establishment of a National Objectives Framework; and managing within water quality and quantity limits. The reforms have subsequently been incorporated into proposed amendments to the NPS-FM (MfE 2013b). Models are seen in these documents as essential for freshwater management.

This paper aims to show how the Catchment Land Use Environmental Sustainability (CLUES) model can be used to aid the implementation of the NPS-FM with respect to managing within catchment water quality limits, including nutrients, namely:

- as a visualisation tool to facilitate communication between various stakeholders within a public setting;
- to assess the current and future states of freshwater bodies at the sub-catchment scale, for regions or specific catchments;
- to help set load limits for nutrients, sediments and bacteria discharged into river catchments; and
- to evaluate the effects of mitigation measures required to meet limits.

Introduction

Access to clean freshwater is at the heart of New Zealand's economic, social, cultural and environmental wellbeing. To safeguard the health of our water ways while maintaining economic output, freshwater management in New Zealand is undergoing fundamental reform. The 2011 National Policy Statement for Freshwater Management (NPS-FM) released by the Ministry for the Environment (MfE 2011) signals a shift towards limits-based freshwater management, integrated catchment management and increased opportunities for community collaboration with councils and other stakeholders. Two other key reform documents are the Freshwater Reform 2013 and Beyond (MfE 2013a) working paper which gives guidance on how the NPS-FM could be implemented and proposed amendments to the NPS-FM released late last year (MfE 2013b) that draw on MfE (2013a) and public submissions to that paper. The reforms have largely been driven by declining river water quality (e.g., Ballantine and Davies-Colley 2010) and over-allocation of water resources in some catchments. In this paper, we concentrate on reforms to catchment management for water quality. The objective is to show how the Catchment Land Use Environmental Sustainability (CLUES) model can be used to aid the implementation of the NPS-FM with respect to managing within catchment water quality limits. The reforms and the Catchment Land Use Environmental Sustainability (CLUES) model are first overviewed followed by a discussion on use of the CLUES model in relation to the reforms.

Freshwater reform

Freshwater management in New Zealand under the Resource Management Act (RMA, New Zealand Government 1991) follows an effects-based approach whereby the effects of activities are managed rather than regulating the activities themselves. The realisation that there has been a decline in the state of many waterways over the last 30 led to a review of freshwater management culminating in the NPS-FM which came into effect in July 2011. Since that date, decision-makers under the RMA must have regard to the NPS-FM in consenting decisions. Moreover local authorities are required to amend operational or proposed regional policy statements, and operational or proposed regional plans to give effect to any provision in the NPS-FM that affects those documents. The goals of the NPS-FM are to maintain or improve overall water quality within a region and to safeguard the life-supporting capacity, ecosystem processes and indigenous species (including their associated ecosystems) of fresh water.

Some of the reforms given in the NPS-FM were put forward by the Land and Water Forum (LWF), which consists of a diverse group of organisations including scientists, primary industry representatives, NGOs and Maori. The LWF was asked by the government in 2009 to conduct a stakeholder-led collaborative process to consider reform of New Zealand's freshwater management system. In September 2010, the LWF produced the first of three reports which identified shared outcomes and goals, and options to achieve them (LWF 2010). The forum found that as far as diffuse-source contaminants go, the Achilles heel of the RMA is the failure to account for cumulative effects: those effects that either arise over time or that occur in combination with other effects. A key recommendation made in the LWF first report which has been incorporated into the NPS-FM, is a shift from effects-based to limits-based water management whereby catchment-scale objectives are set, and limits to water use to achieve those objectives are determined. Freshwater objectives are defined as the intended environmental outcomes for a catchment and limits are the maximum amount of resource available for use, which allows an objective to be met. Recognising that integrated catchment management required to set objectives and limits will require trade-offs and support by a range of stakeholders, the NPS-FM also has provision for collaborative community planning with particular note to the special role of Maori in decision making.

In response to the NPS-FM, the Regional Council Research for the Environment Strategy (2011) states that there is a need for better understanding of the cumulative impacts of human activities on water quality and to identify the ecological limits for those activities beyond which water quality becomes unacceptable. Moreover, there is a need for decision support systems and tools which can be used or scenario building, particularly in terms of natural resources facing pressures such as freshwater.

