CLUES - Catchment Land Use for Environmental Sustainability User Manual

Fifth Edition: CLUES 10.3

Prepared for NIWA core funding

June 2016

Prepared by:
Annette Semadeni-Davies
Sandy Elliott
Ude Shankar

For any information regarding this report please contact:

Annette Semadeni-Davies
Urban Aquatic Scientist
Urban Aquatic Environments
+64-9-375 4532
annette.davies@niwa.co.nz

National Institute of Water & Atmospheric Research Ltd
Private Bag 99940
Viaduct Harbour
Auckland 1010

Phone +64 9 375 2050

NIWA CLIENT REPORT No: AKL2016-017
Report date: June 2016
NIWA Project: FWWQ1605

Quality Assurance Statement		
C. C. Palliser	Reviewed by:	Dr Chris Palliser, Catchment Modeller
K.B.	Approved for release by:	Mr Ken Becker, Regional Manager, Auckland

Contents

Executive summary 6

1 Introduction 8

1.1 New to CLUES 10.3 8

1.2 Manual structure 9

1.3 CLUES availability 10

2 CLUES model description 11

2.1 Water quality models 12

2.2 CLUES Estuary 14

2.3 Socio-economic model 14

2.4 Geodatabase 15

3 Model outputs 19

3.1 Water quality indicators 19

3.2 CLUES Estuary 20

3.3 Social-economic indicators 20

3.4 Types of output reporting 22

3.5 Maps 22

3.6 Tables 23

4 Getting started 26

4.1 System requirements 26

4.2 Downloading CLUES software and regional databases 26

4.3 CLUES Installation 28

4.4 Uninstalling CLUES 30

4.5 Map documents 31

4.6 User Interface 33

4.7 CLUES geo-database feature classes 33

5 Basic functions 38

5.1 Flag selection tools 38

5.2 Polygon selection tool 39

5.3 Running CLUES 40

5.4 Adding barriers 40

5.5 Running CLUES Estuaries 42

6 Scenario tables 44

6.1 Creating scenario tables 44

6.2 Running a scenario 45

6.3 Deleting scenario tables 45

7 Land use change scenarios 47

7.1 Sketching tool 47

7.2 Importing a new land use shapefile 50

7.3 Direct calculation 53

8 Land management scenarios 54

8.1 Farm practice scenarios 54

8.2 Forest harvest scenarios 63

9 Output reporting and display 66

9.1 Maps 66

9.2 ID table tool 71

9.3 Run summary tables 72

9.4 Contaminant tracing tables 75

9.5 Comparing results for scenarios other than the default 77

9.6 Geo-visualisation, spatial analysis and customised symbology 77

Acknowledgements 79

References 79

Appendix A CLUES software terms and conditions for use 82

Appendix B SPARROW *E. coli* model 87

Appendix C Contaminant tracing tables 88

Appendix D Scenario table output fields 90

Appendix E Forest harvest 91

Tables

Table 2-1	Summary of catchment water quality model components in CLUES	13
Table 2-2:	Spatial data included in the CLUES geodatabase.	16
Table 2-3	LCDB3 land cover groupings and corresponding CLUES land use classes.	18
Table 4-1:	List of icons on the CLUES interface.	34
Table 4-2:	Feature classes supplied with the CLUES geodatabase.	36
Table 8-1:	Modification factor scenario table fields that are used to set-up farm practice scenarios.	55

Figures

Figure 2-1:	Overview of the structure of CLUES.	11
Figure 2-2:	The 10 CLUES regions were determined on the basis of catchment and political boundaries.	15
Figure 3-1:	Default TN loads for Raglan Harbour shown as a watershed (top) and river line (bottom) map.	22
Figure 3-2:	Bar chart map showing change in TN concentrations simulated with default land use and all land use changed to intensive sheep and beef farming to the north of Raglan Harbour.	23
Figure 3-3:	Sub-catchment summary table showing the default water quality and socio-economic and estuary indicators.	24
Figure 3-4:	Model summary table showing user selected default outputs (TN, TP and TSS loads) for each reach simulated in a model run.	24
Figure 3-5:	TN tracing table for the default scenario showing the contributions to sediment loads for each REC reach simulated in the model run by land use class.	25
Figure 4-1:	The CLUES interface.	33
Figure 9-1:	Customised display of CLUES output demonstrating the potential for geo-visualisation. Left: TN concentrations classified according to Waikato Regional Council water quality bands compared to 5-year SOE median concentrations (2003-2007). Semadeni-Davies et al. (2009), prepared using CLUES 2.0.6. Right: Change in estimated TN generated yields between 1770 and 2002. Inset shows primary land uses in the study area derived from LCDB2. Marae locations are labelled. Semadeni-Davies (2012), prepared using CLUES 3.1.	78

Executive summary

The Catchment Land Use for Environmental Sustainability (CLUES) model is a steady-state, catchment-scale model with the primary purpose of providing a tool that can rapidly assess the impacts of land use change and land management practices on stream water quality (as indicated by total nitrogen - TN, total phosphorus - TP, sediment and *E. coli*) and a range of social economic indicators. Its intended user group consists largely of central and regional government agencies charged with water policy making, environmental assessment and catchment management. CLUES was initially developed in 2006 and has been continually updated over the past decade to make use of new data and modelling methods. This user manual has been prepared for model version 10.3 that was released in May 2016.

CLUES consists of the following components within the ArcGIS (ESRI software) platform: a geo-database containing model inputs and outputs; a user interface for river reach selection, scenario creation, run control, and output display options; a suite of models; and reporting and display tools. CLUES is supplied with a geospatial dataset derived from publically accessible data sources. Additionally users are able to import other datasets to aid scenario creation or enhance output display. The GIS platform means that users are able to use standard GIS tools for geo-visualisation and geo-spatial analysis of CLUES input data and model outputs.

CLUES operates at the sub-catchment level and the smallest spatial unit is the river reach sub-catchment as defined in the NIWA River Environment Classification (REC). CLUES 10.3 can run with both the original 2004 REC stream network database (REC1) or the 2010 REC2 update.

The model suite consists of three water quality models (OVERSEER, SPARROW and SPASMO), a socio economic model and the CLUES Estuary model which was added in 2015. Model water quality outputs are:

- Cumulative mean annual loads of total nitrogen (TN, t/year), total phosphorus (TP , t/year), suspended sediment (kt/y) and *E. coli* (peta organisms/y) passing through the reach;
- Median concentrations of TN and TP (mg/m^3);
- Generated yields (load reaching the stream network from the associated sub-catchment, divided by the sub-catchment area) for each contaminant and cumulative yields (mean annual load divided by the upstream catchment area) for nutrients;
- Potential dissolved nitrogen (nitrate) and phosphorus concentrations in estuaries.

The socio- economic indicators are grouped into four groups relating to farm economics, energy production, greenhouse gas emissions and infrastructure. Model outputs are reported as maps (water quality indicators only) and in tabular form. The water quality and socio-economic indicators are calculated for each river reach in the REC stream network database. Some 375 estuaries and natural harbours are included in the CLUES Estuary model database.

This manual is split into the following sections

Sections 1 and 2 – Manual introduction and CLUES overview describing the model structure, component parts, geo-database.

Sections 3 – Description and examples of model outputs (i.e., water quality and socio-economic indicators) and display (i.e., maps and tables).

Section 4 – Instructions on how to download and install CLUES 10.2 and an overview of the model interface and geodatabase feature classes.

Section 5 – Instructions on how to make basic (default) model runs and display the outputs.

Sections 6, 7 and 8 – Instructions for creating scenarios and modifying these for land use change and land management options.

Secition 9 – Instructions on how to display and interpret CLUES outcomes.

The software and geospatial data needed to run CLUES are provided to users free of charge for non-commercial uses and can be downloaded from the NIWA at:

ftp://ftp.niwa.co.nz/clues

The terms and conditions for CLUES use set out in the user agreement appended (Appendix A). Downloading or using CLUES implies that the user has read and agreed to the licencing agreement.

1 Introduction

In 2004 the Ministry of Agriculture and Forestry (MAF; now the Ministry for Primary Industries, MPI) in association with the Ministry for the Environment (MfE) engaged NIWA, in partnership with five other agencies (Lincoln Ventures, Harris Consulting, AgResearch, HortResearch / Plant and Food Research, and Landcare Research), to develop a catchment-scale model that can rapidly evaluate the effects of land use change and land management practices on catchment water quality and socio-economic factors at a regional or national level. The model was to have a GIS platform to allow handling, storage and visualisation of geospatial data and it would be used primarily to support central government and regional councils with policy making and catchment planning. The model is known as Catchment Land Use for Environmental Sustainability (CLUES) model and was initially released in 2006. The original framework for CLUES is described in a report by Woods, Elliott, et al. (2006) that details many of the core datasets, concepts, and models components still used in CLUES. Over the past decade CLUES has been continually developed to support a range of new model applications and is regularly updated to remain compatible with default input datasets, component model versions, and ArcGIS versions.

Water quality in CLUES is indicated by annual total nitrogen (TN) and phosphorus (TP) loads, yields and concentrations as well as load and yields of sediment (i.e., total suspended solids, TSS) and *E. coli*. Nutrient loads and concentrations can give an indication of eutrophication and nitrate toxicity. Sediment loads are associated with both the level of turbidity and clarity. *E. coli* has been included to indicate the overall pathogenicity of microbial water contaminants on the understanding that where *E. coli* loads are high, the loads of other harmful pathogens, such as *Campylobacter*, *Salmonella*, *Giardia* cysts, and *Cryptosporidium* oocysts, are also likely to be high. The socio-economic indicators are grouped into indicators for farm economics, energy, greenhouse gasses and infrastructure requirements.

CLUES operates within the ArcGIS (ESRI software) platform which means that the model can be used in tandem with standard GIS tools and users are can add their own geospatial data. In addition to the ArcMap toolbox, the CLUES interface has a range of tools which allow users to develop land use change and land management (i.e., stocking rates, farm intensification and mitigation, forest harvest) scenarios. CLUES results are reported as maps and tables which can be exported to other applications for further analysis or reporting. A steady-state rather than dynamic modelling approach was adopted to reduce input data needs and run times in order to enable rapid scenario assessment to facilitate catchment planning applications.

1.1 New to CLUES 10.3

This manual has been prepared for CLUES 10.3 released in May 2016. New to CLUES 10.3 are the following updates:

- CLUES software is available for either ESRI ArcGIS 10.2 or 10.3 and can be run under Windows 7 or 10 operating systems;
- CLUES geo-databases are available with either River Environment Classifications stream network data versions 1 or 2;
- Inclusion of a tracing tool to allow users to identify which land uses are responsible for the most contamination at-source and in-stream;
- Updated point sources for some regions;

- Updated / recalibrated Sparrow *E. coli* model which includes generated *E. coli* yields as a model output;
- Inclusion of a forestry tool to enable users to set yield changes for harvest years;
- Land use for all regions based on the Land Cover Database version 3 (LCDB3);
- Rainfall and flow based on mean annual averages from 1960-2006 for REC2;
- Ability for CLUES users to set Clues-Estuary parameter values; and
- New Zealand Transverse Mercator 2000 (NZTM2000) projection for all geodatabase feature classes.

1.2 Manual structure

This manual contains the following sections:

Sections 1 and 2 – Manual introduction and CLUES overview describing the model structure, component parts, geo-database.

Section 3 – Description and examples of model outputs (i.e., water quality and socio-economic indicators) and display (i.e., maps and tables).

Section 4 – Instructions on how to download and install CLUES 10.3 and an overview of the model interface and geodatabase feature classes.

Section 5 – Instructions on how to make basic (default) model runs and display the outputs.

Sections 6, 7 and 8 – Instructions for creating scenarios and modifying these for land use change and land management options.

Section 9 – Instructions on how to display and interpret CLUES outcomes.

This edition supersedes the previous manuals that are listed below:

Semadeni-Davies, A., Shankar, U. and Elliott, S. (2012) CLUES 10 Installation and Interface: Addendum to the CLUES 3.1 User Manual. Prepared for the Ministry of Agriculture and Forestry. NIWA Client Report: AKL2012-007.

Semadeni-Davies, A.; Elliott, S. and Shankar, U. (2011) The CLUES Project: Tutorial manual for CLUES 3.1. Commissioned by Ministry of Agriculture and Forestry, NIWA Client Report: HAM2011-003

Semadeni-Davies, A., Shankar, U., McBride, G. and Elliott, S. (2009) The CLUES Project: Tutorial manual for CLUES 2.0.6. Commissioned by Ministry of Agriculture and Forestry, NIWA Client Report: HAM2009-146

Semadeni-Davies, A., Shankar, U., McBride, G. and Elliott, S. (2008) The CLUES Project: Tutorial manual for CLUES 1.5. Commissioned by Ministry of Agriculture and Forestry, NIWA Client Report: HAM2007-170

Semadeni-Davies, A., Shankar, U., and Elliott, S. (2007) The CLUES Project: Tutorial manual for CLUES 1.4. Commissioned by Ministry of Agriculture and Forestry, NIWA Client Report: HAM2007-170

1.3 CLUES availability

The software and geospatial data needed to run CLUES are provided to users free of charge for non-commercial uses and can be downloaded from the NIWA at:

ftp://ftp.niwa.co.nz/clues

Please read the terms and conditions for CLUES use set out in the user agreement appended (Appendix A) to this document before you download or install CLUES software. Downloading or using CLUES implies that you have read and agreed to the licencing agreement.

2 CLUES model description

CLUES has been developed as a tool for the rapid assessment of the impacts of land use and land management at the catchment scale to inform policy making, environmental assessment and catchment planning. CLUES operates at the catchment scale and the smallest spatial unit is the river reach sub-catchment as defined by the River Environment Classification (REC; see Section 2.4). CLUES consists of the following components within the ArcGIS platform: a geodatabase containing model inputs and outputs; a user interface for river reach selection, scenario creation, run control, and output display options; a suite of sub-models responsible for different modelling routines; and reporting and display tools. These components are the hallmarks of a spatial decision support system (SDSS; Armstrong et al., 1986; Densham, 1991; Geertman and Stillwell, 2003; van Delden et al., 2011). The use of SDSSs for environmental management has been discussed, amongst others, by Argent et al. (2009) with regard to water quality modelling and by van Delden et al. (2011) with regard to policy making. The CLUES framework showing how these components are linked is given in Figure 2-1. The component models are described below (Sections 2.1 to 2.3); the geodatabase is described in Section 2.4 and; model outputs are listed in Section 3 along with the types of display; finally, the interface is discussed in Section 4.6 and the feature classes supplied with CLUES are listed in Section 4.7.

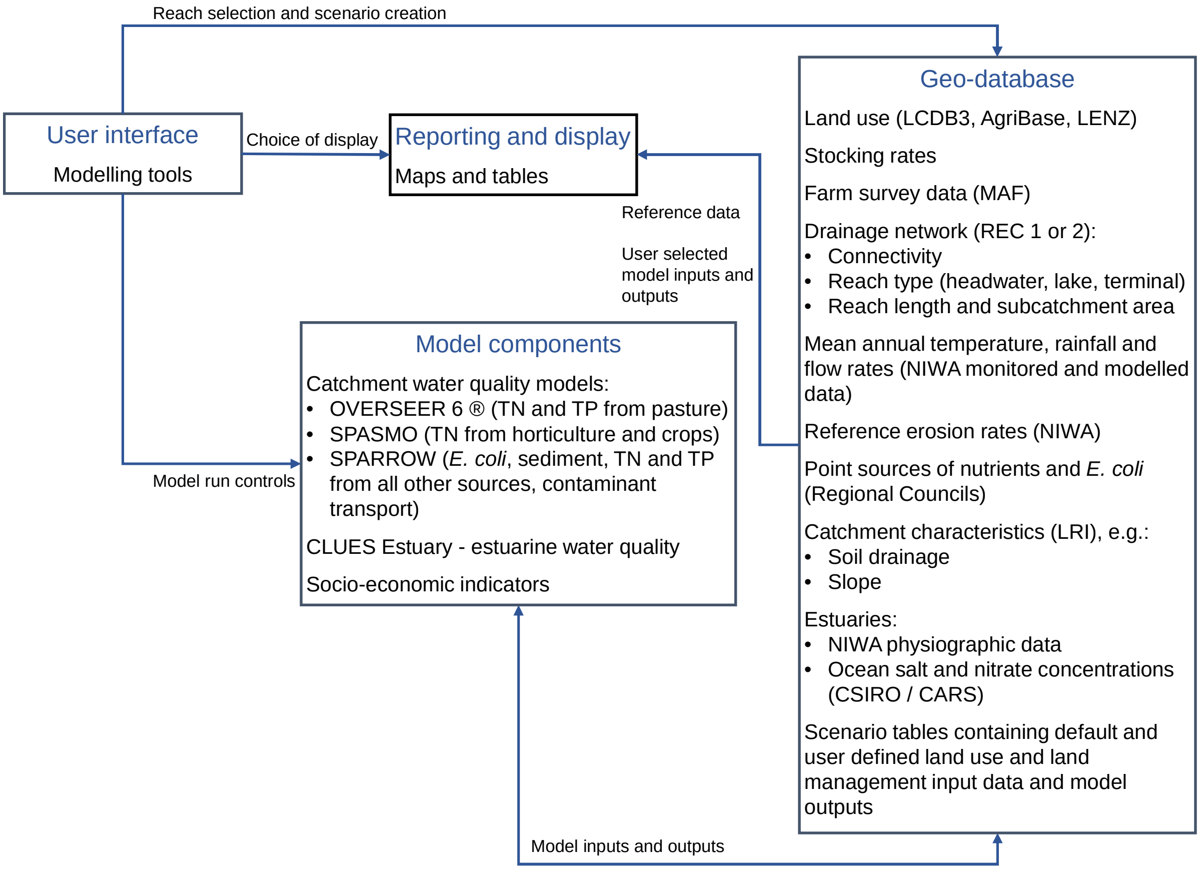


Figure 2-1: Overview of the structure of CLUES.

2.1 Water quality models

Three catchment water quality models lie at the heart of the CLUES framework, these are OVERSEER® Nutrient Budgets Version 6; SPASMO (Soil Plant Atmosphere System MOdel) and SPARROW (Spatially Referenced Regression On Watershed attributes). Each is described briefly below and their key attributes and functions within CLUES are given in Table 2-1.

2.1.1 OVERSEER

OVERSEER is provided for use in CLUES by its developers (AgResearch NZ Ltd) as a Delphi-based dynamic link library (DLL). CLUES uses a customised, pre-parameterised, and simplified version of OVERSEER version 6.1 (Shepherd and Wheeler, 2013; Shepherd et al., 2013; Roberts and Watkins, 2014; Wheeler et al., 2014) to compute annual average nutrient loss for pastoral land uses. OVERSEER is steady-state, agricultural management model that assists farmers and their advisers to examine fertiliser requirements and nutrient movement within a farm to the base of the pasture root zone to optimise production and environmental outcomes. The model is widely used within New Zealand. For the simplified version of OVERSEER, nutrient losses from each river reach sub-catchment are calculated as a function of the stock type, rainfall, soil order and topographic slope class. Default farming stocking rates and fertiliser application rates were derived from national data (Woods, Elliott, et al., 2006), and default soil P fertility status (Olsen P) was also estimated. Default stocking rates vary by farm type and sub-catchment average slope, with North Island farms having higher rates than South Island farms.

2.1.2 SPARROW

The SPARROW model forms the underpinning conceptual and spatial basis for the catchment component of CLUES and is used to both route instream contaminant loads down the stream network and to determine sediment and *E. coli* loads from all land uses and nutrient loads from non-pastoral or horticultural land uses. Full details on SPARROW formulation are given in Schwarz et al. (2006); here we present summary information relevant to the applications in CLUES. SPARROW was developed by the United States Geological Survey as a flexible modelling framework for developing hybrid mechanistic-statistical models of contaminant flux. It includes calibration and prediction components. CLUES only implements the prediction component, while calibration was done at a national level externally to CLUES using the original SPARROW SAS statistical code.

SPARROW is a steady-state model that is based on mass balance approaches to determining mean annual flux through a surface drainage network. Each river reach sub-catchment in the network has a number of attributes that are used to determine sources of contaminants and their delivery to the stream network. Once they have entered the stream, contaminant loads are accumulated down the network and decayed in streams and lakes. The model parameters are determined from calibration to measured loads. In CLUES, the model structure and parameter values are essentially fixed, having been established through calibration, although parameters are stored in text files within the regional CLUES folders. The modelling approach and calibration is discussed in relation to sediment in Elliott et al. (2005a) and to nutrients in Elliott et al. (2005b) and Woods, Elliott, et al. (2006). The *E. coli* model was recalibrated in October 2015 to make use of new data and the results of the calibration are presented in Appendix B.