The *Second Report of the Land and Water Forum* (LWF 2012a) discusses the need for, and barriers to, setting catchment water quality objectives and limits. The establishment of national minimum objectives with respect to a range of biometric, physiochemical, human health and fish productivity indicators, is recommended. It is noted that since each catchment is different, limits to achieve the objectives may vary regionally and between catchments.

Moreover, it is stated that collaborative decision making is essential to enable trade-offs between different stakeholders, including Maori, in order to achieve long term solutions that are more resilient and adaptive to change.

The *Third Report of the Land and Water Forum* (LWF 2012b) overviews the tools and approaches required to set and meet objectives and limits. It is noted that there are already a range of methods and programmes being developed around the country to improve freshwater management which need to be evaluated and where appropriate, reinforced, improved, disseminated and integrated into catchment planning. These include monitoring and modelling methods to assess water quality and management techniques to reduce contaminant yields and loads. Key to the report are 67 recommendations for the implementation of the NPS-FW. Several of these are of direct relevance to the use and further development of the CLUES model:

Recommendation 8 (Managing Water Quality) states that Regional Councils and catchment communities need to identify the sources and volumes (loads) of all contaminants of concern, assess which tools and methods are best to manage them to achieve freshwater objectives, and monitor and review implementation and outcomes.

- Recommendation 10 (Managing Water Quality) states that the tools adopted should be appropriate for, amongst other factors:
  - the contaminants to be managed
  - the physical characteristics of the catchment
  - the range of land uses in the catchment

- Recommendation 63 (Enabling Change) calls for continued investment in the development of models and measurement-based monitoring systems for *practical application to water quality management*.

- Paragraph 84 (Models) stresses the need for continued investment in models that:
  - are based on a strategic approach;
  - concentrate on a limited number of interoperable models for application at different scales (catchment and enterprise level) and contaminants;
  - concentrate on a limited number of models that can serve multiple land uses;
  - are be undertaken in partnership (central and local government, science providers and sector organisations); and
  - include guidance and protocols for the use of the modelling tools where they are applied to water quality management in a regulatory framework.

The Freshwater Reform 2013 and Beyond working paper (Mfe 2013a) proposes a set of reforms for the implementation of the NPS-FM that addresses some of the issues raised by regional councils and the LWF. The goal of the reforms is This document calls for transparent and adaptive management systems and notes that to be successful, these systems need to be supported by stakeholder communities and a good scientific and economic understanding of processes operating within a catchment. A number challenges to freshwater management in New Zealand are recognised including declining water quality in some catchments, lack of robust information on the impacts and outcomes of management decisions, management systems which are insufficiently adaptive or dynamic and failure to fully consider the interests and values of Maori in planning and decision making. To ensure the sustainability of freshwater resources and to meet these challenges, action is proposed in three key areas:

- **Planning as a community** – starting by introducing a collaborative planning option as an alternative to the current system under the RMA 1991. Community planning means that councils should consult and collaborate with community groups including Maori to ensure inclusive, democratic and transparent decision making which reflects the diverse range of community values and interests.

- **A National Objectives Framework** (NOF) – this action point requires councils to set objectives and limits at the catchment level in their regional plans. Freshwater objectives are defined as the intended environmental outcomes for a freshwater body (i.e, lakes, rivers, wetlands) that will provide for the water values the community considers important at the catchment-scale. Limits refer to the maximum amount of the resource available for use which allows a freshwater objective to be met. With respect to water quality, "*limits to use are derived from the specified freshwater objectives for each catchment and refer to the total amount of contaminants that can be discharged into it without jeopardising the desired outcomes".*
  Values include a range of water uses and activities. For each value there will be a number of water quality attributes (e.g., turbidity/clarity, periphyton, temperature, pH, dissolved Oxygen, contaminant concentrations) specific to that value. Each attribute will have associated indicator bands which represent the range of environmental states A to D (e.g., excellent, good, fair and unacceptable). For each attribute, the threshold between bands C and D represents the national minimum state or bottom-line. The NOF will have a standard list of values a water body could be manage for, two of which – ecosystems health and human health for secondary contact - would be mandatory for all water bodies. While the values chosen for a particular water body would be a community decision, the associated attributes and bands would be set at a national level.