Table 2-1 Summary of catchment water quality model components in CLUES

Attribute	OVERSEER	SPARROW	SPASMO
Description	Farm-scale nutrient budgeting and loss estimation	Catchment-scale mass accounting and empirical parameter estimation	Physically-based dynamic generic plant growth and nutrient leaching
Main Developer	AgResearch Ltd. (NZ)	United States Geological Survey (USGS)	Plant and Food Research Ltd. (NZ)
Latest release	Version 6.1, 2014	Version 2.9, 2007	Ongoing development
URL	http://overseer.org.nz/	http://water.usgs.gov/nawqa/sparrow/	none
CLUES water quality outputs	Nitrogen and phosphorus	Nitrogen, phosphorus, microbes and sediment	Nitrogen
Intended purpose	Estimation of nutrient and greenhouse gas budgets for pastoral farms and arable and horticultural paddocks	Prediction of mean annual contaminant loads in streams	Estimation of, leaching (N, pesticides) from horticulture and crops and irrigation requirements
Geographic range limitations	New Zealand	None	None
Spatial resolution	Farm or block	Sub-catchment, reach	Point in space
Spatial extent	Farm or small catchment / aquifer / river network / lake / estuary	Medium or large catchment / aquifer / river network / lake / estuary or coastal embayment	Point model
Temporal resolution	Annual steady state	Annual steady state	Usually daily, dependent on climate data available (dynamic). CLUES uses meta-model for mean annual losses.
Inputs	Climate data Irrigation rates Fertilizer application rates Soil type / drainage Land use Crop and stock types and attributes	Drainage network Climate data Land use Soil drainage class Stream flow Topographic slope Erosion terrains	Climate data Irrigation rates Soil drainage and nutrient properties Land use Crop and stock types and attributes Crop and stock management

2.1.3 SPASMO

SPASMO (Rosen et al., 2004) is a daily time-step model used to predict the fate of surface-applied chemicals. SPASMO measures the impact of nitrate movement below the root zone and promotes efficient water management by providing a risk assessment of irrigation needs. It has been validated against data from grazed pasture. Mean annual losses derived from SPASMO are used within CLUES to estimate nitrogen losses from cropping and horticultural areas. To achieve this, a number of SPASMO runs were conducted for different crop types, rainfalls, and key soil types and the results were summarised as lookup tables and continuous functions of rainfall.

2.2 CLUES Estuary

The CLUES Estuary model was added to the CLUES modelling framework in 2014 and provides estimates of long-term mean annual TN and TP concentrations for the evaluation of estuary eutrophication (Zeldis et al., 2012). At present, the model has been set up for 375 estuaries, tidal inlets and natural harbours around the country (henceforth referred to collectively as estuaries). For each estuary, the land inputs from the catchment components of CLUES and oceanic inputs are flushed and diluted within the estuary using hydrodynamics determined by the physiography of the estuary and the volumes and salinities of water entering from land and sea end-members.

Depending on the properties of the estuary, CLUES Estuary selects either a modified tidal prism model (Luketina, 1998) for well-mixed, tidally dominated estuaries; or a two-layer box model, ACExR (Gillibrand et al., 2013), which includes vertical mixing processes in addition to tidal flows for estuaries that are expected to be stratified. The mean (spatial and temporal) averaged TN and TP concentrations in the estuary are calculated using CLUES derived TN and TP concentrations in the freshwater inflow, while the oceanic concentrations are obtained from the CARS2009 climatology (CSIRO, 2011). The CLUES Estuary model contains a classification step to determine which of the hydrodynamic models is applied to the estuary based on physiographical data including tidal prism (i.e., the difference in volume between the mean high tide and mean low tide), estuary volume, and freshwater inflow volume. The tidal prism and estuary volume are obtained from the Coastal Explorer database (Hume et al., 2007a), a physiography of approximately 400 estuaries in New Zealand. Users are able to the override these CLUES estuary parameters with their own parameter set. A more in-depth description of the CLUES Estuary model is given by Plew et al. (2015).

2.3 Socio-economic model

The socio-economic model provided within CLUES is based on existing farm survey data – primarily using Ministry of Agriculture and Fisheries Farm Monitoring data from 2009. The outputs of the model are available in the sub-catchment ID table under the Economics tab. There are four sets of indicators, these are: economic indicators relating to farm income and costs; energy indicators relating to the total use of fossil fuels by rural enterprises and the energy produced by those enterprises; greenhouse gas emissions; and infrastructure and quality of life indicators which estimate the government revenue use to provide the infrastructure required to support rural enterprises. More information can be found in Harris et al. (2009).

2.4 Geodatabase

All default spatial data required to run CLUES are supplied to users as feature classes in an ArcGIS geodatabase. These feature classes are listed in Section 4.7. In addition to the CLUES geodatabase, users are able to add other geospatial information to enhance the interpretation of model results and to aid in the development of scenarios.

To improve data handling within the model, CLUES splits the country into 10 geographical regions on the basis of political and catchment boundaries (Figure 2-2). Separate geodatabases have been created for each of these regions. All data held in these regional geodatabases have been derived from publically available national datasets, this was done to ensure that all users had open access to data required by the model. The data sets and their sources are summarised in Table 2-2.

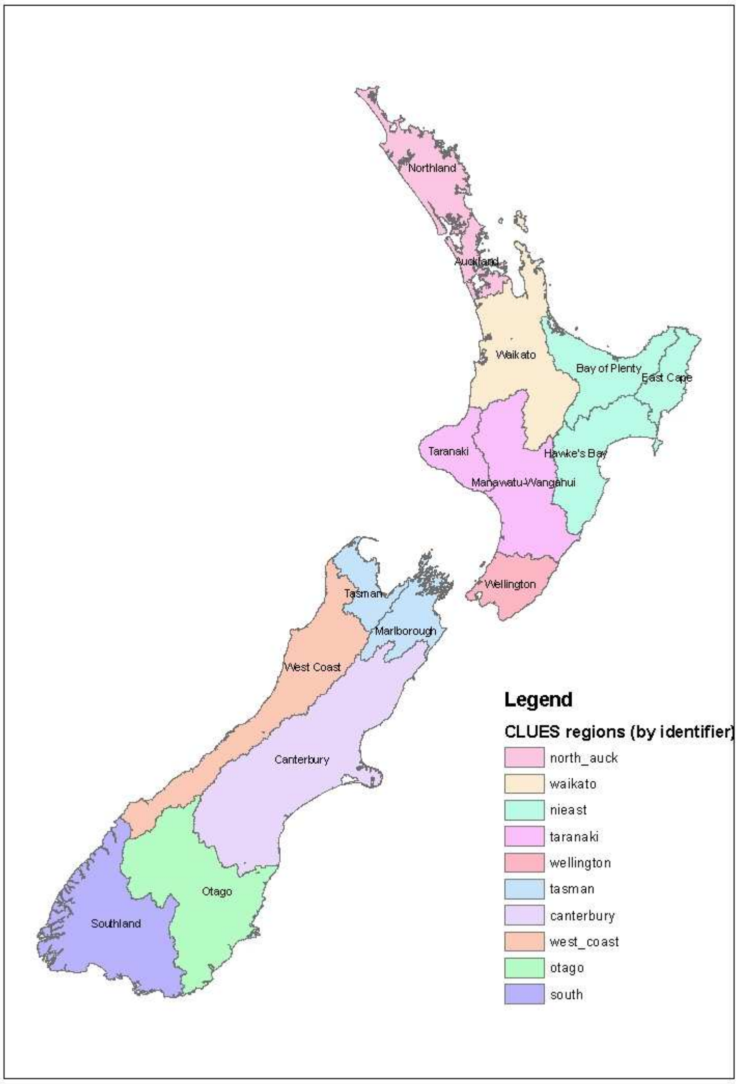


Figure 2-2: The CLUES regions were determined on the basis of catchment and political boundaries.

Table 2-2: Spatial data included in the CLUES geodatabase. Note that these data sets are required by the model. Other data included in the CLUES database are provided for reference purposes.

Data set	Data type	Source	Geodatabase location
Drainage network	Mean annual discharge	Woods, Hendrikx, et al. (2006)	Stream network feature class
	Reach type	REC1 or 2	
	Flow paths and direction	REC1 or 2	
	Mean annual average rainfall	NIWA climate data (1960-2006)	
	Sub-catchment boundaries,	REC1 or 2	Sub-catchment feature class
	Confluences	REC1 or 2	Stream nodes feature class
Catchment characteristics	Dominant soil type and drainage class	LRI	Stream network feature class
	Average slope class	LRI	
	Point nutrient sources	Regional councils	
Land use and farm practices	Land use class	LCDB3, Agribase, LENZ	Default scenario attribute table
	Stocking rate	Woods, Elliott, et al. (2006)	Default scenario attribute table
Estuaries	Physiographic data (freshwater fraction, estuary surface areas and, volume, tidal prism, etc.)	NIWA Coastal Explorer	Estuary feature class
	Ocean salt and nitrate background concentrations	CARS	

LRI – Land Resources Inventory
REC – River Environments Classification, users can choose between REC1 or REC2
LCDB3 – Land Cover Database version 3
LENZ – Land Environments of New Zealand
CARS - CSIRO Australian Regional Seas

CLUES operates at the catchment scale (>10km^2) with the smallest spatial units being river reach sub-catchments derived from the River Environments Classification (REC, Snelder et al., 2010) developed by NIWA for the Ministry for the Environment. CLUES 10.3 is available for the original 2004 REC stream database (REC1) and the 2010 update (REC2). In each version, the REC database consists of point (confluence nodes), line (stream network) and polygon (sub-catchments) feature classes that describe the physical characteristics of river systems in New Zealand. A river reach is defined as a section of river between upstream and downstream confluences; reaches are typically between 500-1500m in length with an average length of around 750m. Each reach has a unique reach identity number, these are the NZ reach for REC1 or the NZ segment for REC2[1]. This number is used extensively in CLUES to join input and output data held in scenario tables and in the Hydroedge

[1] Note that while the reach ID for REC2 is called the NZ segment number, it is referred to as the NZREACH number in the scenario tables and model output tables. This was done to allow CLUES to operate with both the REC1 and REC2 datasets.

feature class to the spatial geometries held in the geodatabase stream and catchment feature classes. The REC was derived from a digital elevation model built at a 30x30-pixel size using 20 m elevation contour data. Stream reaches associated with lakes are identified by overlaying reaches with lake boundaries from national topographic datasets.

Stream data held within CLUES for each reach includes stream type (headwater, lake inlet or outlet, terminal reach), Strahler order, length and connectivity as well as sub-catchment boundaries and areas. Mean annual flow rates have been estimated for each reach from surfaces of rainfall, potential evapotranspiration, and empirical relationships between runoff and the ratio of rainfall to potential evapotranspiration (Woods, Hendrikx, et al., 2006). Catchment characteristics required for CLUES (i.e., soil drainage class and slope) were derived from the Land Resources Inventory geo-database (LRI; Newsome et al., 2008). The spatially weighted mean of these parameters was determined for each REC sub-catchment for use in CLUES. .

CLUES represents land use within a sub-catchment by the area covered by each of 19 land use classes representing key rural enterprises, native and exotic forest and urban areas. The areas of each land use type in each sub-catchment is represented in CLUES as a field in a scenario attribute table held in the CLUES geodatbase (see Section 6). The default land use scenario table provided with CLUES 10.3 relates to the baseline year 2008 and was developed with extensive reference to the national Land Cover Database version 3 (LCDB3, Landcare Research ltd, 2013), AgriBase (AsureQuality, 2008 base-line year)[2], and the Land Environments of New Zealand (LENZ, Leathwick et al., 2002) geodatabases. AgriBase and LENZ were used to split the LCDB grassland land covers into pastoral land uses for different stock types that are characterised by different contaminant yields (e.g., lowland intensive, hill country and high country sheep and beef farming) on the basis of a priori knowledge. The LRI, LCDB3 and LENZ databases are available for free download from the Landcare Research web-portal[3]. The CLUES landuse classes are listed in Table 2-3 by LDCB3 land cover groupings. Note that the change from LCDB2 to LCDB3 has resulted in a change in the name of some land use classes compared to earlier versions of CLUES.

Where more recent land use data are available, users are able to create their own land use scenarios, for instance LCDB4 land use data were provided by Waikato Regional Council as part of the Healthy Rivers / Wai Ora programme for a range of modelling exercises including CLUES modelling (e.g., Semadeni-Davies and Elliott, 2014). These data are used in Section 7.2 to illustrate the creation of a land use scenario using an imported land use shapefile.

Estimates of annual nutrient and *E. coli* loads from known point sources (e.g., waste water treatment plants, abattoirs, paper mills) draining to each river reach are used to increase contaminant loads in reaches where sources are located. These data were obtained from monitoring records or estimated from populations and typical wastes' concentrations, as part of the model set up for the SPARROW model (Elliott et al., 2005b) and are regularly updated when new data become available. The most recent update of point sources was for the Waikato Region and was taken from an evaluation of nutrient sources in the Waikato and Waipa River catchments (Vant, 2014)[4].

[2] https://www.asurequality.com/ - date of last access 17 May 2016, Agribase with a baseline year 2008 is used under licence to Agrisure.
[3] https://lris.scinfo.org.nz/ date of last access 17 May 2016
[4] If new or updated data are available for your region, please contact NIWA so that these data can be included in later versions of CLUES.

Table 2-3 LCDB3 land cover groupings and corresponding CLUES land use classes.

LCDB3 land cover groupings	CLUES land use class		Description
	Old codes	New codes	
Grassland	DAIRY	DAIRY	Dairy farming
	SBINTEN	INTENSIV	Sheep and beef: lowland intensive
	SBHILL	HILL	Sheep and beef: hill country
	SBHIGH	HIGH	Sheep and beef: high country
	DEER	DEER	Deer
	OTHER_ANIM	PAST_OTH_A	Other stock types
	TUSSOCK	TUSS_DAIRY	Tussock
	UNGR_PAST	PAST_UNGR	Ungrazed pasture
Cropland	MAIZE	MAIZE	Arable crops (based on maize)
	ONIONS	ONIONS	Vegetables (based on onions)
	POTATOES	POTATOES	Potatoes
	KIWIFRUIT	KIWIFRUIT	Kiwifruit
	APPLES	APPLES	Pip fruit (e.g., apples, pears)
	GRAPES	GRAPES	Viticulture, vineyards
Forest	PLANT_FOR	LC_EXOTIC	Plantation or exotic forest
	NAT_FOR	LC_NATIVE	Native forest
Scrubland	SCRUB	LC_SCRUB	Scrubland
Artificial surfaces	URBAN	LC_URBAN	Urban (note, there are no sub-urban classes)
Other land use types	OTHER	OTHER	Other land covers (e.g., ice, water, bare soil etc.)

Farming stocking rates and fertiliser application rates have been derived from national data (Woods, Elliott, et al., 2006). Stocking rates are defined by the number of units per hectare. Stocking rates are set lower for the South Island compared to the North Island and decrease with increasing slope. Dairy and beef cattle have lower stocking rates than sheep. Default farming stocking rates for each pastoral land use were derived from statistical interpretation of national data (Woods, Elliott, et al., 2006), with representative values for each of five slope classes in each region. These stocking rates can be adjusted by the user, as part of scenario creation.

The CLUES Estuary tool takes nutrient concentrations calculated by CLUES for the terminal river reaches draining to the coast as primary input. Physiographic data was derived from NIWA's Coastal and Water Explorer database (Hume et al., 2007b). The tool also takes seasonally-adjusted oceanic values of nitrate and salt from the CSIRO Australian Regional Seas (CARS) climatology[5] (Ridgway et al., 2002).CLUES outputs can be displayed with other geospatial information to enhance the interpretation of model results and to aid in the development of scenarios.

[5] http://www.marine.csiro.au/~dunn/cars2009/ date of last access 23 December 2014

3 Model outputs

CLUES reports model inputs and outputs in either map or tabular format or both depending on the output variable. This means that CLUES can be used for geo-visualisation as well as to provide model data for further analysis.

3.1 Water quality indicators

The following water quality indicators are estimated by CLUES for each REC river reach selected in a model run.

Mean annual in-stream loads

In-stream loads are the cumulative loads calculated for the downstream node of a river reach. The loads are calculated as the sum of upstream loads and loads from the river reach sub-catchments less reservoir decay for reaches classed within CLUES as a lake reach. In-stream loads are available in maps displays as well as in tabular form. The loads calculated are:

- Nutrients – TN and TP (t/year);
- Sediment – TSS (kt/year); and
- *E. coli* (10^{15} or one "peta" of organisms/year).

Summer nutrient flux ratios

The summer TN and TP flux ratio are provided to allow users to estimate the summer-time nutrient loads. The summer-time loads can be calculated by multiplying the annual load by the relevant flux ratio. The flux ratios are found only in the model outputs summary table.

Median annual in-stream concentrations

Annual median concentrations (mg/m^3) of TN and TP are estimated by determining flow-weighted concentrations from the modelled mean nutrient load and mean annual flow rate, and then converting these to median concentrations using a conversion ratio of mean to median flows that is obtained from regressions against catchment characteristics (Elliott and Oehler, 2009; Oehler and Elliott, 2011). Similarly the flux of TN in summer, which is relevant to seasonal eutrophication potential in estuaries, is determined as a ratio of the mean annual flux (Elliott et al., 2014). The nutrient concentrations are available in map displays as well as in tabular form.

Concentrations are not determined for sediments or *E. coli* as there is insufficient data for these contaminants available around the country to determine the statistical relationships required.

Mean annual cumulative yields

The mean annual cumulative yield is the in-stream yield for a particular reach and represents the total yield for that reach and its up-stream tributaries. It is calculated as the mean annual in-stream load divided by the upstream area. The cumulative yields are calculated for TN and TP (kg/ha/year) and are available in maps displays as well as in tabular form.

Mean annual generated yields

The mean annual generated yield is the yield generated by each specific sub-catchment, that is, the sum of the loads calculated for all the land uses found in the river reach sub-catchment divided by the sub-catchment area. This information can be used to identify those sub-catchments that are acting as contaminant sources. Generated yields are available in map displays as well as in tabular form. The generated yields calculated are:

- Nutrients – TN and TP (kg/ha/year);
- Sediment – TSS (t/ha/year); and
- *E. coli* (peta of organisms/ha/year).

3.2 CLUES Estuary

The CLUES Estuary model provides estimates of long-term mean annual TN and TP concentrations. The outputs of the model are available in the sub-catchment ID table under the Estuary tab.

3.3 Social-economic indicators

The following socio-economic indicators are estimated by CLUES for each REC river reach selected in a model run. All the socio-economic indicators are cumulative values, that is, they take into account the catchment area upstream of the sub-catchment reported.

Economic Indicators:

Economic indicators relate the costs and revenue of rural enterprises including farming and forestry.

- Revenue ($/year), revenue is calculated on the basis of returns per stock unit or cow, and for other sectors on a per ha basis.
- Farm expenses (FE; $/year), for pastoral land, farm expenses are calculated as the sum of fixed costs per ha and variable costs per stock unit. Expenses for other agricultural land used are calculated with single expenses/ha. Forestry calculates silviculture and harvest costs by land class, and transport costs by distance to nearest price point.
- Cash flow surplus (CFS; $/year), output from the land use after farm working expenses have been deducted, but before interest, leases, wages of management, and capital expenditure. CFS is used an indicator of on-farm welfare. It should not be taken as a direct measure of on-farm welfare.
- Total gross domestic product (GDP, $/year), an estimate of the total value arising from the farming, horticulture, and pine plantation land uses. GDP is calculated using regional multipliers.
- On-farm Full-Time Equivalent (FTE), the degree of employment, based on the proportion of a 40-hour week, work associated with the agricultural land use.
- Total FTE, Full Time Equivalent employment is estimated using regional multipliers. This amalgamates part- and full-time jobs based on the proportion of a 40-hour week worked.

Energy Indicators

Energy indicators give estimates of the amount of total energy and fossil fuels used by each rural enterprise and the energy produced by the enterprise.

- Fossil fuel (GJ/year), the amount of fossil fuel used in the land use and in the rest of the regional economy that links to that land use. Based on regional multipliers.

- Total energy use (GJ/year), the amount of total energy used in the land use and in the rest of the regional economy that links to that land use. Based on regional multipliers.

- Energy produced by farm (GJ/year), the farm energy output is the amount of energy embodied in the product from that land use. For instance the protein and fat in milk solids is converted to an energy equivalent. This uses standardised estimates of product energy content per dollar revenue for each land use, multiplied by the revenue per ha.

- Protein (t/year) farm protein output, the amount of protein embodied in the product from that land use. This uses standardised estimates of product protein content per dollar revenue for each land use, multiplied by the revenue per ha.

Greenhouse Gas Indicators

Greenhouse gas indicators estimate gas emissions for farms.

- Direct greenhouse gas emissions (GHG; CO_2 equivalent, t/year), the farm greenhouse gas output is estimated using the greenhouse gas generated per unit output from Overseer.

- Total greenhouse gas emissions (CO_2 equivalent, t/year) in the regional economy are linked to the land use and estimated from regional multipliers.

Infrastructure and Quality of Life Indicators

These indicators estimate the government revenue used to provide the infrastructure that supports rural enterprises.

- Government Revenue ($/ha/yr), an indicator of changes in infrastructure and quality of life which uses standard multipliers for central and local government from regional input-output (IO) tables.

- Total activity in the transport sector ($/ha/yr), transport expenditure changes throughout the economy associated with a particular land use, this indicator uses standard multipliers for central and local government from regional IO tables.

3.4 Types of output reporting

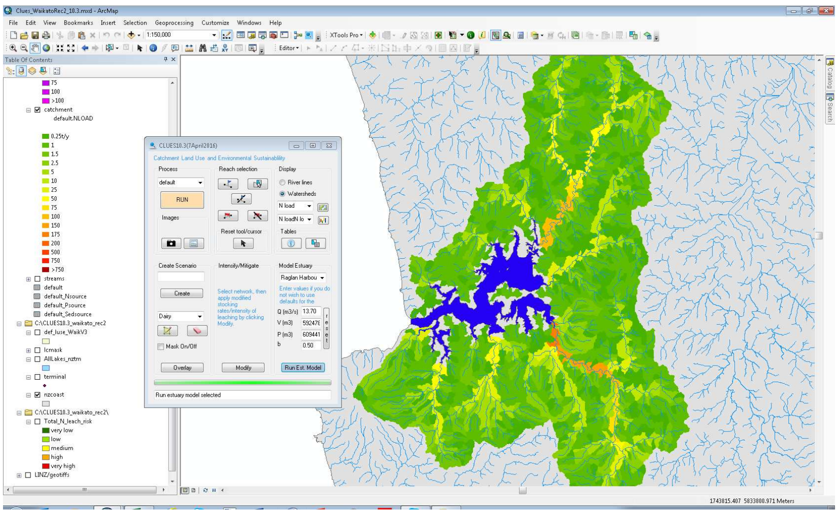
CLUES outputs are available as maps and tables, examples of these are given below for the default land use scenario. Instructions for displaying CLUES outputs are given in Section 9.

3.5 Maps

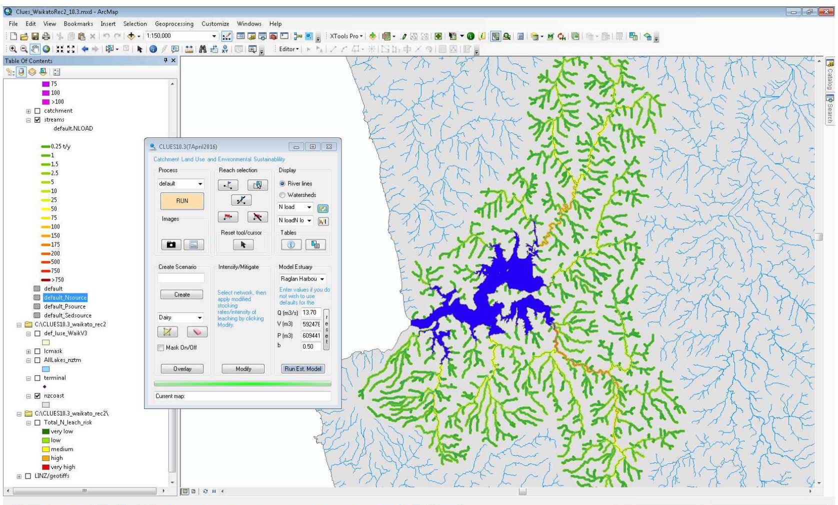
Three types of map display are available for water quality outputs, these are listed and illustrated below. The symbology for CLUES maps are automatically updated in the ArcGIS table of contents (TOC) for the Stream (river line maps) or Catchment (watershed and bar chart maps) feature classes. The water quality indicator mapped is given in the CLUES status bar at the bottom of the CLUES interface.

Watershed and river lines maps

Watershed maps automatically join the Catchment feature class to the scenario table for the selected scenario. River line maps automatically join the Stream feature class to the scenario table for the selected scenario. The example in Figure 3-1 shows default TN loads estimated for the streams draining to Raglan Harbour mapped using the watershed (top) and river lines (bottom) mapping options.



Watershed



River lines

Figure 3-1: Default TN loads for Raglan Harbour shown as a watershed (top) and river line (bottom) map.

Bar charts

Bar chart maps are used to compare the outputs of a user created scenario against the outputs estimated for the default scenario. This example (Figure 3-2) shows the output of a land use sketch scenario that has converted all land uses for catchments draining to the north of Raglan Harbour catchment area to intensive sheep and beef farming (see Section 7.1).

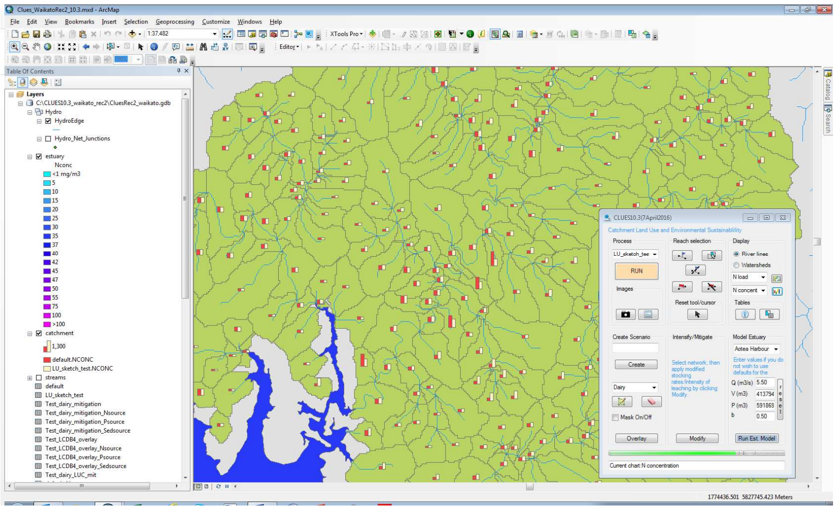


Figure 3-2: Bar chart map showing change in TN concentrations simulated with default land use and all land use changed to intensive sheep and beef farming to the north of Raglan Harbour.

3.6 Tables

CLUES 10.3 provides three types of tables that can be used to summarise model results and, where new scenarios have been created, compare the outputs of these scenarios against the default scenarios.

ID table tool

The ID table tool is used to display all the indicators estimated by CLUES for a specific REC sub-catchment or estuary selected by the user. The table has separate tabs for the water quality, socio-economic and estuary indicator output sets (Figure 3-3).

Model summary table

Model summary tables show model outputs for each reach simulated in a model run (Figure 3-4). Users are able to select which results they want summarised. The tables are saved as text files and can be exported to other applications for further analysis or display.

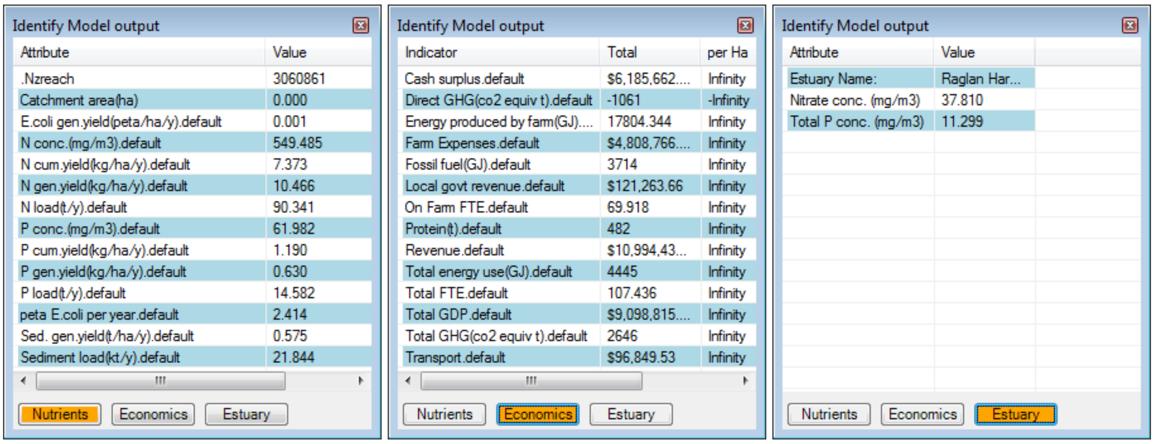


Figure 3-3: Sub-catchment summary table showing the default water quality and socio-economic and estuary indicators. The water quality and socio-economic indicators have been estimated for REC2 reach 3060861; the estuary indicators are for Raglan Harbour.

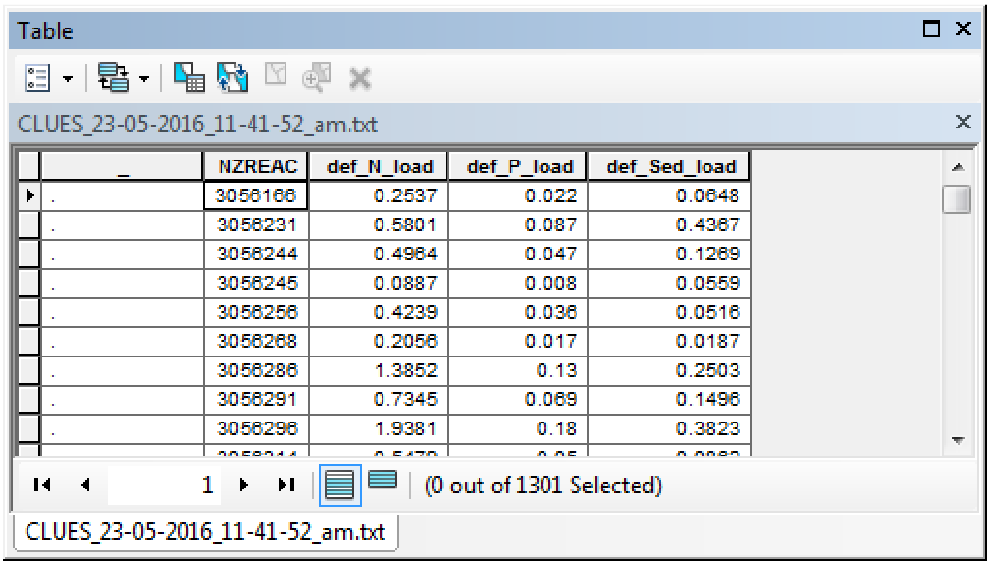
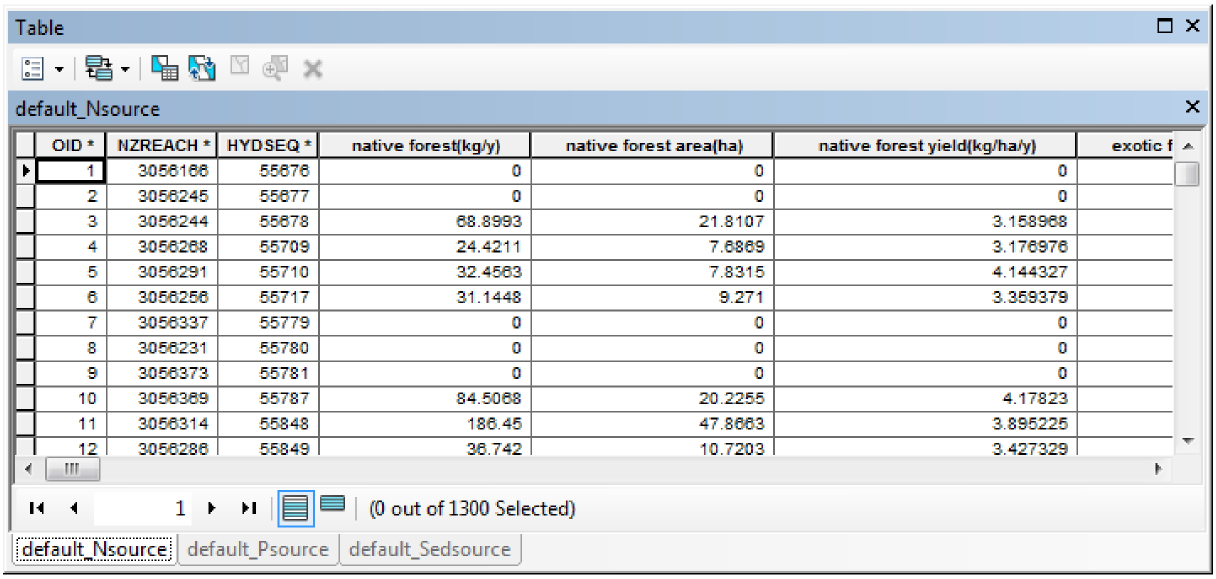


Figure 3-4: Model summary table showing user selected default outputs (TN, TP and TSS loads) for each reach simulated in a model run.

Contaminant tracing tables

Contaminant tracing tables were added to CLUES in 2015 as part of an Envirolink project for Tasman District Council (Semadeni-Davies et al., 2015) and are returned for each of TN, TP and sediment. No table is produced at this stage for *E. coli*. These tables contain the generated and cumulative loads and yields estimated for each corresponding contaminant by an aggregated land use class for all the REC reaches selected for the model run. For each land use class and REC sub-catchment, the tables provide two sets of results; these are the sub-catchment generated and cumulative (instream) loads, areas and yields, respectively. An example of a summary table is given in Figure 3-5.



Table

default_Nsource

OID *	NZREACH *	HYDSEQ *	native forest(kg/y)	native forest area(ha)	native forest yield(kg/ha/y)	exotic f
1	3056166	55676	0	0	0	
2	3056245	55677	0	0	0	
3	3056244	55678	68.8993	21.8107	3.158968	
4	3056268	55709	24.4211	7.6869	3.176976	
5	3056291	55710	32.4563	7.8315	4.144327	
6	3056256	55717	31.1448	9.271	3.359379	
7	3056337	55779	0	0	0	
8	3056231	55780	0	0	0	
9	3056373	55781	0	0	0	
10	3056369	55787	84.5068	20.2255	4.17823	
11	3056314	55848	186.45	47.8663	3.895225	
12	3056286	55849	36.742	10.7203	3.427329	

1 (0 out of 1300 Selected)

default_Nsource default_Psource default_Sedsource

Figure 3-5: TN tracing table for the default scenario showing the contributions to sediment loads for each REC reach simulated in the model run by land use class.

Due to the way in which CLUES has been parameterised, the tables for the different contaminants are slightly different with regard to the land use classes they contain with some land uses being aggregated in the tables.

The contaminant tracing tables have been provided to allow users to determine the estimated contaminant load from each land use within each sub-catchment and to track loads originating from a particular land use downstream. This means that users can identify which land uses have the most impact on the estimated load within each sub-catchment and down the stream network. This information in turn can be used to support catchment scale mitigation planning – that is, which land uses should be targeted and in which sub-catchments to obtain the greatest reduction in contaminant loads at different points along the catchment.

More information about the tables and the information they contain can be found in Appendix C.

4 Getting started

4.1 System requirements

You will need the following to install and run CLUES 10.3:

- PC with the Windows 7 or Windows 10 operating systems;
- ESRI ArcGIS v. 10.2.2 or 10.3.1 (either the ArcEditor / Standard or ArcINFO / Advanced versions of ArcGIS is required to run CLUES under the Windows 10 environment);
- At least 2 GB RAM;
- Web connection (optional for display of ESRI World Imagery basemaps)

4.2 Downloading CLUES software and regional databases

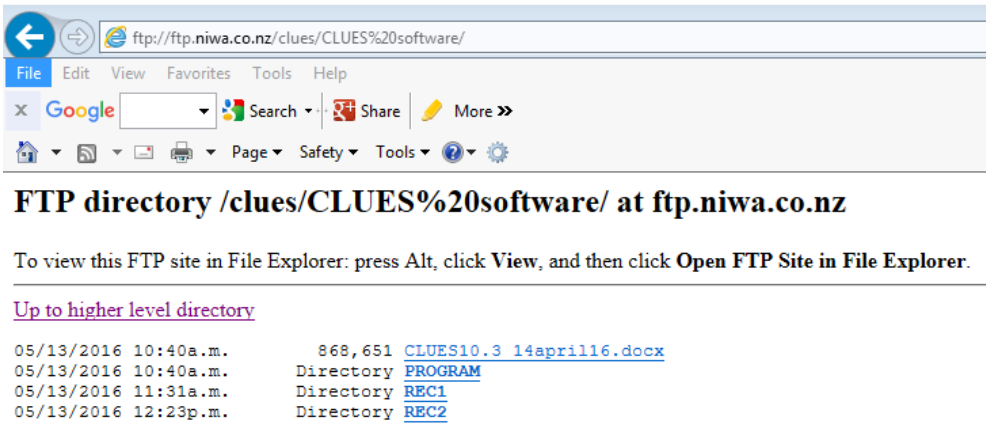
The software and geospatial data needed to run CLUES are provided to users free of charge for non-commercial uses and can be downloaded from the NIWA at:

ftp://ftp.niwa.co.nz/clues

The terms and conditions for CLUES use set out in the licencing agreement appended to this document (Appendix A). Downloading or using CLUES implies that the user has read and agreed to the licencing agreement.

Note that CLUES is available for either ArcGIS 10.2.2 or ArcGIS 10.3[6] and with the REC1 or REC2 stream network databases. Future updates and maintenance for CLUES 10.3 will be carried out only for ArcGIS 10.3 with the REC2 stream network. This manual has been prepared using ArcGIS 10.3 with the REC2 regional database for Waikato.

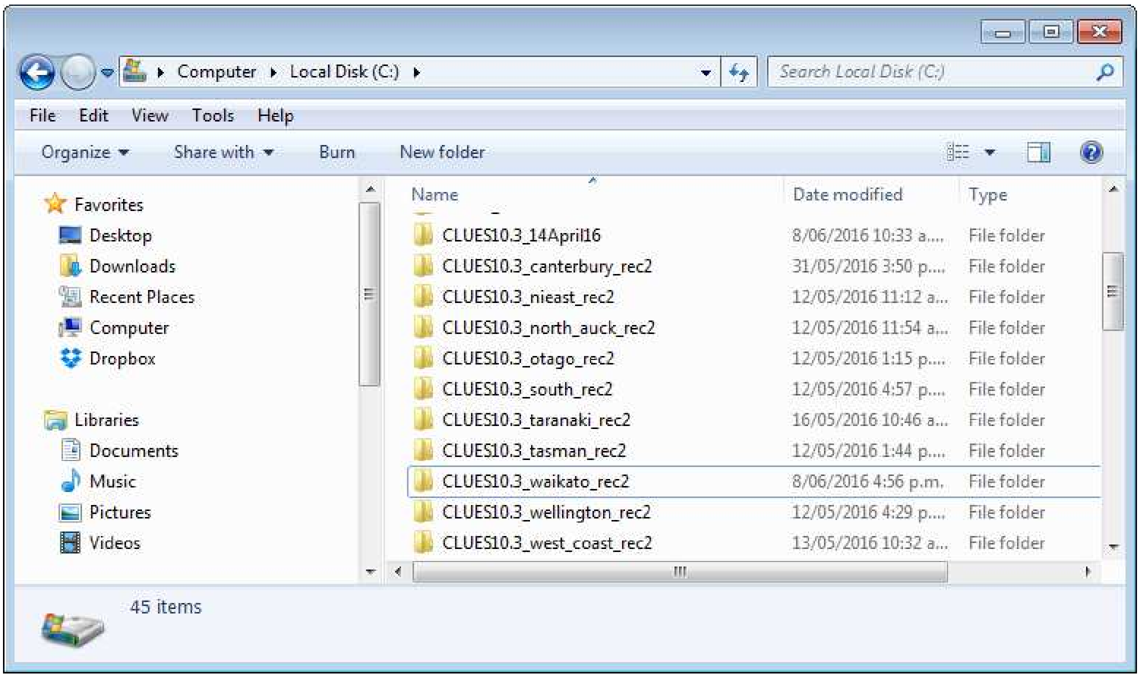
1. Navigate to the CLUES software directory under the ftp site



2. Open the program directory and select the version of CLUES 10.3 compatible with the version of ArcMap you are currently using and double click on the zip file contained in the directory to download. You will need to extract the zipped CLUES program directory of your choice to your local drive (e.g. C:\CLUES10.3_14April16).

[6] CLUES for ArcGIS 10.3 will also work with ArcGIS 10.3.1

3. Navigate back to the CLUES software ftp site and open either the REC1 or REC2 directory depending on your choice of stream network database. Double click on the directory for you region to download. Again, the zipped directory will need to be extracted into your local drive (e.g., C:\CLUES10.3_waikato_rec2). Note that some regional directories may have a shell directory around the regional directory, if this is the case, save only the inner directory to your local drive.