- **Managing within water quality limits** – the goal of this action point is to achieve the catchment objectives by either improving water quality or creating headroom for development while maintaining water quality. Where limits are not exceeded, managing to limits will allow communities to identify where there are opportunities for enhanced water use. Where water quality limits are already or will be exceeded following land use change, measures are required. The choice and level to which these measures are applied requires councils to identify and quantify all sources of contaminants within a catchment and to know the environmental, social and economic impacts of the measures implemented.

Proposed amendments to the NPS-FM were put forward in November 2013 (MfE 2013b) on the basis of MfE (2013a) and public submissions to the that document. These include *the adoption of a NOF with a suite of national freshwater values, description of associated attributes and a process to use the NOF to support and guide the setting of freshwater objectives*. The NOF would have a menu of values that are important to communities. The values of ecosystem health and human health for secondary contact would be compulsory for all water bodies. National bottom-lines would be set for the attributes associated with each of the compulsory values. There is also a proposed requirement to monitor progress towards achieving the objectives. The proposed amendments are illustrated in Figure 1 along with the steps proposed for freshwater management under the reforms.

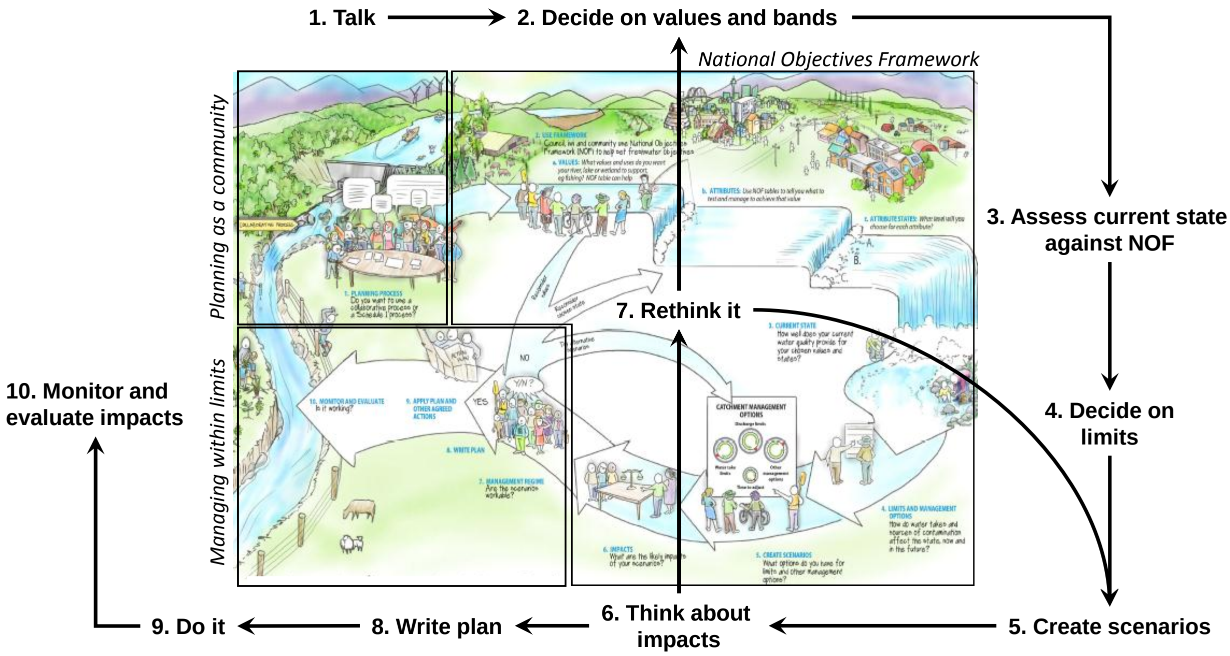

Figure 1 Managing freshwater in New Zealand showing key action areas and steps to choosing objectives and setting limits (Adapted from MfE 2013b)

The CLUES Model

CLUES is a modelling system for assessing the effects of land use change on water quality and socio-economic factors at a minimum scale of sub-catchments (~10 km^2 and above). The model was developed by NIWA for the Ministry of Primary Industries (formally the Ministry of Agriculture and Forestry) and MfE in partnership with AgResearch, Lincoln Ventures, Harris Consulting, Plant and Food Research (formally HortResearch and Crop & Food Research) and Landcare Research. CLUES couples a number of existing models within a GIS-platform and is provided to users as a front-end interface for ESRI ArcGIS which queries a geo-spatial database that is provided with the model software. The CLUES interface has a range of tools which allow users to develop land use change and farm practice (i.e., stocking rates, intensification and mitigation) scenarios. CLUES results are provided as maps and tables which can be exported to other applications for further analysis or reporting.