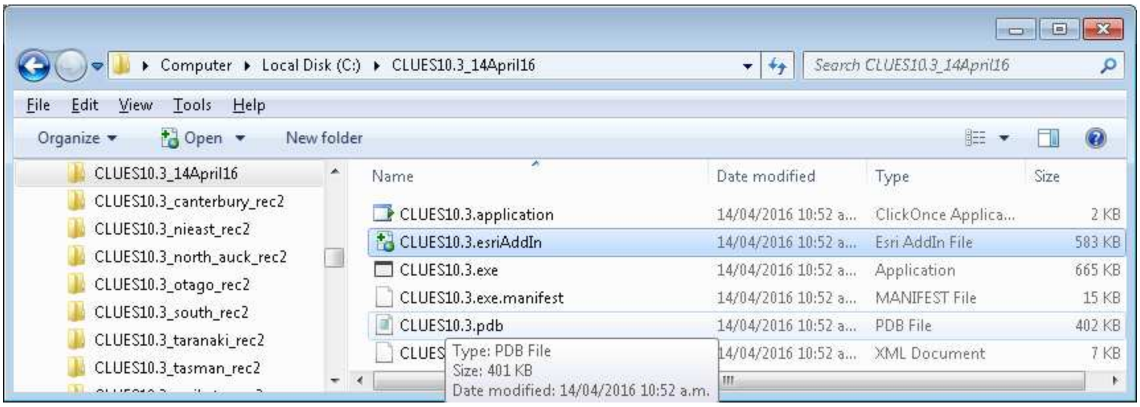


4.3 CLUES Installation

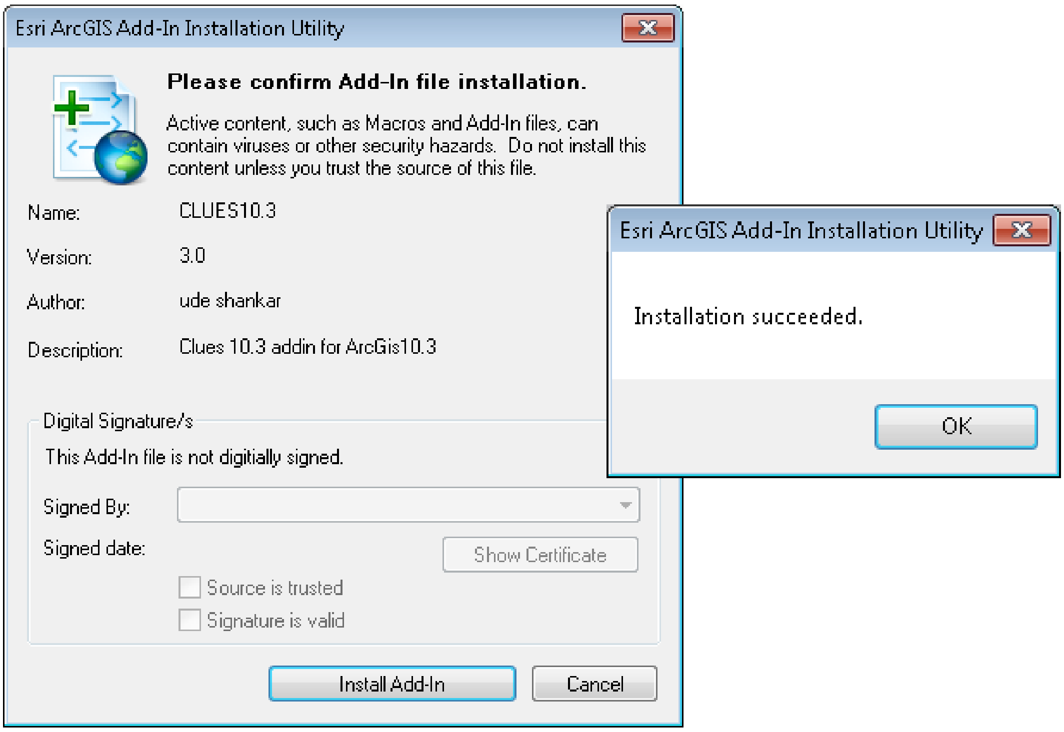
1. Remove any older versions of CLUES from ArcGIS following the instructions in Section 4.4 and close ArcGIS.

2. Open the CLUES software folder that you have downloaded and extracted into your local drive.

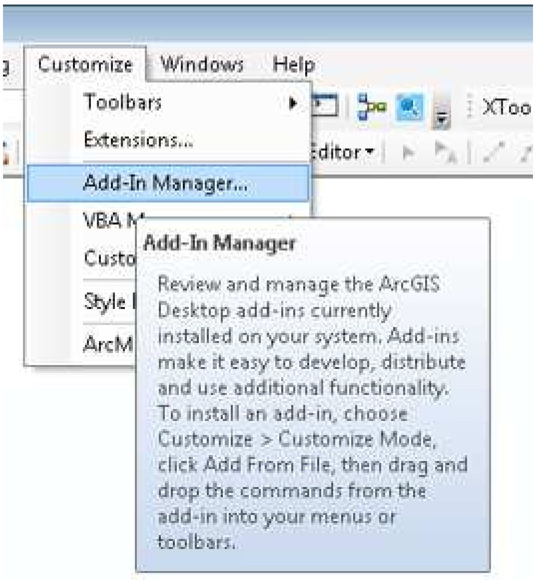
3. Double click on the Esri AddIn File for CLUES (CLUES10.3.esriAddIn).



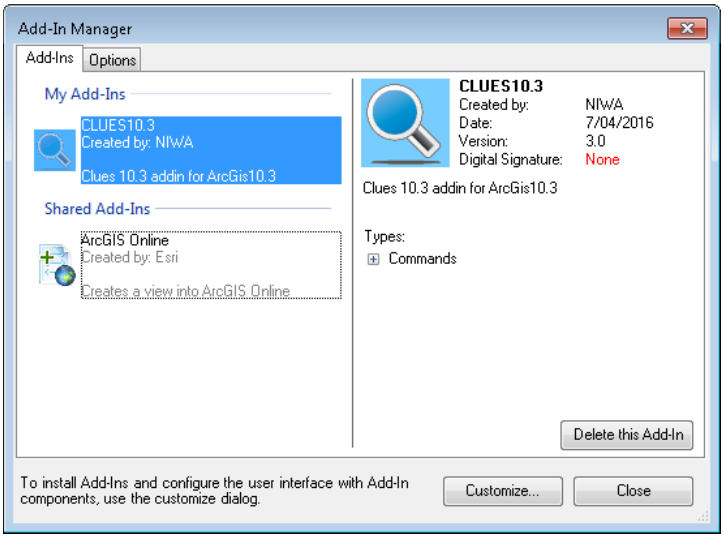
4. Click on the Install Add-In button and confirm the installation.



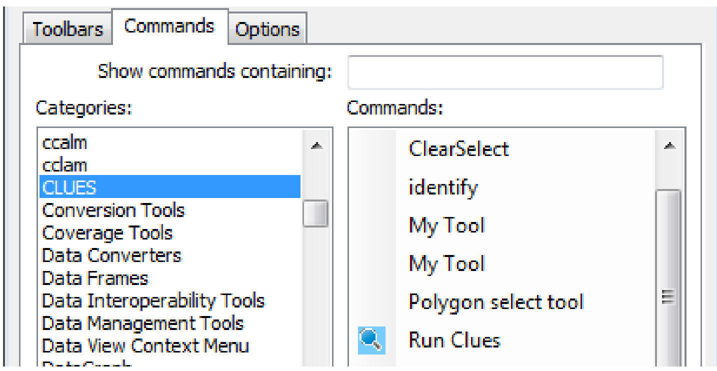
5. Open ArcGIS with a blank map document and click on the Add-In Manager box under the Customize menu



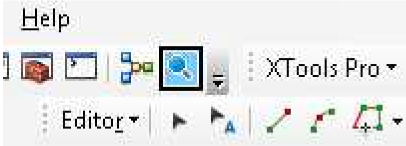
6. CLUES should be shown as an Add-In.



7. Click on the Customize button and open the Commands tab. Scroll down to CLUES under the Categories list and select CLUES. This will show the CLUES toolbar magnifying glass icon.



8. Click and drag the icon up onto the ArcGIS toolbar.



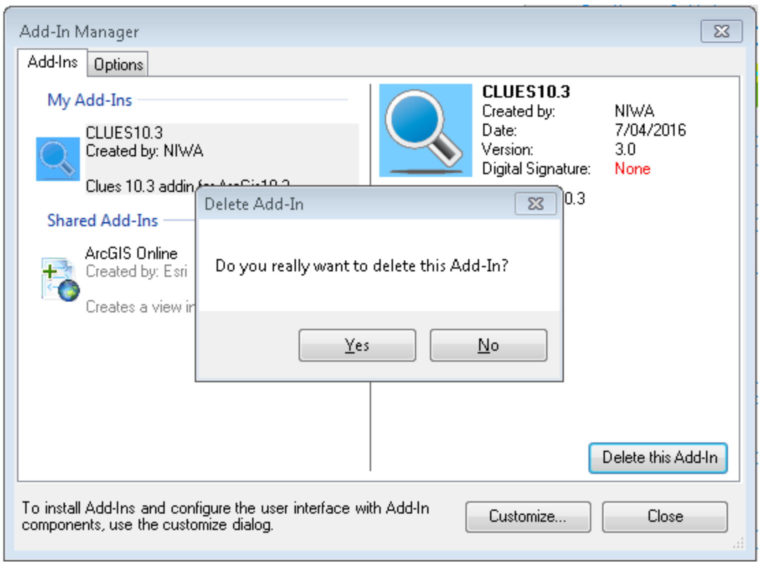
Close the dialogue box. CLUES is now ready to run. Open a CLUES map document. Double clicking on the icon will open the CLUES interface (see Section 4.6).

4.4 Uninstalling CLUES

It is best practice to remove any older versions of CLUES when updating your CLUES software.

1. Open the Add-In Manager box under the Customize menu

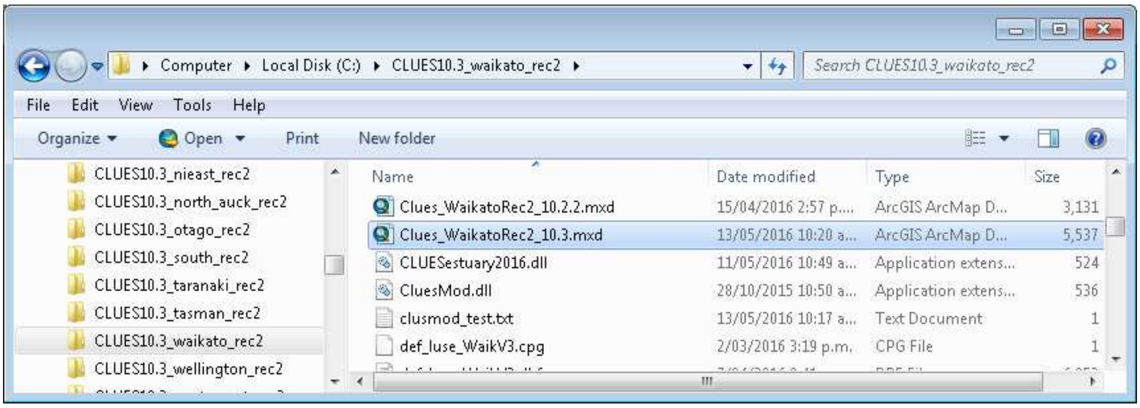
2. Highlight the CLUES add-in and click the Delete this Add-In button and confirm the deletion.



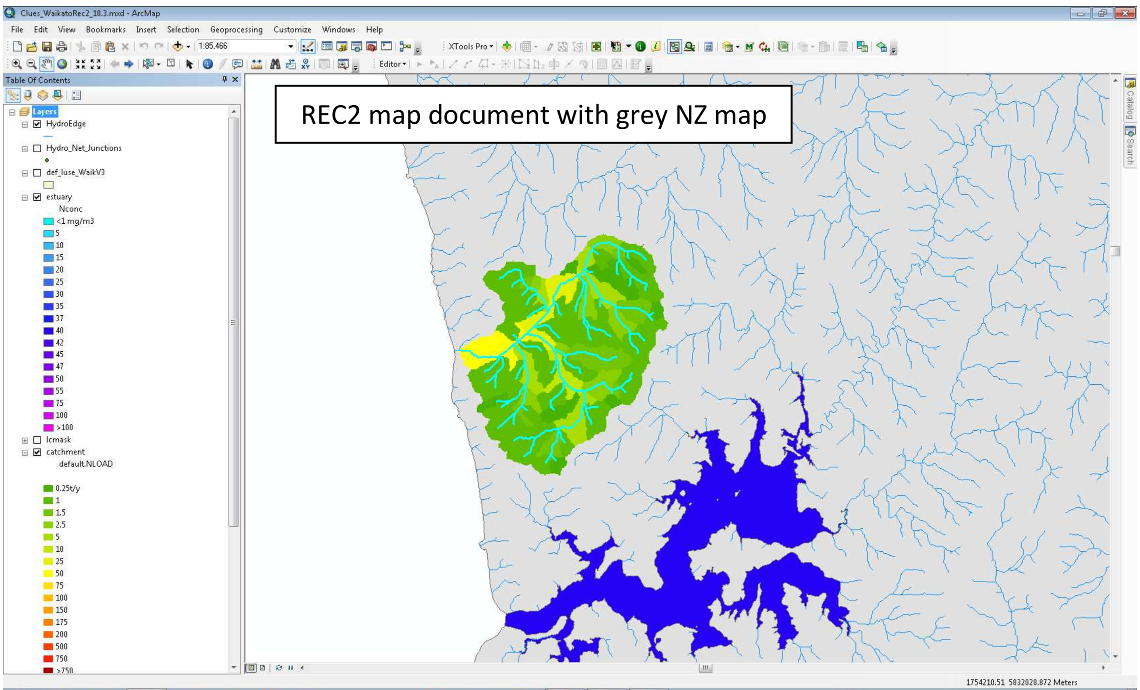
3. While CLUES will no longer be installed as an Add-In, but the CLUES icon will still be visible on the toolbar. To remove the icon, click the Customize button and select the Commands tab. Click and drag the CLUES icon onto the Customize box. Close the box.

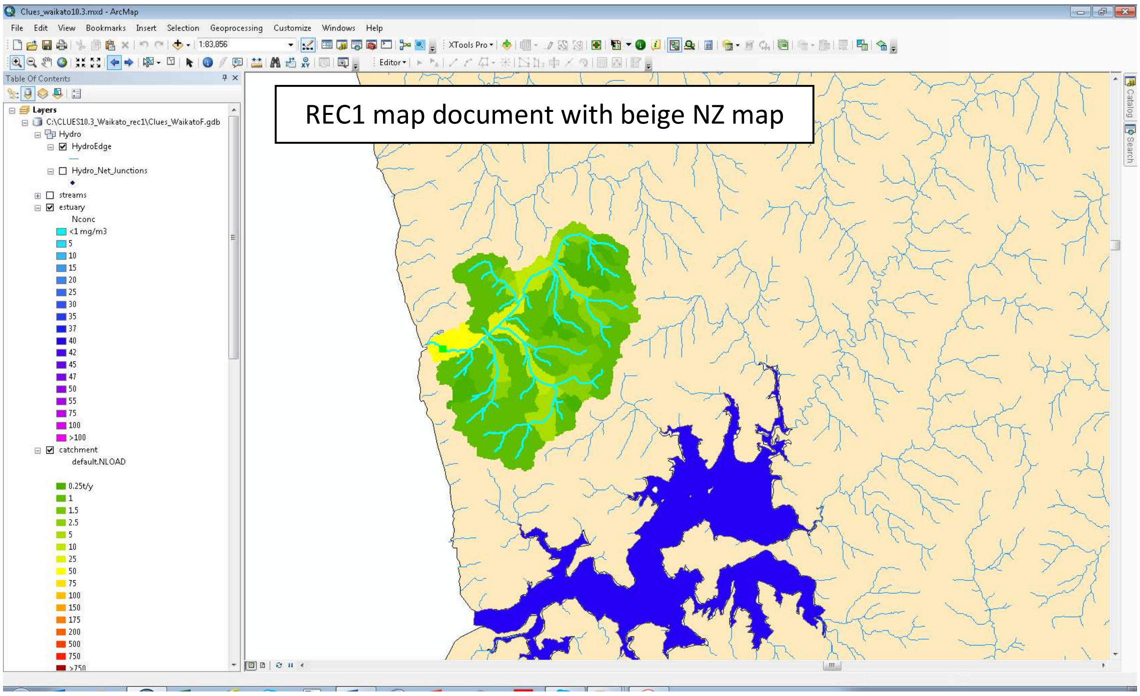
4.5 Map documents

1. Map documents (mxd files) can be opened within ArcGIS or Windows Explorer (recommended). Navigate to the downloaded regional directory that has been saved in the local drive. Select and open the map document compatible with either ArcGIS 10.2 or 10.3. Here, the REC2 Waikato map document for ArcGIS 10.3 is opened in Windows Explorer.

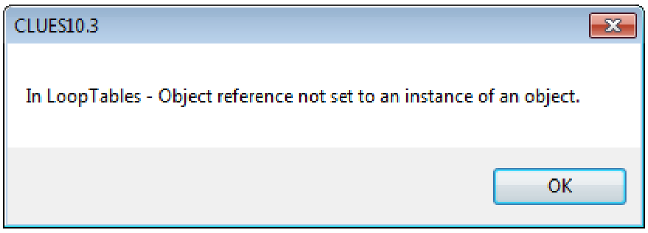


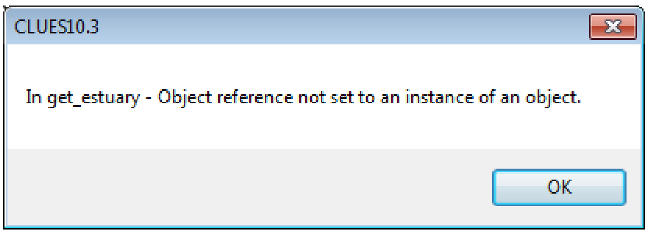
2. Note that the map document will show the results of the previous run. The first time the map document is opened, the results of a test run carried out before CLUES was uploaded to the ftp site will be displayed. Thereafter, the map document will display the results of the last model run in the previous session each time it is opened. Note the NZ coast symbology is grey for REC2 version of the map document and beige for the REC1 version.

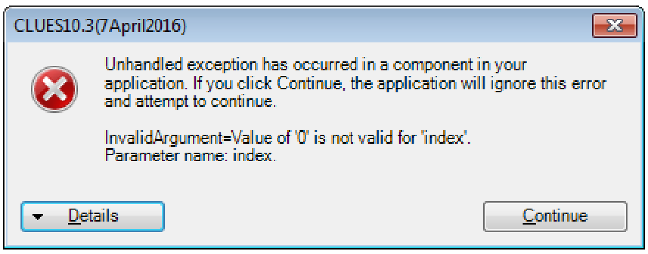




Once the map document is open, double clicking the CLUES icon on the ArcGIS toolbar will open the CLUES interface (see Section 4.6). CLUES will not run if there is no regional map document open, in which case, the following messages will appear before the interface is displayed.







3. Other feature classes can be added to the map document for display or to inform the development of scenarios without affecting CLUES.

4.6 User Interface

Double clicking on the CLUES icon will bring-up the CLUES 10.3 interface. The interface is split into sections, shown in Figure 4-1, according to function. The interface icons are listed in Table 4-1.

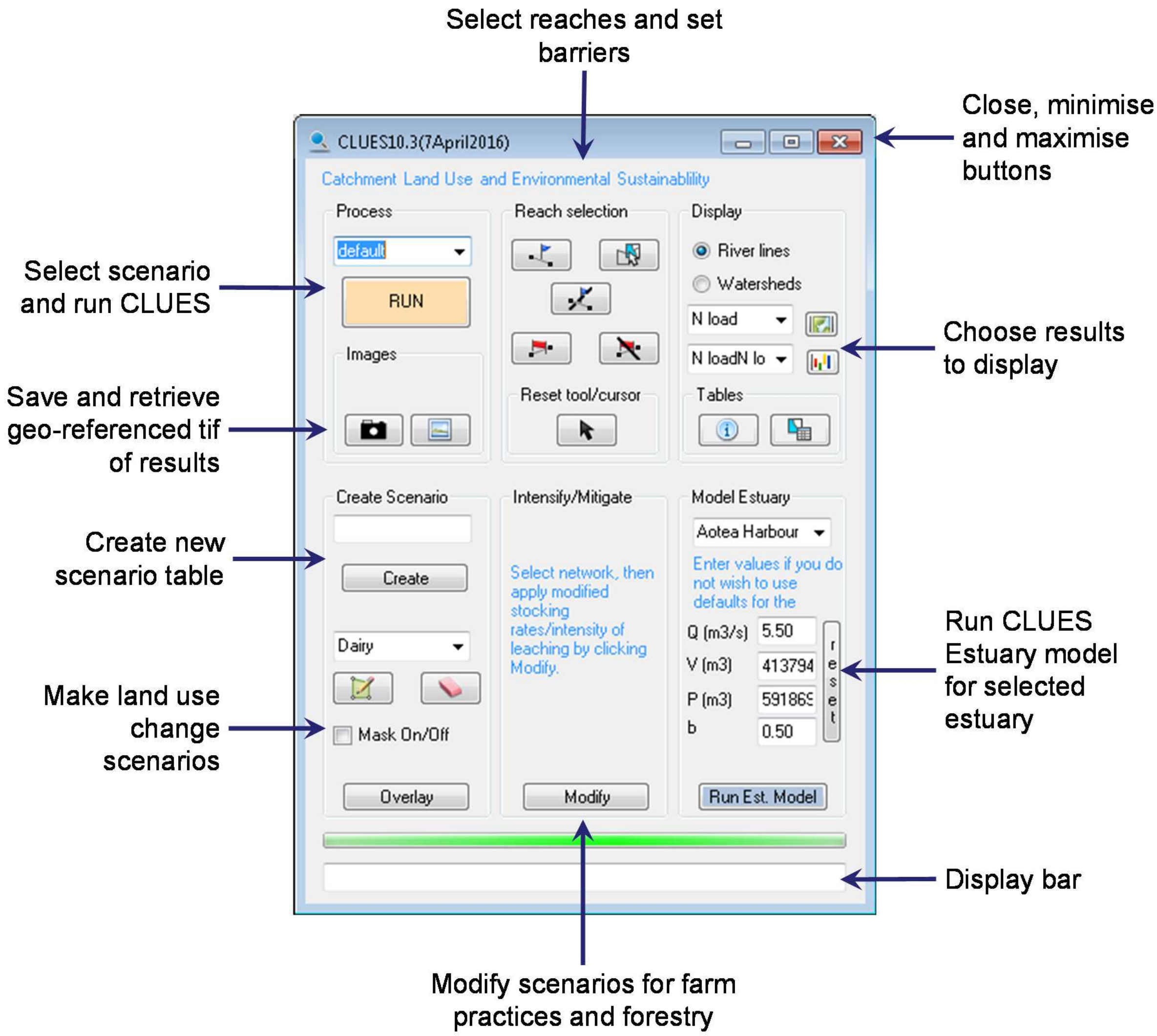
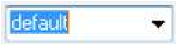
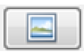
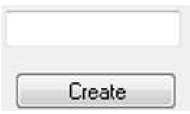


Figure 4-1: The CLUES interface.