Models incorporated into the CLUES framework are:

- **OVERSEER®** (AgResearch, Wheeler et al. 2006) – a customised, pre-parameterised, and simplified version of OVERSEER 6 is provided within CLUES which computes nutrient leaching for dairy, sheep and beef and deer farming. It provides annual average estimates of nutrient losses from these land uses, given information on rainfall, soil order, topography and fertiliser applications. For other variables, such as fertiliser application rates, typical values are used based on the region and land use.

- **SPARROW** (Spatially Referenced Regression on Watershed attributes) - predicts annual average stream loads of total nitrogen, total phosphorus, sediment and *E. coli*. It includes provisions for stream routing and loss processes (storage and attenuation). This modelling procedure was originally developed by the United States Geological Survey (Smith et al. 1997) and has since been applied and modified in the New Zealand context with extensive liaison with the developers. SPARROW has been applied to nitrogen and phosphorus in Waikato (Alexander et al. 2002) and subsequently to the whole New Zealand landscape (Elliott et al. 2005). The SPARROW sediment transport routines were assessed by (Elliott et al. 2008) and simulations compared favourably with measured sediment load data.

- **SPASMO** (Soil Plant Atmosphere System Model) - calculates the nitrogen budget for a range of horticultural enterprise scenarios. Detailed simulations for many cases (combinations of crops, climate, fertiliser use) have been run (using a daily time step) to build look-up tables that CLUES queries. It has been validated against data from grazed pasture (Rosen et al. 2004) and pasture treated with herbicide (Close et al. 2003; Sarmah et al. 2005).

- **Harris – triple bottom line** (Harris et al., 2009) - 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 from that land use, given as a function of output. The calculations are based on the MAF farm monitoring models.

- **EnSus** (Environmental Sustainability, Landcare Research) - provides maps of nitrogen leaching risk, used as an adjunct to interpretation of CLUES results

The base areal unit of CLUES is the river-reach sub-catchment which comes from the NIWA River Environment Classification (REC, Snelder et al. 2010). Predictions of the CLUES surface water quality and financial indicators can be made for any reach within the REC. CLUES does not contain a groundwater model - rather, it is assumed that water percolating into the ground will emerge in the same surface river reach sub-catchment. CLUES is available free of charge from NIWA for non-commercial. Further details on the modelling framework can be found in(Woods et al. 2006) and information on setting up and running CLUES scenarios can be found in (Semadeni-Davies et al. 2011).

Water quality indicators generated by CLUES are:

- Nutrient (total nitrogen, total phosphorus; kg/year), sediment (kilo-tonnes/year) and *E. coli* (10^{15} organisms/year) loads in each stream reach.

- Nutrient concentrations (mg/m^3)

- Nutrient (kg/ha/year) and sediment (t/ha/year) catchment generated yields – i.e., the yield generated by each REC sub-catchment.

- Nutrient (kg/ha/year) and sediment (t/ha/year) in-stream cumulative yields - calculated as the in-stream load for a river reach divided by contributing area including stream tributaries.

CLUES within Freshwater Management

Modelling is an integral part of the freshwater management process under the reforms outlined above. MFE (2013a,b) notes that models can be used for a variety of purposes within the regulatory context including to estimate contaminant loads and concentrations and to evaluate the effectiveness of water quality improvement options and the environmental and economic impacts of those options. Two of the CLUES component models (OVERSEER and SPASMO) are cited within MFE (2013a) as examples of water quality models that could be used for freshwater management with the caveat that these models require further development before they are precise enough to be used for enforcing quantitative conditions on land use. Note that those two models predict losses only at the scale of an individual farm, rather than catchment-scale losses. CLUES too can play a role in Steps 1, 3, 5 and 6 of Figure 1 from (MfE 2013b) as follows:

Step 1 Planning process – community collaboration
CLUES has a range of methods that can be used to create scenarios with varying levels of sophistication. This flexibility makes it possible to run CLUES in a public setting to facilitate communication as well as behind the scenes by experts to provide background information.

Step 3. Assess the 'current state' of the catchment
CLUES can simulate the current state of water quality at the REC sub-catchment scale. Simulations can be for the region as a whole or for specific catchments.

Step 4 Decide on limits
CLUES can assist with determining the load limits to either improve or maintain water quality and can assess the capacity for change within a catchment.

Step 5-6 Create scenarios of management options required to achieve limits and assess the potential impacts of those options
The ability of CLUES to run multiple land use and farm practice scenarios allows comparison of the impacts of those measures that can be used to manage water quality. In addition to water quality, CLUES also has a number of socio-economic scenarios (e.g., farm full time equivalents) which means that the model can use used to assess the costs of various management option, CLUES can also be coupled to other tools to assess downstream impacts.

The possible use of CLUES to help implement the reforms is discussed further below with respect to the three key action areas outlined above.

Community Planning
Community planning provides a forum for sharing disparate knowledge bases and values from stakeholders to enable informed decision making (e.g., Geertman and Stillwell 2003). The process democratises decision-making by making background information and outcomes transparent and by allowing disparate stakeholders with different values and communities of practice to have their say. Stakeholder participation leads to more informed, holistic and equitable decision making, promotes consensus and improves the acceptance by stakeholders of unpopular decisions (i.e., the greater good). Community planning requires political and community support as well as an institutional climate that allows inter-organisational co-operation and encourages innovation. In addition, community planning requires consistent and robust scientific information in a form that is readily understandable by non-professionals in order to facilitate communication. Up-to-date tools, such as models and visualisation methods (e.g., charts, maps, diagrams, graphics, photos, animations and videos) are also required to allow stakeholders to understand the issues and evaluate alternative solutions.

CLUES is an example of a Computer Supported Co-operative Work (CSCW) technology. CSCW describes how people work together when interacting with computer and communication technology to assist an organisational activity such as decision making. CSCW technologies enable people to communicate and collaborate through shared workspaces. CSCW technologies can be conceptualised within a matrix (Figure 2) where interaction between participants and technology spans time and distance (e.g., Johansen et al.

1988; Baecker et al. 1995; Helander et al. 2000). A CSCW can be used as an aid to participation in different quadrants of the matrix – or rather, at different stages of the decision making process, each of which has different communication needs. Consider the case of model output to be used at a public planning meeting. The model may be used onsite as an aid to collaboration whereby participants can fine-tune scenarios for on-the-spot simulation and evaluation (i.e. co-located synchronous communication). Alternatively, it may be used to inform stakeholders of pre-defined alternative outcomes simulated by an expert group prior to the meeting (remote asynchronous communication). In the former case, the model would need to be simple to use with relatively quick set-up and run-times. In the latter case, the model could be more sophisticated requiring more data for scenario creation and longer set-up and run times. CLUES can be used for both of these examples using different options for scenario building (i.e., sketch or import tools) and can be seen as a complement for other, more sophisticated models, such as the full version of OVERSEER, in a tiered process.

In addition to scenario simulation, the ability of CLUES to supply model results as maps and exportable tables means that CLUES can be used geo-visualisation as well as to provide model data for further analysis. With respect to visualisation, the symbology of CLUES results can be customised to aid stakeholder understanding and to improve communication using standard GIS tools. For example, CLUES results can be displayed with other geospatial information and post-processing can be used to derive new data sets such as changes in yields between scenarios or sub-catchment rankings. The example below (Figure 3) shows the change in total nitrogen yields between pre-European and default current land use scenarios simulated for the Kaipara Harbour (Semadeni-Davies 2012). The inset shows default land use showing forested areas and sheep and beef, and dairy farming. The location of marae and catchment boundaries are also mapped and labelled.