4.7 CLUES geo-database feature classes

The feature classes supplied with the geodatabase that are listed on the TOC are described in Table 4-2 below. They consist of both geodatabase (gdb) files and shapefiles. All the feature classes have NZTM2000 projection. The two versions of the REC have different stream network and catchment feature classes albeit with the same names. While the REC1 and REC2 data sets may have different layouts and field headers, the core catchment data needed to run CLUES are provided in each. In addition to these feature classes, users can add ESRI basemaps or their own spatial data to the map document display.

Table 4-1: List of icons on the CLUES interface.

Tool	Function
	Scenario selection drop-down menu
	Run CLUES for selected reaches and scenario
	Reach selection flag tool
	Catchment (terminal reach) polygon selection tool
	Remove selection
	Barrier flag, removes all upstream reaches from selection
	Remove barriers
	Reset cursor from selection mode – same as arrow tool on the ArcGIS toolbar.
	Map type selection radio buttons
	Result selection drop-down menu and map display button
	Result selection drop-down menu and bar chart display button
	Reach summary table, shows all results for selected reach or estuary
	Result summary table, shows selected results for all reaches modelled
	Imaging tool: creates a geo-referenced Tagged Image Format (tif) file of the displayed map results
	Add a saved geo-referenced .tif file to the display
	Name and create a new scenario table
	Land use drop-down menu for creation of land use sketch scenarios
	Make a land use polygon for sketch scenario
	Remove land use sketch polygons
	Land use sketch mask display control

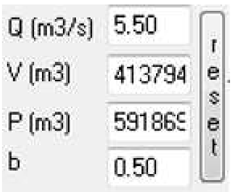
Tool	Function
	Open dialogue box to overlay new land use data onto the selected scenario
	Open dialogue box to modify yields to simulate changes in stocking rates or mitigation (i.e, farm practices) or sediment yields associated with forestry.
	Estuary drop-down menus – selects estuary and all contributing catchments
	Manual override for CLUES estuaries parameters and reset default parameters button. Q = mean annual flow into estuary V = estuary low water volume P = tidal prism volume b = return flow fraction
	Run CLUES estuaries for selected estuary and scenario

Table 4-2: Feature classes supplied with the CLUES geodatabase. Active feature classes contain data that are used in CLUES calculations, reference feature classes are provided for geo-visualisation and are not used by CLUES. The table states whether the data are displayed (On) or not (Off) in the map document.

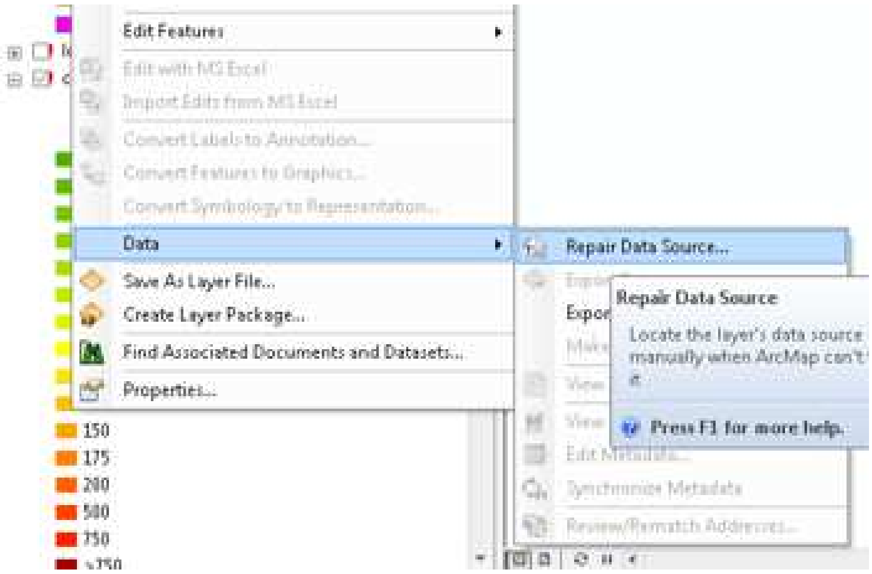
Feature Class Name	Type	Description	Status
HydroEdge	gdb line feature class	REC stream network data.	Active / On
Hydro_Net_Junctions	gdb point feature class	Stream reach nodes.	Active / Off
Estuary	gdb polygon feature class	Estuary model results	Active / On
Catchment	gdb polygon feature class	REC reach sub-catchments. Joined to selected scenario table for watershed or bar chart display	Active / automatic*
Streams	gdb line feature class	REC reaches. Joined to selected scenario table for riverlines map display	Active / automatic*
def_luse_*region*	Polygon shapefile	Default land use as a percentage area for each REC sub-catchment	Reference / Off
lcmask	Polygon shapefile	Land use sketch polygons created by user for overlay	Active / Off
AllLakes_nztm	Polygon shapefile	Lakes larger than 1 ha	Reference / On
terminal	Point shapefile	End nodes of terminal coastal (mouth) reaches	Active / Off
nzcoast	Polygon shapefile	NZ outline map. Shown in grey for REC2 map document and beige for REC1	Reference / On
Total_N_leach rate	Raster file	Landcare Research ENSUS nitrogen leaching risk map	Reference / Off

*Display is dependent on user map display choice.

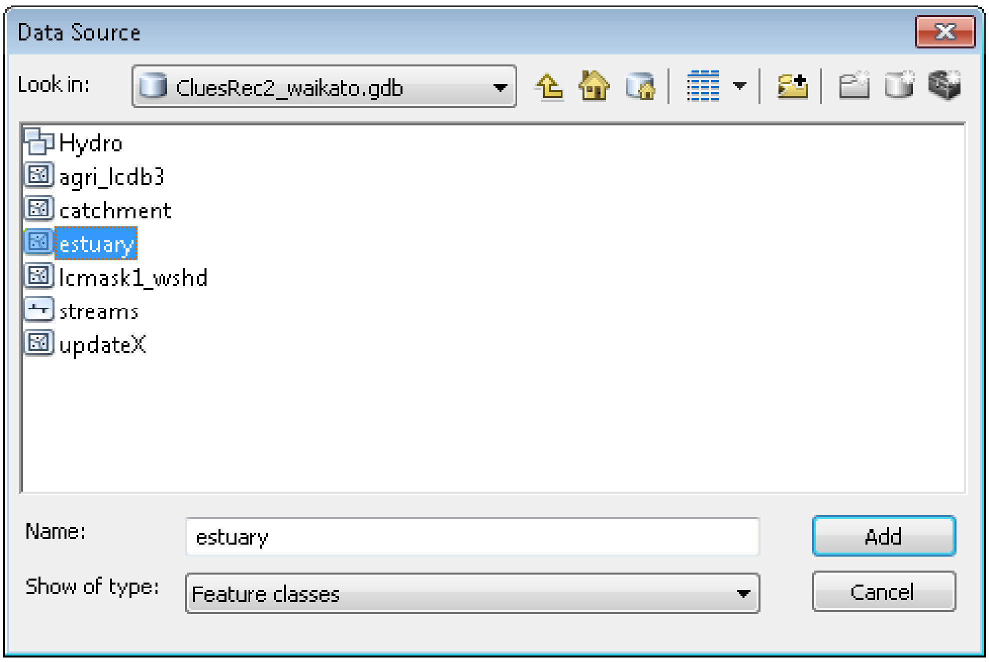
4.7.1 Repairing links

Sometimes the links between CLUES feature classes and their shapefiles / geodatabase files may be broken during the file transfer so that the map appears to be blank. The files with a broken links will have a ! next to them in the TOC. It is easy to repair these links.

1. Right click on any one of the feature classes under the TOC that is marked with a !. In the example, the estuary feature class has been selected. Click on *Repair data source* under the *Data* menu.



2. Click on the home button to navigate to the correct folder for the map document and find the data source file for your selected feature class. Note that the estuary, catchment and streams feature classes are found in the geodatabase and that HydroEdge is located under the Hydro feature class group within the geodatabase.



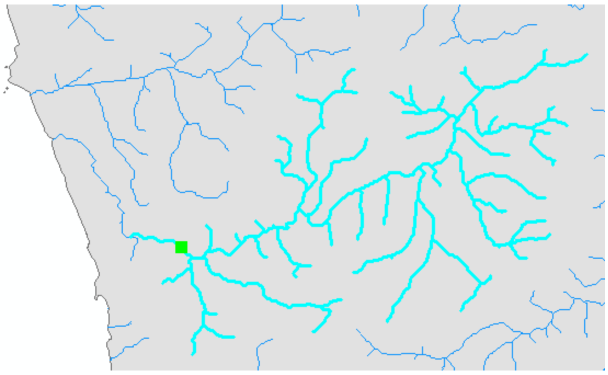
Select the relevant file source and click Add; all the feature class links in the mxd should now be fixed.

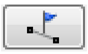
5 Basic functions

This section demonstrates how to select reaches and run CLUES for the default land use scenario.

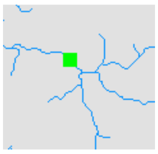
5.1 Flag selection tools

1. The reach flag selection tool is used to select single or multiple stream reaches. Click on the icon and select a reach by moving the + curser over the reach and double clicking. Note that CLUES automatically selects all reaches upstream of the selected reach in the HydroEdge feature class. The point of selection is marked by a green tag.

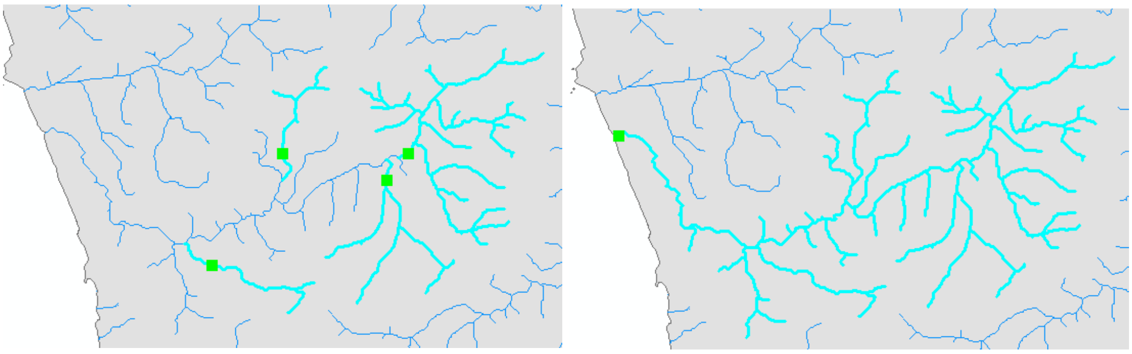




2. Clicking on the remove selection icon on the ArcGIS Tools toolbar will remove the highlighting, but the selection will remain saved in CLUES.



3. The flag tool can be used to select multiple reaches and selecting a terminal reach (mouth) of a stream will select the entire catchment.



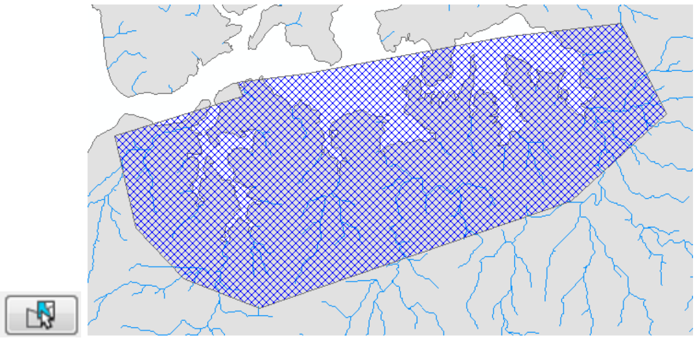
4. CLUES selections will remain in CLUES temporary memory during a GIS session, but will be removed from memory when ArcMap is closed. Clicking on the remove flag selection tool will remove the selection from CLUES.

5. To reset the cursor, click the  icon which can be found both on the CLUES interface and on the ArcGIS Tools toolbar.

5.2 Polygon selection tool

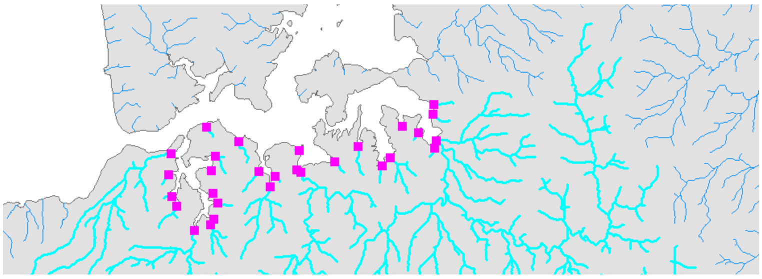
The polygon selection tool is used to select catchments by selecting coastal terminal reaches (i.e., river mouths). Multiple catchments can be selected by drawing a polygon over a section of coast. In this example, the tool is used to select the streams draining to the southern part of the Raglan harbour. Note that the Estuary feature class has been unchecked to remove it from the map display.

1. Click on the polygon selection tool and navigate the cursor to the coastal area you want to select. In this example, the tool is used to select the streams draining to the southern part of the Raglan harbour. Click around the area to be selected. Double click when the polygon is complete.



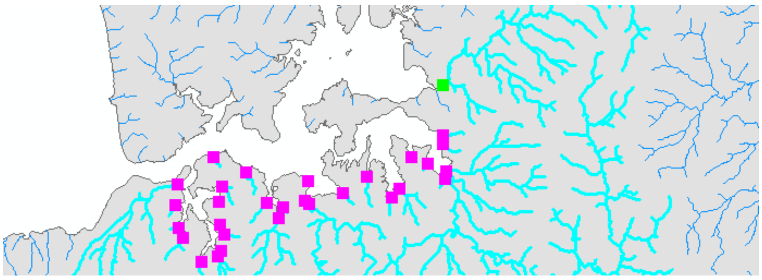
Note that the Estuary layer has been unchecked to remove it from the map display.

2. All the terminal reaches within the polygon will be selected and marked with a magenta tag.



3. Clicking on the remove flag selection tool will remove the selection.

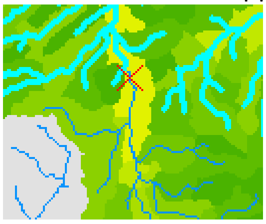
4. You can use both the polygon and flag tools to select multiple reaches. Here, the Ohautira Stream (green tag) has been added to the polygons selected above using the flag tool.



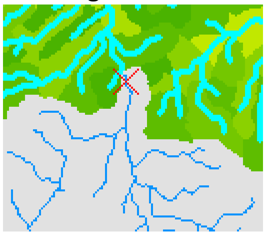
5.3 Adding barriers

Sometimes it is useful to place a barrier in CLUES that will restrict the model's reach selection. The barrier tools are also useful for creating land management scenarios.

1. Click the red flag barrier button and move the cursor to the reach where the barrier is to be placed. Click on the reach. The reach and all its upstream tributaries will be removed from the selection. A red cross will appear on the reach. Barriers can be placed on multiple reaches

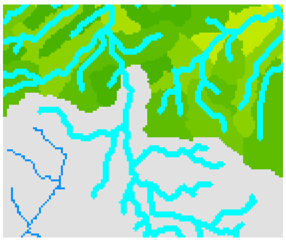
    

2. Running CLUES will remove the reaches upstream of the barrier from the simulation.

3. To reset the cursor, click the  icon which can be found both on the CLUES interface and on the ArcGIS Tools toolbar.

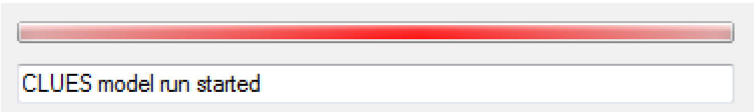
4. To remove barriers, click on the remove barrier button, this will add the reach and its upstream tributaries back to the reach selection.

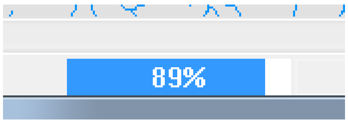
    

5.4 Running CLUES

To run CLUES for the default land use supplied with the regional geodatabase, select the reaches to be simulated using the instruction above and click the Run button.

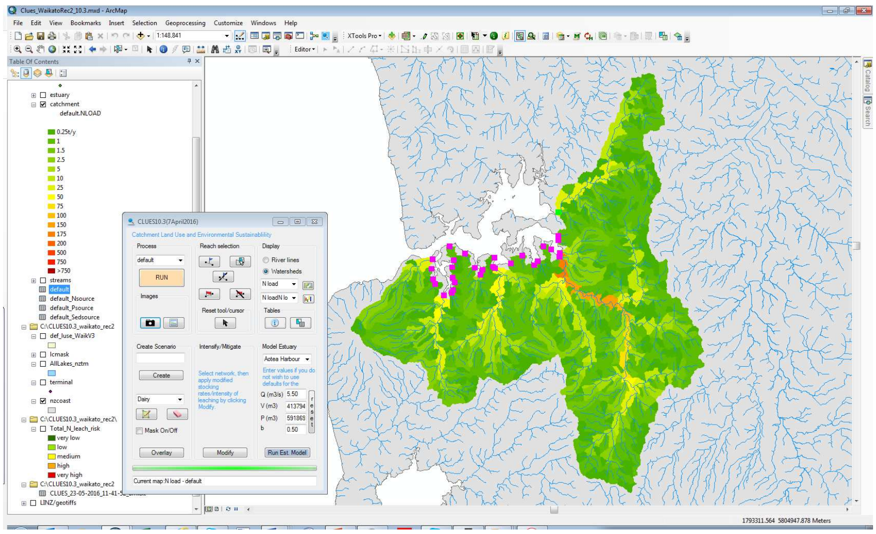
It may take several minutes for CLUES to run depending on the number of reaches to be simulated. The green progress bar at the bottom of the CLUES interface will show turn red and the model's progress will be indicated at the bottom of the ArcMap window.





Once the run is complete, the model outputs for TN loads will be displayed as a watershed map. See Section 9 for instructions on how to view other model outputs.

Note that CLUES automatically updates model outputs for a specific scenario each time the model is run with that scenario. This means that if CLUES is run for different catchment selections, the outputs will need to be saved under a new name if you want to refer to them at a later time. This can be done using the Model Summary table tool (Section 3.6), by creating a geo-referenced .tif file image (Section 9.1.3) or by exporting the catchment (watershed maps) or stream (riverlines) layers as new feature classes.

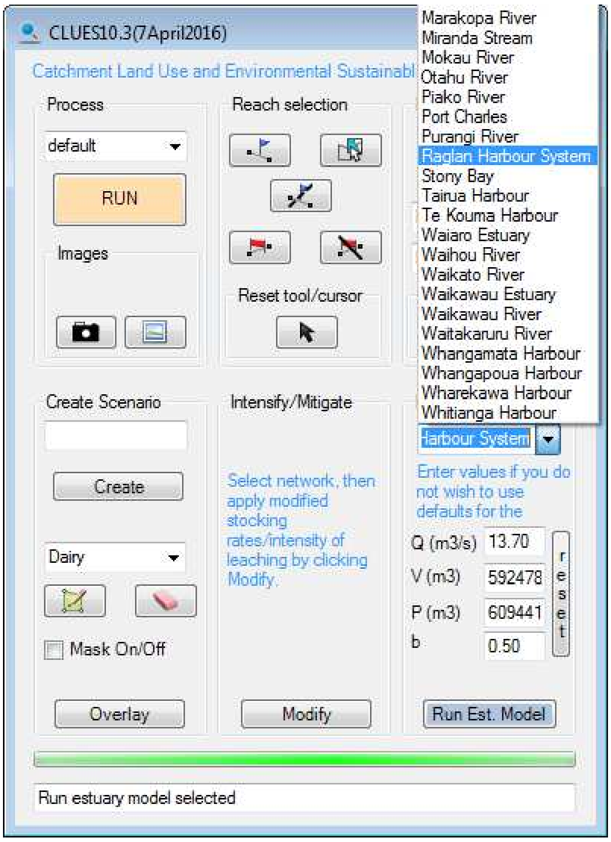


5.5 Running CLUES Estuaries

The CLUES Estuary model automatically runs CLUES for all the stream networks draining to the selected estuary or natural harbour and uses the CLUES outputs to estimate the nitrate and TP concentrations in the estuary. Currently, there are 375 estuaries and harbours included in the CLUES estuaries database. CLUES Estuary can only be run for one estuary at a time and can be used in combination with any CLUES scenario. However, since the outputs for estuaries are saved directly into the estuary feature class, the CLUES will only return the results for the last scenario run using CLUES Estuary.

1. The estuaries available for selection will be displayed when the estuary feature class is checked on the TOC. This feature class displays the most recent model outputs (TN concentration) generated by CLUES and is updated for the selected estuary when CLUES Estuary is run.