Space / Time	Same site (co-located)	Different / multiple sites (remote)
Same time (synchronous communication)	Face to face interaction: • Public meetings • Single display groupware • Shared tables	Remote interaction: • Shared view desktop systems • Video conferencing • Multi-user editors • Media spaces
Different times (asynchronous communication)	On-going tasks: • Team rooms • Public display • Shift-work groupware	Communication and co-ordination: • Email, blogs and wikis • Bulletin boards • Workflow management • Preparation of reports/pamphlets

Figure 2 Computer Supported Co-operative Work matrix showing time and spaced-based views of CSCW technologies (after Johansen et al. 1988)

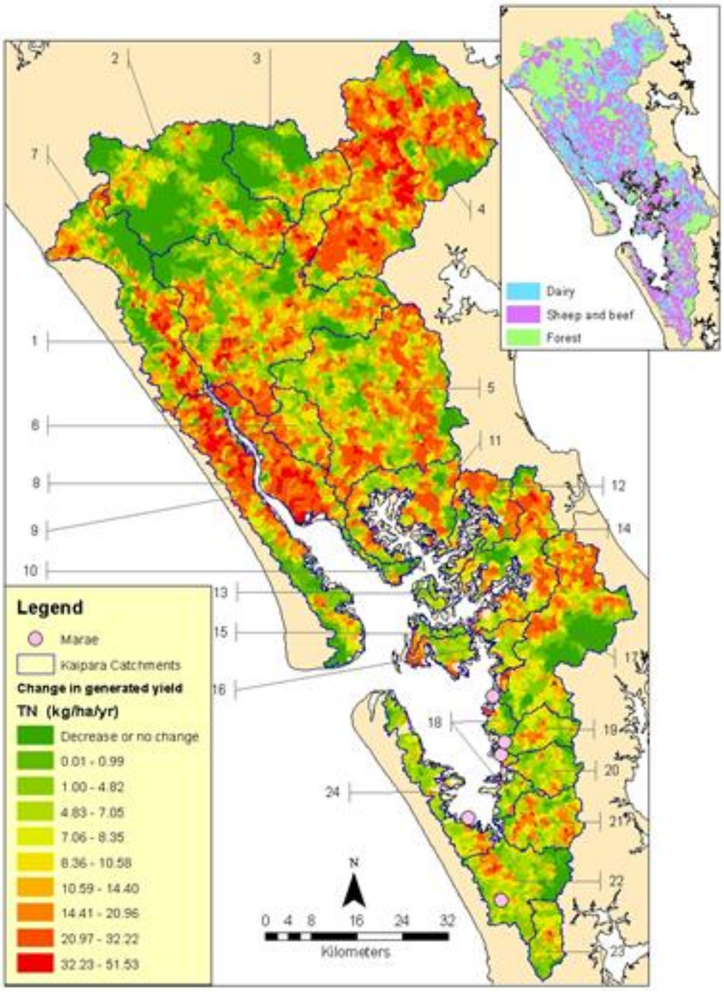

Figure 3 Example of CLUES potential for geo-visualisation.
Source: (Semadeni-Davies 2012)

The successful use of models within the community planning process very much depends on the way they are applied and presented to stakeholders. Stakeholders need to be aware that all models, CLUES included, are subject to errors and uncertainties and are limited by their choice of spatial and temporal scales and the processes that they simulate (e.g., Walker et al. 2003). Voinov and Brown Gaddis (2008) discuss their experiences of using watershed models as part of community catchment planning which are relevant to use of CLUES. They state that decision alternatives based on purely analytical models can be rejected by decision makers, particularly if they are unpopular or are likely to result in conflict, as they do not take into account the values, knowledge or priorities of the human systems that affects and is affected by the system being modelled. They use case studies to illustrate a number of rules for successful participation using models which are summarised below:

- Gain trust and establish neutrality as a scientist, the structure of the model must be scientifically sound and defensible to maintain credibility among decision makers, scientists and stakeholders.

- Select appropriate modelling tools to answer questions that are clearly identified. In the case of CLUES, the model is intended for catchment-scale applications to simulate long term impacts of land use and farm practices on water quality as indicated by annual loads.

- Incorporate stakeholder knowledge to help identify processes that should be included in the model. The model should be flexible enough to add new knowledge as it comes to light. CLUES input data can be readily updated by either creating new scenarios or by editing the geospatial database (e.g., point source locations and loads).

- Gain acceptance of the modelling methodology before presenting model results. Model transparency and clear documentation is essential. CLUES is a well-documented model with manuals and software available for download free of charge.

- Develop scenarios that are both politically feasible and cost effective. The decision alternative which has the best environmental outcome may not be viable politically, socially or economically. Stakeholders can provide solutions that are innovative and fulfil community needs.

- Engage stakeholders in discussions regarding uncertainty so that they understand that model results are indicative rather than predictive.

- Interpret results in conjunction with stakeholders. Community planning is iterative and stakeholders can develop further decision alternatives on the basis of model results.