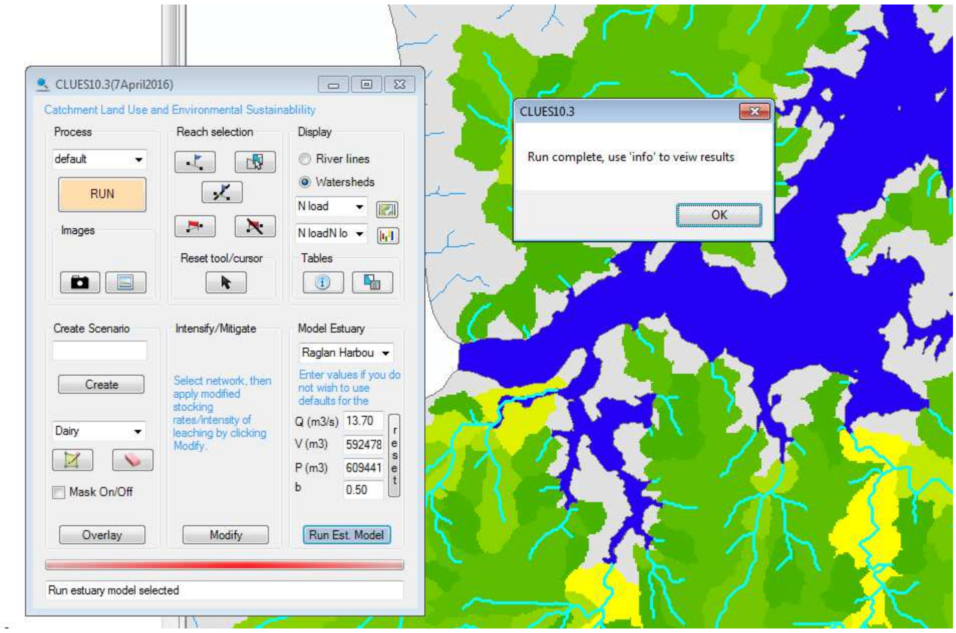
2. Under the CLUES Estuary model section of the interface, click on the Estuary drop down menu and highlight the estuary or harbour to be simulated. Note In this example, Raglan Harbour has been selected.



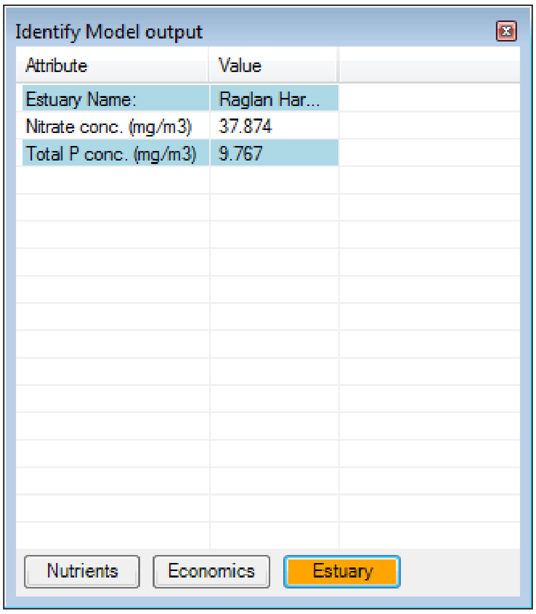
3. The CLUES Estuary default parameters can be replaced by users manually. The parameters are:

   - Q, mean annual discharge rate of freshwater to the estuary or harbour;
   - V, the volume of the estuary or harbour;
   - P, the tidal prism volume; and
   - b, the return flow fraction.

Clicking the reset button will replace the user's values with default values from the CLUES geodatabase.



4. Click the Run Est. Model button, this will automatically select all the stream draining to the estuary or harbour and run both CLUES (to obtain the catchment outputs) and the CLUES Estuary model. The output of the CLUES Estuary model can be obtained using the ID table (see Section 9.2).



Tip: running CLUES Estuary is a quick and handy way of selecting and running CLUES for all the reaches draining to a specific estuary or harbour. However, the selection will not be saved in the CLUES selection memory.

6 Scenario tables

In addition to the default land use scenario, CLUES 10.3 allows users to create two kinds of scenarios: land use change and land management. The latter includes changes to farm practices and, new to CLUES 10.3, forest harvest. Users can also create combined scenarios which have changed land use and management options in place allowing users to determine, for example, whether a particular mitigation measure can reduce the impacts of a planned intensification or increase in farmed land. There is no restriction in the number of that can be created.

The set up and model outputs for each scenario are held in a table saved in the CLUES geodatabase. A scenario table contains an entry for each reach in a region, these are identified by the NZ reach (REC1) or segment (REC2) number under the NZREACH field in the scenario table. These identifiers are used by CLUES to join the scenario table to either the stream or catchment feature classes for display.

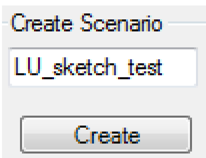
There are three blocks of fields in each scenario table, the first set are model outputs (see Appendix D for a list of model output fields and their units), and the second and third describe model set-up for land use and land management respectively. Creating a scenario will create a new scenario table in the CLUES geodatabase that is a copy of the default scenario table. Overlaying land use change and land management options using the CLUES scenario tools updates the model set-up fields. Running CLUES for a scenario updates the model output fields, a value of -0.1 for a reach indicates that the reach was not selected for the model run. (Hint, to locate the reaches that have been simulated in the scenario table, sort any of the output fields in descending order or select the reaches that have any output > -0.1)

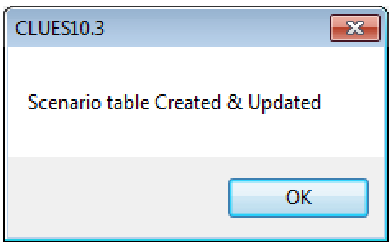
Note that the scenarios created in this manual are for demonstration only and do not represent any actual or planned change to land use or management in the Waikato region.

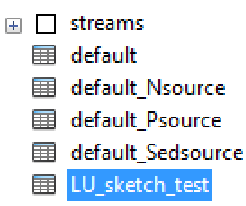
WARNING: NEVER DELETE OR MODIFY THE DEFAULT SCENARIO TABLE 

6.1 Creating scenario tables

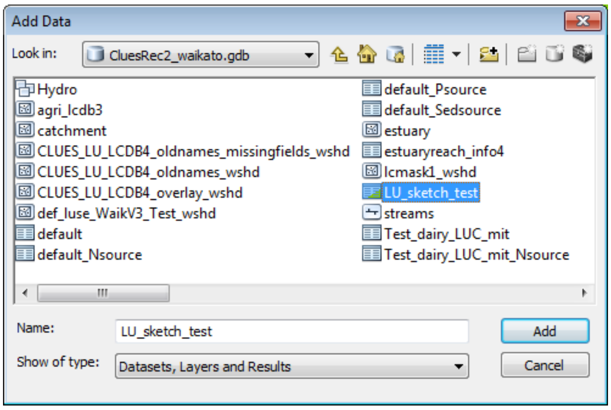
1. Type the name of the scenario in the Create Scenario box. Note that while numbers can be used in a scenario name, the initial character must be a letter. Underscores should be used instead of spaces. Click Create to build the scenario table. A notification box will appear when the scenario has been created and the scenario table will be listed in the TOC (source tab).







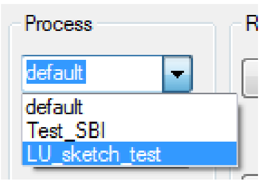
2. The scenario table will be a copy of the default scenario table and is ready for modifying the model set up fields. If you cannot see the scenario in the TOC list, you can add it to the display using the add data tool on the ArcGIS Standard toolbar. It will be saved in the CLUES geodatabase.



6.2 Running a scenario

1. Modify the scenario as required using the instructions given in Sections 7 and 8.

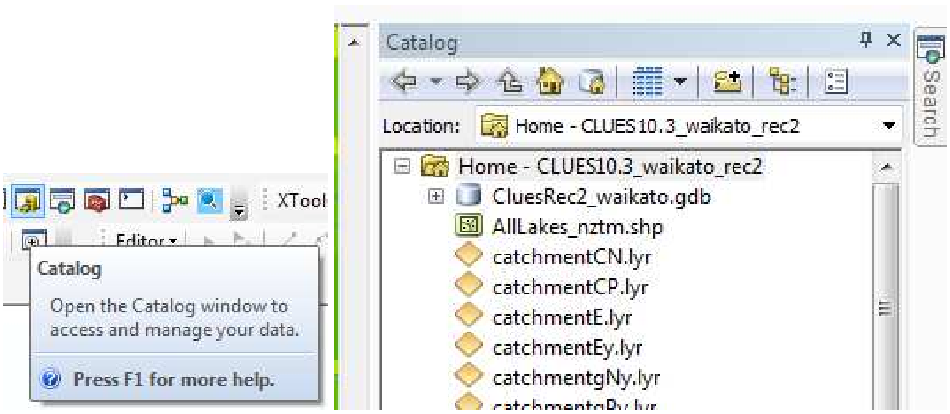
2. Select the scenario from the scenario drop-down menu and click the Run button.



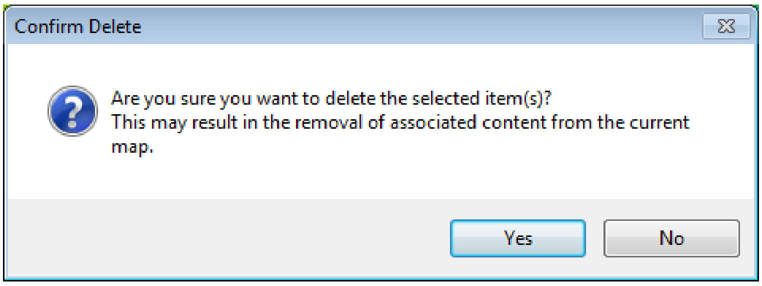
6.3 Deleting scenario tables

Scenario tables can be removed from the map document by right clicking on the table in the TOC and selecting remove, however, it will still be saved in the geodatabase. In this example, a scenario used for CLUES testing (Test_SBI) is still in the geodatabase and will be removed.

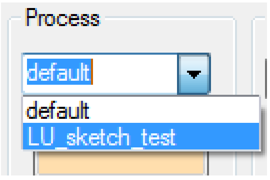
1. If the table is shown on the TOC, remove it. Click the ArcCatalog button on the ArcGIS Tools toolbar to view the geo-spatial data in the regional directory.



2. Open the CLUES geodatabase (.gdb) and delete the scenario table. If the scenario has been run, delete the contaminant tracing tables generated for the scenario.



3. Close and reopen the CLUES interface to refresh the scenario list. The scenario will no longer be available under the drop-down menu.



7 Land use change scenarios

Land use change scenarios change the areal coverage in the selected sub-catchments for the 19 land uses classes available in CLUES. There are three methods that can be used to create a land use scenario in CLUES; sketching land use polygon or importing a new land use shapefile; or direct calculation. These methods are demonstrated below.

7.1 Sketching tool

The sketching tool creates a mask polygon that replaces the land use in the scenario table for the reaches covered by the mask with the user defined land use classes. Where a sketch polygon completely covers a REC sub-catchment, the user defined land use class will cover the entire catchment area. Where a sketch polygon intersects a REC sub-catchment, only the proportion of the sub-catchment covered by the mask will be affected.

In this example, the land use in the sub-catchments for the northern streams draining to Raglan harbour will be replaced by intensive sheep and beef farming and the land use in the south will be replaced by exotic plantation forest.

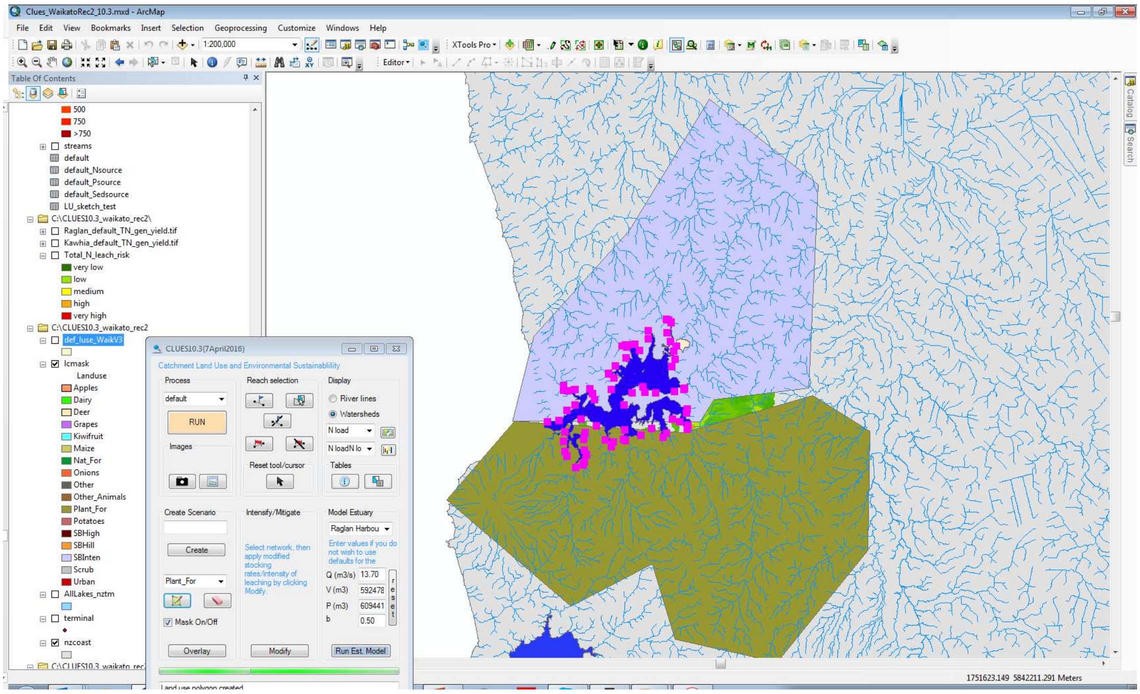
1. Choose the land use to be overlaid from the drop down menu. The land use classes in CLUES are listed in Table 2-3 (Section 2.4).

2. Check the Mask On/Off button to turn display (or remove) the land use change polygon. This button controls the display of the lcmask feature class.

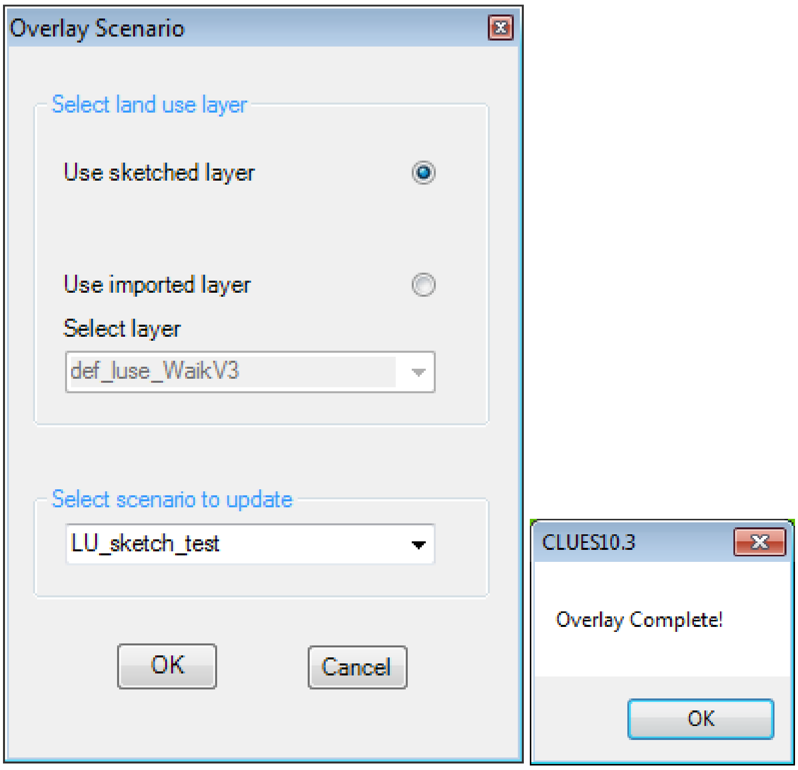
3. If there are any earlier masks that are not part of the scenario, remove them by clicking on the eraser button.

4. Click the polygon sketch button to activate the sketching tool. Click and drag the + cursor on the map display to set the vertices of the land use mask polygon. Double click to complete the polygon.

5. Polygons can be any size or shape. It is possible to draw multiple polygons with the same or different land use. If the Mask is displayed, the sketched land use polygons will appear on the display when they are completed. In this example, the purple polygon represents intensive sheep and beef and the olive represents plantation forest

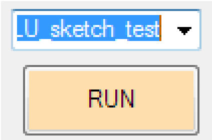


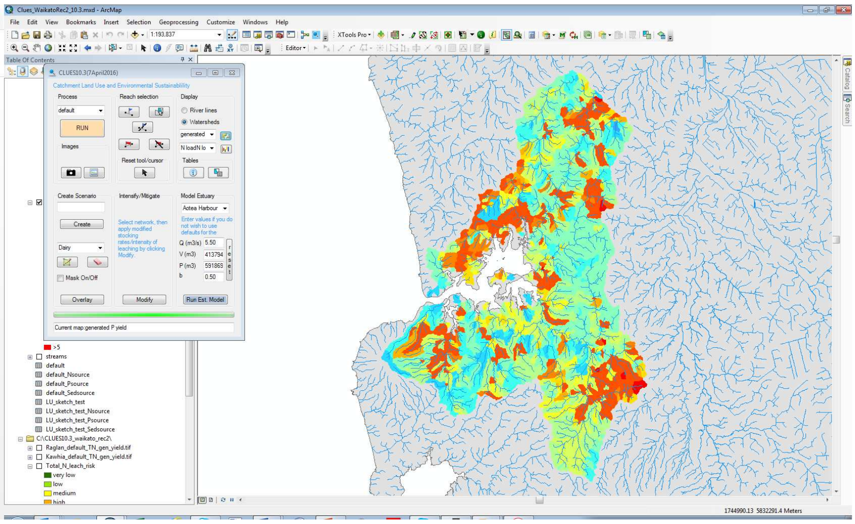
6. Click the Overlay button to overlay the sketch land use polygons over the scenario table. Check the Use sketched layer radio button and select the scenario to be overlaid.



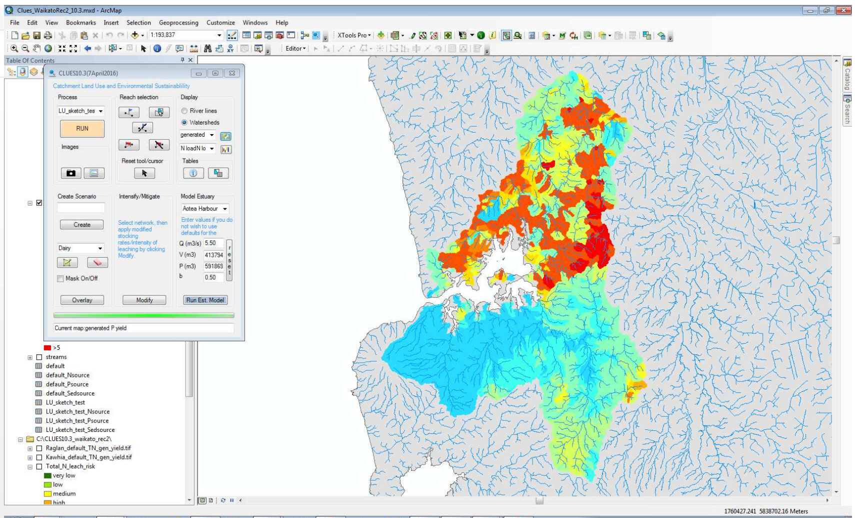
Overlays can take time. Progress will be displayed at the bottom of the ArcGIS window and a notification will appear when the overlay is complete.

7. Run CLUES for the default and land use changes scenarios. The generated TP yields are shown below for the default land use and for the sketched land use change scenario.





Default TP generated yield



Land use scenario change TP generated yield

Intensive sheep and beef in the north and plantation forest in the south.

8. To check the overlay has been applied, open the scenario table and look at the land use set-up for the scenarios. Here all the land use in the reaches covered by the land use masks have been updated to either SBInten (north) or Plant_For (south).

DAIRY	SBINTEN	SBHILL	SBHIGH	DEER	OTHER_ANIM	I
0	755243.91686	0	0	0	0	
0	369070.58348	0	0	0	0	
0	806554.17851	0	0	0	0	
0	204340.6347	0	0	0	0	
0	58511.552675	0	0	0	0	
0	153030.47045	0	0	0	0	
0	49509.855949	0	0	0	0	
0	59411.774485	0	0	0	0	
0	128725.78718	0	0	0	0	

North

APPLES	GRAPE	PLANT_FOR	NAT_FOR	SCRUB	UI
0	0	1689547.6095	0	0	
0	0	1689456.5379	0	0	
0	0	1681391.1689	0	0	
0	0	1673101.4633	0	0	
0	0	1668687.1365	0	0	
0	0	1664787.2722	0	0	
0	0	1662789.3178	0	0	
0	0	1660634.2139	0	0	
0	0	1648533.5926	0	0	

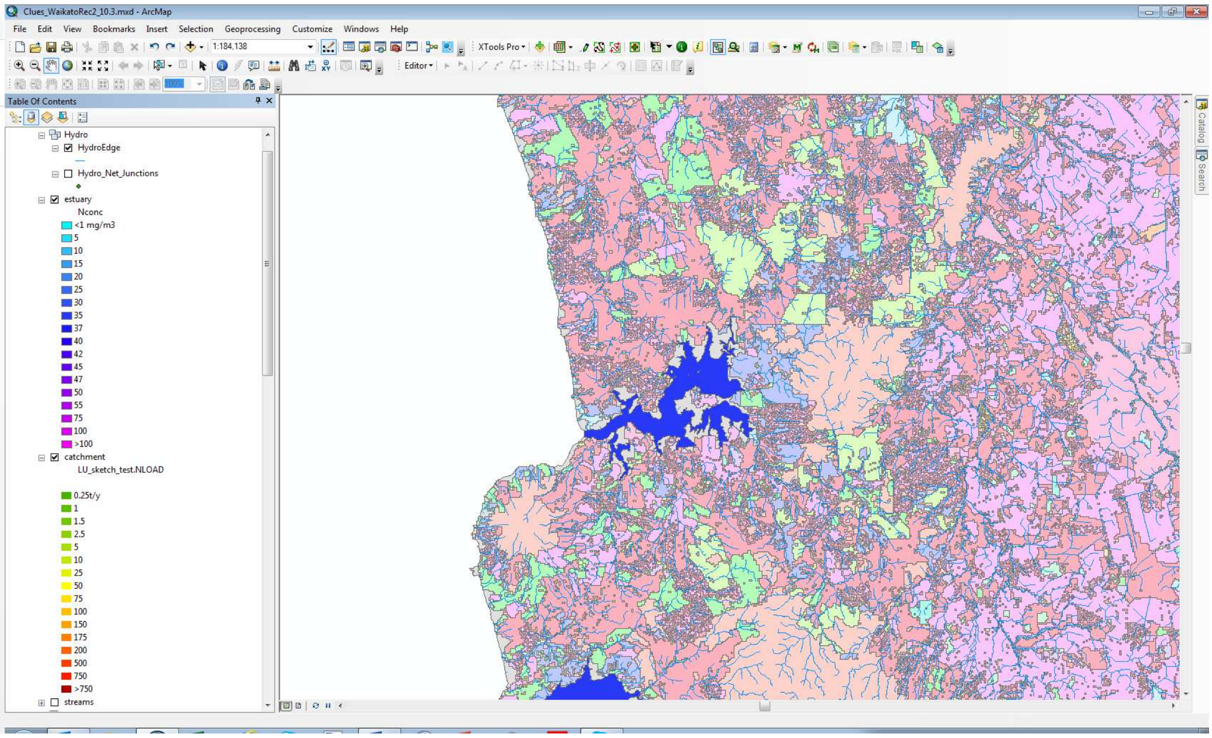
South

7.2 Importing a new land use shapefile

CLUES can overlay an imported land use shapefile as long as it has the same land use classes as CLUES and the field headers are the same as the default land use reference shapefile (def_luse_region) provided with CLUES as a land use scenario template. This shapefile gives the percentage (integers) breakdown of each land use type by REC reach. However, the imported land use shapefile is not restricted to the reach polygons.

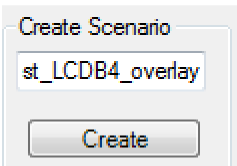
The imported shapefile must use the NEW CLUES land use class codes as listed in Table 2-3. The overlay will work with the old codes, but will not give the correct area values. If you have an existing CLUES scenario from a previous version of CLUES, change the field headers to the new codes.

In this example, a CLUES land use polygon shapefile created by Waikato Regional Council[7] that is based on LCDB4 (2012) land cover is imported and overlaid to create an updated land use scenario.



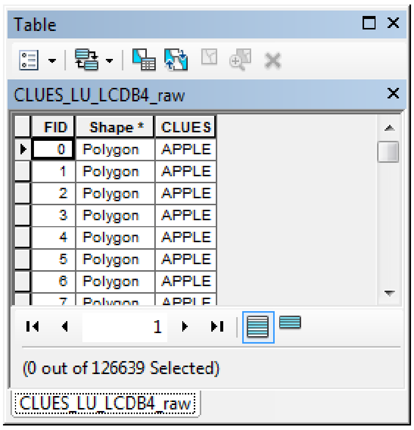
The WRC created the land use shapefile by converting a raster layer to a polygon shapefile (raster to feature class) such that each polygon has a single land use (i.e., 100% coverage). While the land use is classified into CLUES land use classes, it is not in a format that can be overlaid and needs to be adjusted so that it has the same fields as the CLUES def_luse_region shapefile.

1. Create a new scenario table for the imported land use scenario.



[7] Used with permission from Waikato Regional Council (Dan Borman / Bevan Jenkins).

2. Convert the imported land use data into a shapefile with the same format as the def_luse_region shapefile (def_luse_Waik3 for Waikato). This step can be done in ArcGIS or some other software package.



In this example, the data from the land use shapefile (CLUES_LU_LCDB4_raw) attribute table (above) was exported as text file and opened in Excel. The first row of the def_luse_Waik3 shapefile attribute table was copied and pasted into the spreadsheet to make sure that the attribute table for the scenario overlay shape files will have the fields required for the overlay[8]. It does not matter if the fields are in a different order as long as their headers and number formats (integers) are the same. Since each polygon has a single land use in the land use shapefile, a simple formula was used for each land use field to assign a value of 100 if the row has the same land use as the field header and a zero if it is different.

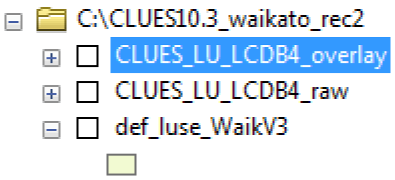
	A	B	C	D	E	F	G
1	FID	LandUse	GRID_COD	Area	DAIRY	HILL	INTENSIV
2566	2564	DAIRY	2565	0	100	0	0
2567	2565	DAIRY	2566	0	100	0	0
2568	2566	DAIRY	2567	0	100	0	0
2569	2567	DAIRY	2568	0	100	0	0
2570	2568	DAIRY	2569	0	100	0	0
2571	2569	DAIRY	2570	0	100	0	0
2572	2570	DAIRY	2571	0	100	0	0
2573	2571	DAIRY	2572	0	100	0	0

As well as fields for the land use classes listed in Table 2-3, the def_luse_region shapefile has four other fields, these are:

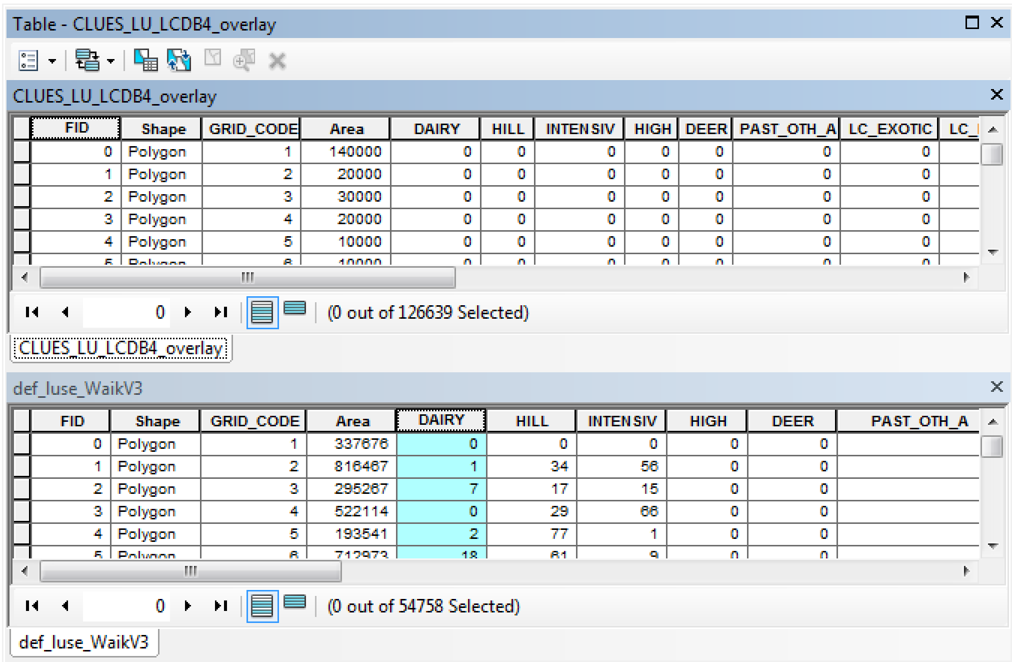
- FID – row ID number assigned automatically to all shapefiles by ArcGIS
- Shape – shapefile geometry type (polygon) assigned by ArcGIS
- GRID_CODE – CLUES polygon identifier, this must be a whole number (tip, add 1 to the FID number)
- AREA – optional reference field giving the area in square meters of the land use polygon (tip, use the ArcGIS geometry calculator to calculate the area once that data has been imported back into ArcGIS).

[8] There is a field called LC_water in the def_luse_region table, this land cover is currently not used in CLUES, leave the percentage as zero.

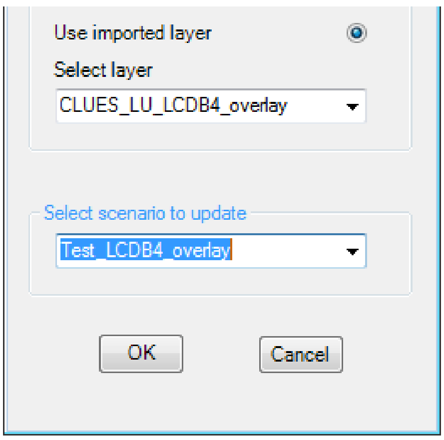
The amended text file was imported back into ArcGIS and joined to the original land use shapefile by the FID number. The joined data was saved as a new shapefile (CLUES_LU_LCDB4_overlay) in the regional directory to create the land use scenario for the overlay (tip, once this has been done, remove the join between the original shapefile and the imported text file, as having joins in a map document can make ArcGIS very slow).

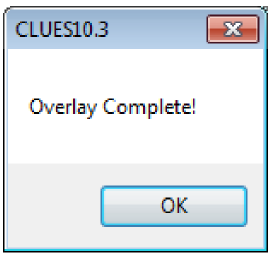


The area for each polygon was calculated using the calculate geometry tool and any fields not required for the overlay were deleted from the shapefile. The resultant shapefile has the same fields and data format as the def_luse_region shapefile.



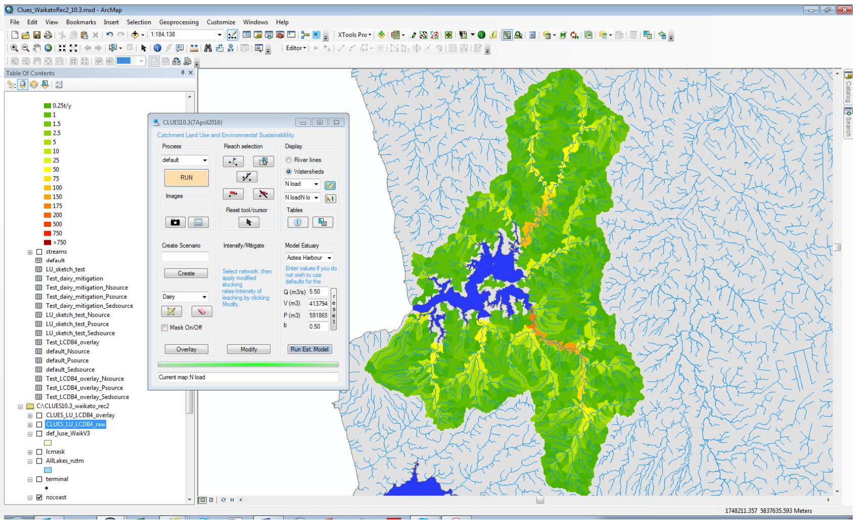
3. Click the Overlay button to open the Overlay Scenario box. Check the Use Imported Layer radio box and select the land use scenario shapefile and the land use scenario table from the relevant drop-down menus. Click OK to overlay the land use data into the scenario table.



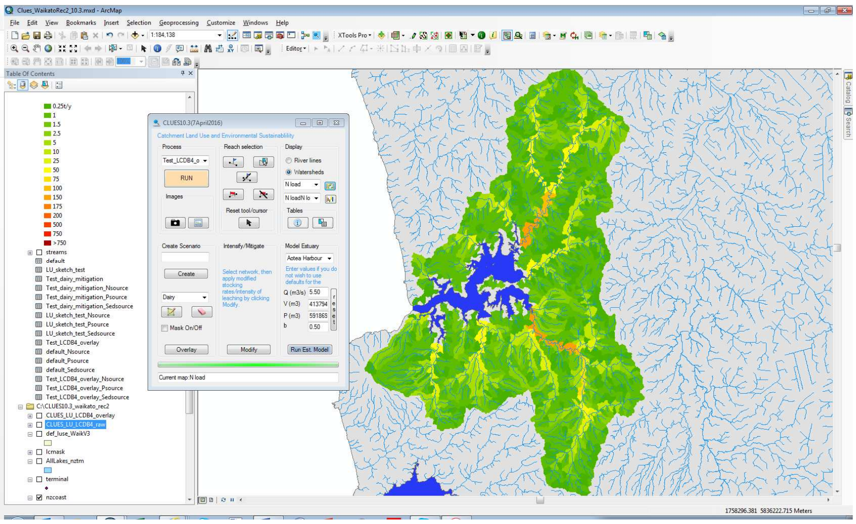


CLUES automatically performs an intersect command and area calculations to determine from the percentage land use breakdown, the equivalent area for each land use class in each REC reach sub-catchment. This step can take some time depending on the extent of the land use scenario and the number of polygon to be overlaid. A notification will appear when the overlay is complete.

4. Run CLUES for the default and land use change scenarios.



Default N load



TN calculated using the land use scenario derived from the Waikato Regional Council LCDB4 land use update

7.3 Direct calculation

In addition to overlaying land use scenarios, users can use the ArcGIS field calculator to adjust the coverage of each affected land use class directly in a scenario table. However care must be taken to ensure that the sum of the areas for the different land use classes remains the same as the total area of the sub-catchment. A further refinement is to join the scenario table to the geodatabase feature classes (e.g., Hydroedge, cathments) using the reach identifier field so that reaches with specific characteristics (e.g., slope class or soil drainage class) can be selected for the calculation.

This method should only be attempted by users with a good understanding of GIS.

8 Land management scenarios

Land management scenarios are used to adjust the contaminant yields associated with particular land use types to simulate the effects of farm practices (e.g., stocking rates, mitigation measures), and forest harvest. Land management scenarios can be run separately by creating a new scenario table or in combination with land use change scenarios.

8.1 Farm practice scenarios

Farm practice scenarios change the contaminant yields by a user defined percentage (known as a modification factor) to simulate the effects of increased (or reduced) stocking rates or farm practices which either intensify or mitigate the impacts of farming. Three methods can be used to create farm practice scenarios:

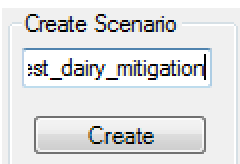
- interactive selection and assignment of river reach modification factors;
- importation of a text file containing the modification factors for each reach affected by the scenario; and
- direct modification of the scenario table using the ArcGIS field calculator.

Each of these methods enables the user to update a set of fields in the scenario table (listed in Table 8-1 below) that change the model parameters associated with stock for each of the selected sub-catchments. The default value for the modification factors is 100; that is, no change in default stocking rate or yields for the stock type. A factor less than 100 represents a reduction in the stock rate or yield. Since the modification factor is a multiplier, it represents the yield remaining after modification. This means, for example, a mitigation measure with a removal efficiency of 20% of nitrogen loads from dairy cattle would have a TN modification factor of 80 for dairy. Similarly, a modification factor greater than 100 represents an increase in the stocking rate or yield. So a 20% increase TN yield would be represented by a modification factor of 120. Note that the percentages must be integers.

8.1.1 Interactive farm practice modification method

In this example, a new scenario is created that mitigates nutrient loads from dairy farms in the drainage area south of Raglan Harbour by 30% for TN and 15% for TP.

1. Create a new scenario table (alternatively, the scenario can be applied to an existing land use change scenario).



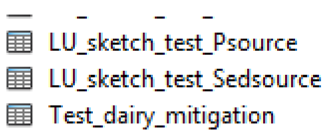
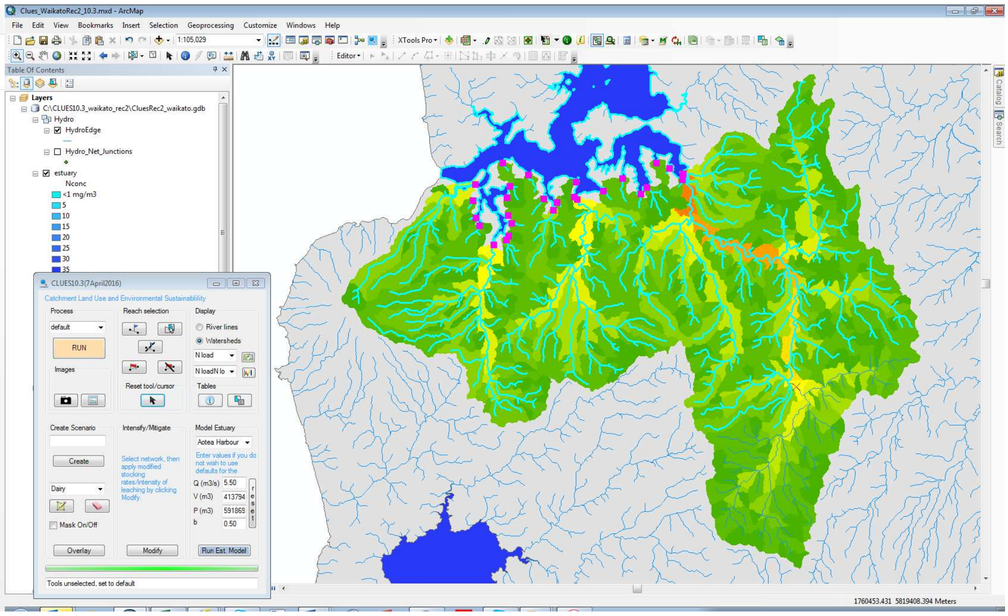


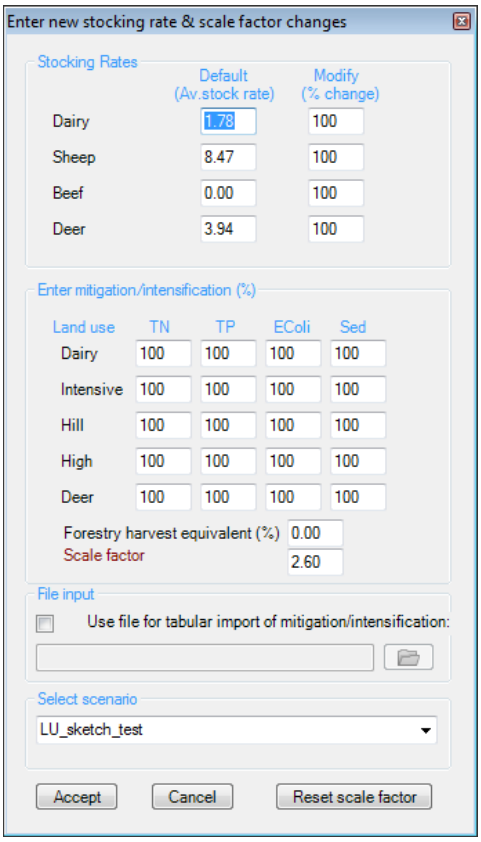
Table 8-1: Modification factor scenario table fields that are used to set-up farm practice scenarios.

Field name	Description
SRdairy SRsheep SRbeef SRdeer	Percentage change to default stocking rates by stock type
pcTND pcTPD pcECD pcSdD	Percentage change to the yields of TN, TP, *E. coli* and TSS for dairy farming
pcTNI pcTPI pcECI pcSdI	Percentage change to the yields of TN, TP, *E. coli* and TSS for intensive lowland sheep and beef farming
pcTNH pcTPH pcECH pcSdH	Percentage change to the yields of TN, TP, *E. coli* and TSS for hill country sheep and beef farming
pcTNHi pcTPHi pcECHi pcSdHi	Percentage change to the yields of TN, TP, *E. coli* and TSS for high country sheep and beef farming
pcTNDe pcTPDe pcECDe pcSdDe	Percentage change to the yields of TN, TP, *E. coli* and TSS for deer farming

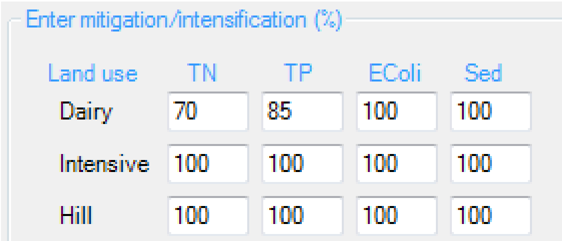
2. Select the reaches to be mitigated using the selection and barrier tools. The barrier flag is useful for restricting the location of the mitigations to a certain part of a catchment. Here a barrier has been placed on the Coopers Creek tributary to the Waitetuna River. The screen shot shows the TN load simulated for the default scenario. Note that the barrier has removed a section of the Waitetuna River catchment from the reach selection.