- Treat the model as a process. The model is only part of decision making. Use the experiences gained in decision making to further develop the model for future use.

The National Objectives Framework – Setting Water Quality Limits

While limit-based freshwater management is key to the reforms, there is little information on how limits should be set or achieved in practice. Indeed, MFE (2013a) states that methodologies for deriving limits need to be developed. Setting water quality limits requires knowledge of the impacts of contaminants discharges on water quality at the site and catchment-scales and requires an understanding of contaminant dynamics and the response of ecosystems to those contaminants. Moreover, the impacts are cumulative such that management decisions made upstream will have a downstream effect. Consider the case of headwater streams; setting limits for first order streams may improve water quality to the desired level locally, however, it may not be enough for second order streams if the assimilative capacity of these streams is exceeded by the total load from all their tributaries. Clearly, load limits to achieve objectives in first-order streams must also be cognisant of the objectives in the second-order stream that they feed into. And so on down the stream network. However, it should not be assumed that limits should be set for the highest order stream due to the effects on water quality of dilution and decay in the main-channel.

A possible solution is to identify for each catchment a “critical point”, which is the location that has environmental objectives which require a stricter contaminant load limits to achieve than any other place in the catchment. If we can identify that critical point, and manage the catchment for the associated critical-point load limit, then we can assume that the objectives are being met catchment-wide. It stands to reason that managing for the critical-point load limit will also lead to over-achievement of objectives at places in the catchment other than the critical point, which means that stakeholders may be mitigating or paying for outcomes that are not necessarily local to them which could lead to conflict. More generally, this raises questions about approaches to spatial allocation of mitigations or discharge increases. There are also theoretical difficulties in this approach. For instance, how should we evaluate the attributes for different types of water body in the same stream network (e.g., periphyton as a nutrient indicator for stony-bed streams versus chlorophyll-a in lakes)? And should the critical point be determined solely on the basis of current water quality or should the sensitivity of different points in the catchment which may currently meet the water quality objectives but are vulnerable to change also be assessed? Moreover, how should changing values and sites of economic, social and cultural significance along a river (e.g., location of swimming holes, taniwha and fishing spots) be considered? Issues surrounding the identification of critical points using the CLUES model are discussed further in Semadeni-Davies et al. (2009).

A further challenge is that while attributes are expressed as either long-term average contaminant concentrations or water quality indicators, limits are most likely to be imposed on contaminant loads coming from various sources in a catchment. Setting limits thus requires a transformation of loads to concentrations or indicators or vice versa. (Elliott and Snelder (2011)) outlined a possible loads-based approach using CLUES, to estimate annual *E. coli*, sediment and nutrient loads reaching rivers for current land use. These loads are then equated to the observed long-term average water quality as indicated by nutrient and microbe concentrations, clarity and periphyton assuming a linear relationship between the contaminant loads and the environmental indicators. For each of these attributes, if the current level is greater than the target level, then the associated contaminant loads must be reduced proportionally. In contrast, if the current level is less than the target, the difference represents the capacity for change in the catchment.

Managing to Catchment Water Quality Limits

Managing within water quality limits requires both the management of contaminant yields (i.e., source control) and the reduction of contaminant loads reaching freshwater bodies through different measures including mitigation. The primary purpose of CLUES is to evaluate the impact of land use change and farm practices on water quality at the catchment scale. Thus CLUES is well placed as a tool for the assessing mitigations needs to manage within water quality limits.

CLUES has been applied in a number of projects undertaken to assess the impacts of land use change, notable dairy conversion, and farm practices on water quality. These studies have been used to inform planners and policy makers in both regional and national government. Examples include national nutrient mapping for current and future land use (Parshotam et al. 2013), assessments of mitigation options in the Mataura and Oreti river catchments in Southland (Monaghan et al. 2010; Semadeni-Davies and Elliott 2011), and Waikato (Semadeni-Davies and Elliott 2012) and an evaluation of the potential for wetlands to reduce regional contaminant loads from dairy farms in Southland / South Otago (Hughes et al. 2013) for current land use and with dairy conversion of all pastoral land. The techniques used in these applications can be adapted to assess different land use and water management options and whether they meet the limits set.

Mitigation within CLUES is simulated as a percentage decrease in yields from affected land uses in each REC sub-catchment. Simulation requires the development of rules which determine where the chosen farm practices can be applied with respect to land use and catchment characteristics such as Land Use Capability (LUC, Lynn et al. 2009), soil drainage class, and the removal efficiency of each farm practice for each contaminant. These rules have been based on expert knowledge, literature and output from models such as OVERSEER. Mitigations that have been simulated include stock exclusion, standoff pads, wetlands, changed management of farm dairy effluent, use of dicyanodiamide (DCD) fertiliser and conservation planting.

In addition to water quality indicators, CLUES has sub-routines to simulate a range of socio-economic indicators (Harris et al. 2009) and can also be coupled with other models to assess the economic and social impacts of the management measures.

Future CLUES Development

There are a number of limitations to CLUES use for freshwater management. For instance, the model does not currently include groundwater and is unable to simulate seasonal changes in water quality. Moreover, there are scaling issues in the application of scenarios. CLUES also requires local calibration in some regions. With these limitations in mind, a stakeholder workshop consisting of CLUES end users from regional councils and other agencies (e.g., researchers, government departments) was hosted by the Ministry for Primary Industries (MPI) in March 2012 in order to determine how CLUES is currently being used for policy and planning applications and to suggest ways in which the model can be improved.

As a result of the workshop, we are planning the following updates to CLUES for 2014

- Incorporation of the LCDB3 land use database to replace the default LCDB2 database currently used in CLUES. Additionally, it is expected that there will be a formalised link between CLUES and the MPI farms online web-tool to enable regular updates of core land use data;

- Incorporation of the updated REC database into CLUES; and

- Re-calibration of SPARROW model parameters to include new water quality data:

Ongoing model maintenance includes;

- Maintenance of code and documentation;

- User support, web page maintenance and training;

- Incorporation of any updates to the OVERSEER model into CLUES, including updating of default stocking rates; and

- Update socio-economic model parameters.

Additionally, funding is being sought to make the following model improvements:

- Addition of new tools to allow easier creation of land use and farm practice scenarios and to determine land use capacity limits with respect to water quality.

- Initiate the improved simulation of groundwater and irrigation. CLUES currently does not take either into account which has led to problems with the model's use in areas with complex links between surface water and ground water.

- Increase the temporal resolution from annual to seasonal in recognition that there are seasonal differences in land use practices (e.g., irrigation, application of fertiliser) and climate and therefore hydrological response;

- Improve spatial resolution. CLUES operates at the sub-catchment scale and spatial information within each sub-catchment is spatially lumped that can lead to problems with the representation of land use and mitigation when setting up scenarios. Modifications will be required within CLUES to capture the benefit of improved spatial resolution of the SPARROW sub-model currently underway.

- Evaluation of other tools and data sets for integration with CLUES (e.g. hydrological models, improved erosion models).

Conclusions

Under the NPS-FM, the way in which freshwater is managed in New Zealand is changing from effects-based to limits-based management with more emphasis on cumulative effects. MFE (2013a) has proposed three action points to aid implementation which have been incorporated into proposed amendments to the NPS-FM (MfE 2013b). These are: planning as a community; establishment of a National Objectives Framework; and managing within water quality and quantity limits. Central to the proposed reforms is the need for methods and models to be developed which are underpinned by robust science and good quality data. MFE (2013a,b) notes that models can be used to estimate contaminant loads and concentrations and to evaluate the effectiveness of water quality improvement options and the environmental and economic impacts of those options. Models can also be used to facilitate communication between stakeholders engaged in community planning.

In this paper we have discussed how the CLUES model can be applied to help implement the NPS-FM with respect to each of the action points. CLUES is a catchment-scale model which simulates long-term water quality (i.e., annual nutrient, sediment and *E.* coli loads) in response to land use and farm practices. The GIS-platform, for example, can aid geo-visualisation of water quality issues and alternative solutions. CLUES is able to both assess the current state of water quality and to simulate changes to water quality following land use change which makes it possible to use the model to assist with determining load limits. However, there is a need to refine the methods used to set load limits. Similarly, the ability to create and run both land use and farm practice scenarios means that CLUES can be used to evaluate different mitigation options to reduce contaminant loads in order to achieve limits. CLUES, like any model, has a number of limitations, some of which are being addressed with planned, user-driven, development to improve the model.

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