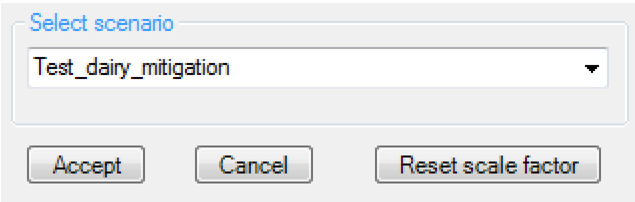
3. Click the Modify button to open the interactive land management scenario box.

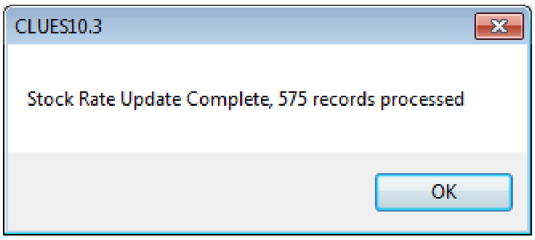


4. Make the percentage modifications to the Stocking Rates or Mitigation/Intensification boxes as required. Here the TN and TP modification factors for dairy farming are set to 70 and 85 to represent nutrient reductions of 30% and 15% respectively.

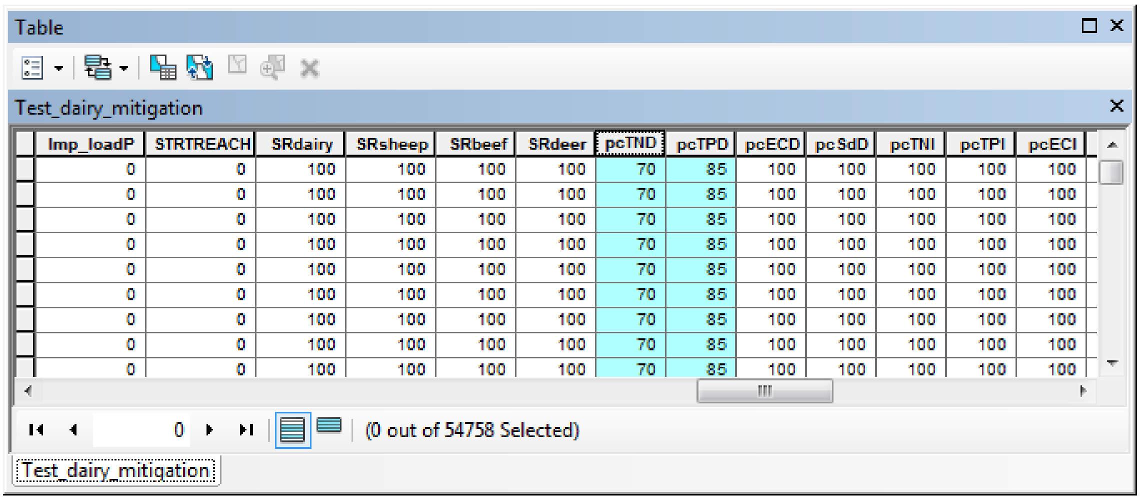


5. Select the scenario table the modification to should be applied to and click Accept. CLUES will return a notification when the scenario table has been updated. In this case, the modification has been applied to 575 river reaches.



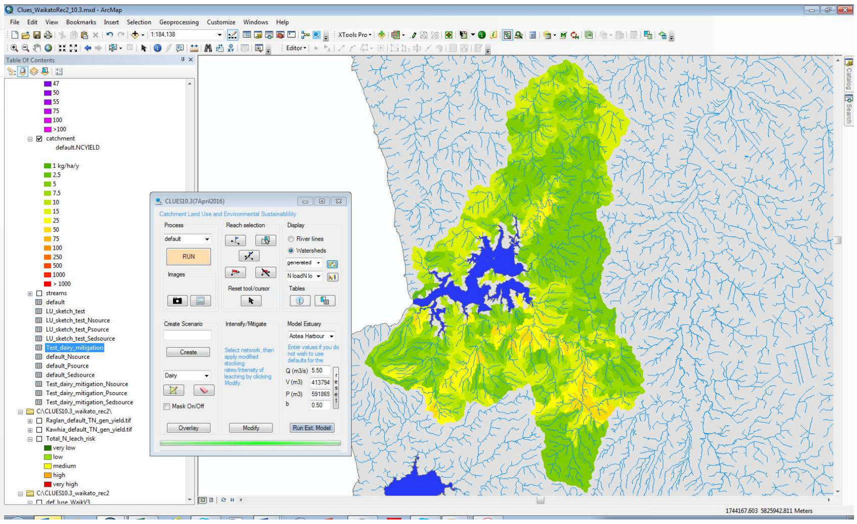


6. The modifications can be checked in the scenario table for the scenario.

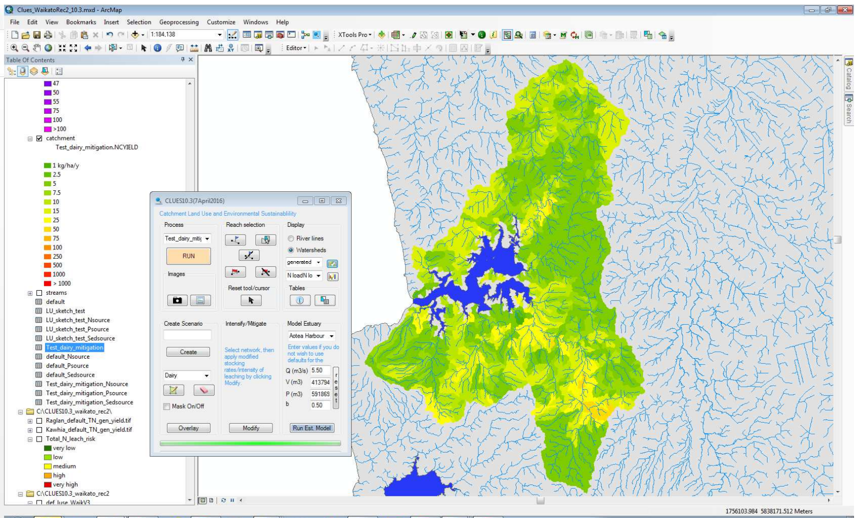


Imp_loadP	STRTREACH	SRdairy	SRsheep	SRbeef	SRdeer	pcTND	pcTPD	pcECD	pcSdD	pcTNI	pcTPI	pcECI
0	0	100	100	100	100	70	85	100	100	100	100	100
0	0	100	100	100	100	70	85	100	100	100	100	100
0	0	100	100	100	100	70	85	100	100	100	100	100
0	0	100	100	100	100	70	85	100	100	100	100	100
0	0	100	100	100	100	70	85	100	100	100	100	100
0	0	100	100	100	100	70	85	100	100	100	100	100
0	0	100	100	100	100	70	85	100	100	100	100	100
0	0	100	100	100	100	70	85	100	100	100	100	100
0	0	100	100	100	100	70	85	100	100	100	100	100

7. Run the model for the default and new farm practice scenarios. If the reach selection used to create the scenarios is different from the reach selection required for modelling, update the reach selection using the CLUES selection tools. In this example, the mitigation barrier at Coopers Creek was removed and all the catchments draining to Raglan Harbour were selected prior to running CLUES for both the default and modified scenarios.

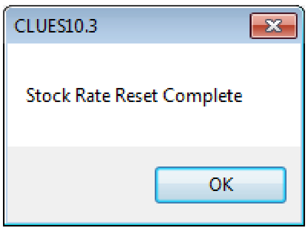


Default TN generated yield



Mitigated TN generated yield in south. No mitigation in north or south of the barrier at Coopers Creek.

8. The reset scale factor button will replace all previous modifications in the scenario table with the default value of 100 if required. A notification will appear when the reset is complete.



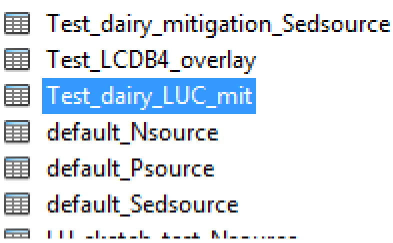
8.1.2 Importing a farm practice scenario template

This method of modifying a scenario table to simulate changes in farm practices involves setting up and importing a comma separated value (.csv) file that contains the modification factors for a pre-selected set of reaches. CLUES joins the text file to the scenario table by the NZREACH identifier (NZ reach for REC1 or segment number for REC2) identifier and automatically updates the modification factors for those reaches. An Excel template (Farm_Practice_template.xlsx) that can be used to create a .csv file with the correct formatting is available from the CLUES ftp site. The advantage of this method is that it allows users to set variable modification factors and to select reaches depending on some spatial criterion. For instance, a mitigation practice may be more effective or only suitable in locations with specific characteristics such as stream order, slope, soil drainage or climate or a combination of these.

Examples of this method can be found in Monaghan et al. (2010) and (Hughes et al., 2013a; Hughes et al., 2013b) for Southland and Semadeni-Davies and Elliot (2013) for the Waikato. In these studies, a range of mitigation practices were applied to different locations based on spatial data from the LRI. For instance, Monaghan et al. (2010) demonstrated proportional weighting of modification factors for the Oreti catchment to simulate a range of potential farm mitigation measures separately and in combination. Each mitigation had its own application criteria with respect to stock type, soil drainage and LUC class such that some reaches had a higher modification factor than others depending on the combination of mitigation practices possible and the proportion of the reach sub-catchment suitable for mitigation. Sub-catchments were split into polygons with unique combinations of land use[9], soil drainage class and Land Use Capability (LUC) using the ArcMap Union tool and the area of the resulting polygons calculated. Those polygons which had a land use of dairy or sheep / beef were selected for further processing in Excel. Pivot tables were used to determine the proportion of land in each reach meeting the various criteria with respect to the total sub-catchment area. These proportions were used to weight the modification factors for each stock type within each sub-catchment. The modification factors were finally imported back into ArcMap for overlay onto a farm practice scenario table within CLUES.

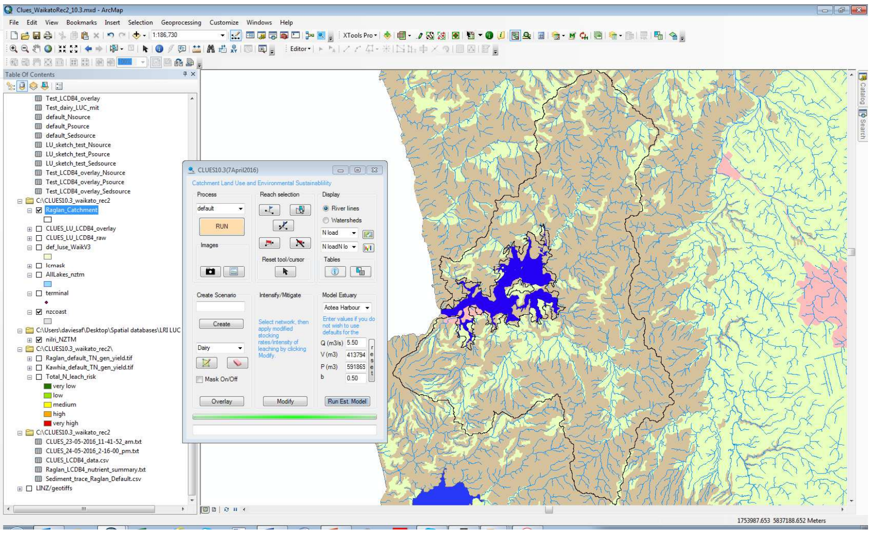
In this example, a mitigation measure for dairy farming in sub-catchments with an LUC class of 1 to 4 (i.e., suitable for intensive pastoral land use) is simulated by reducing the TN dairy yields by 30% (i.e., modification factor of 70%). For simplicity, the modification factors are not spatially-weighted; that is, all dairy farms will be mitigated in a sub-catchment which intersects an LRI polygon with an LUC of 1-4.

1. Create a new scenario table (alternatively, the scenario can be used in combination with a land use scenario).

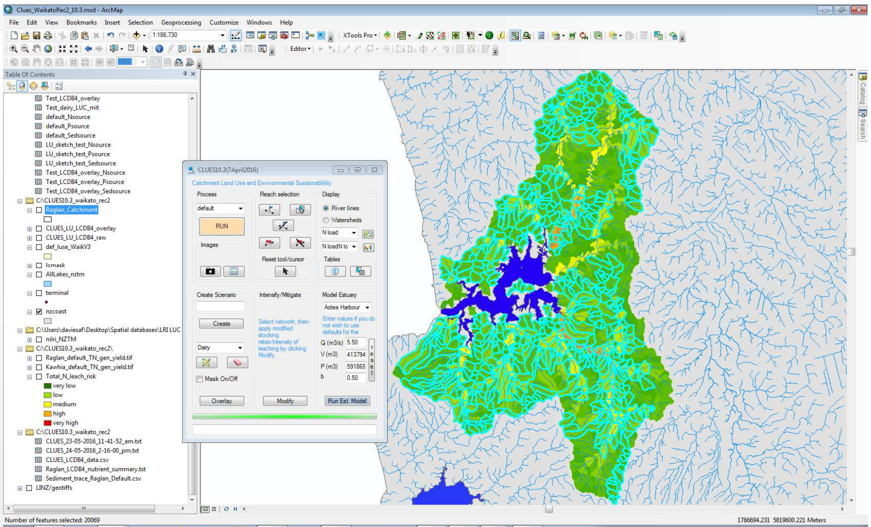


9 From the underlying CLUES land use database used to derived the default land use scenario supplied with CLUES.

2. Select the sub-catchments to be modified from the catchment feature class using ArcGIS selection tools. In this example, 752 sub-catchments in the Raglan harbour drainage area that intersect an LUC polygon with a classification of 1-4 (shown in green) have been selected.



LRI data showing areas with an LUC suitable for pastoral land use (classes 1-4) in green



REC sub-catchments in the Raglan Harbour drainage area that intersect an LRI polygon suitable for pastoral land use.

3. Export the list of REC reaches meeting the selection criteria from the catchment attribute table as a text file and open this file in Excel. Alternatively, the selected reaches can be copied and pasted directly into Excel if the number of selected reaches is not very long (tip, display the selected reaches in the catchment attribute table and right click on one of the small squares to the left of the table to bring up a dialogue box, then click on copy selected).

4. Download the Farm_Practice_template.xlsx spreadsheet from the CLUES ftp site: ftp://ftp.niwa.co.nz/clues/

5. Open the template and paste the reach identity numbers (either the NZ reach for REC1 or NZ segment for REC2) for the selected sub-catchments into the INZREACH column of the Data entry worksheet.

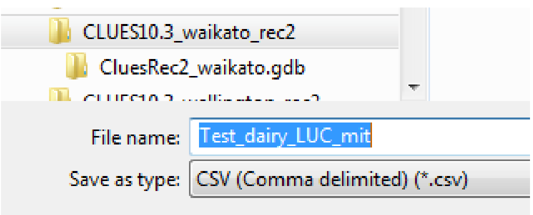
6. Enter the modification factor (this must be an integer) in the appropriate columns. In this example, the TN yield for dairy farms is reduced by 30% (i.e., a modification factor of 70), all other yields are assigned the default value of 100 (i.e., no change in yield).

	A	B	C	D	E	F	G	H	I
1	INZREACH	pcTND	pcTPD	pcECD	pcSdD	pcTNI	pcTPI	pcECI	pcSdI
2		dairy N	dairy P	dairy E col	dairy sedi	SB intensi	SB intensi	SB intensi	SB intensi
3	3056166	70	100	100	100	100	100	100	100
4	3056231	70	100	100	100	100	100	100	100
5	3056244	70	100	100	100	100	100	100	100
6	3056245	70	100	100	100	100	100	100	100
7	3056256	70	100	100	100	100	100	100	100
8	3056296	70	100	100	100	100	100	100	100
9	3056314	70	100	100	100	100	100	100	100
10	3056337	70	100	100	100	100	100	100	100
11	3056369	70	100	100	100	100	100	100	100

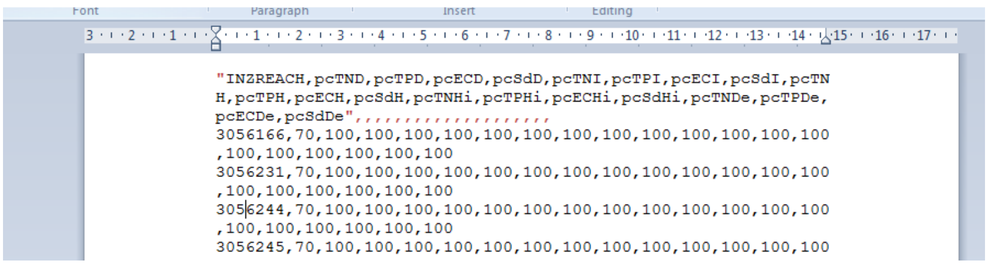
7. Open the CSV format worksheet. This worksheet is linked to the Data entry worksheet. Copy down the formulae in Cells A2-U2 for the required number of NZREACH numbers

	A	B	C	D	E	F	G
1	INZREACH	pcTND	pcTPD	pcECD	pcSdD	pcTNI	pcTPI
2	3056166	70	100	100	100	100	100
3	3056231	70	100	100	100	100	100
4	3056244	70	100	100	100	100	100
5	3056245	70	100	100	100	100	100
6	3056256	70	100	100	100	100	100

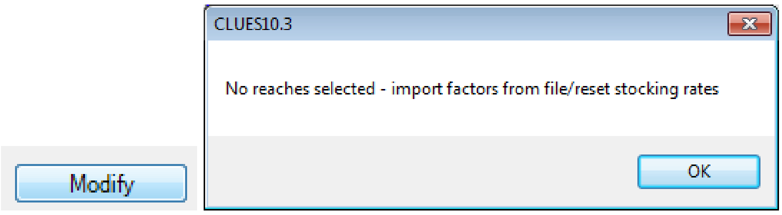
8. Save the CSV format worksheet as a .csv file into the CLUES regional directory and close Excel.



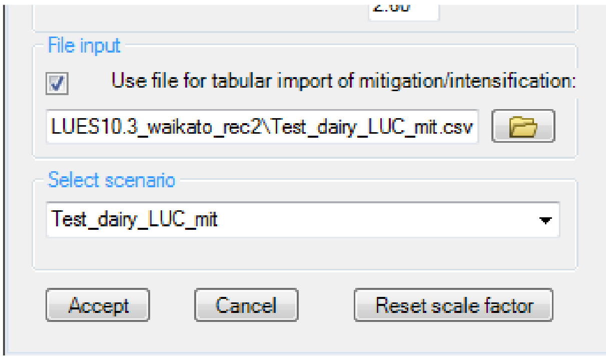
Note: Excel may save the file with extra place-holder characters in the first or header row. If this is the case, CLUES will not be able to read the file. To check, open the file in WordPad or NotePad, if the header row has quotation marks around the field names or is followed by commas (red in the screenshot below), delete these. The header row should start with INZREACH and end with pcSdDe. Save and close the file.

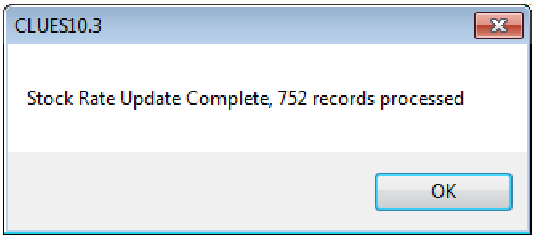


9. In ArcGIS, click the Modify button on the CLUES toolbar to open the modify dialogue box. If no reaches have been selected, an error message will pop-up; click OK, this will not affect the modification as the reaches to be modified are listed in the .csv file.

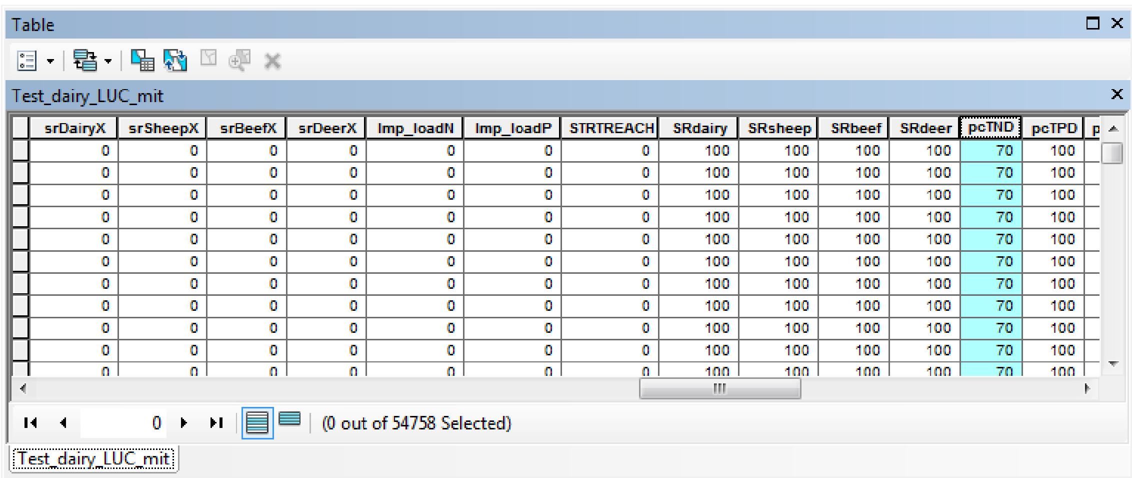


10. Browse to the modification .csv file and select the scenario to be modified. Click Accept to apply the modification. CLUES will return a notification when the scenario table has been updated.



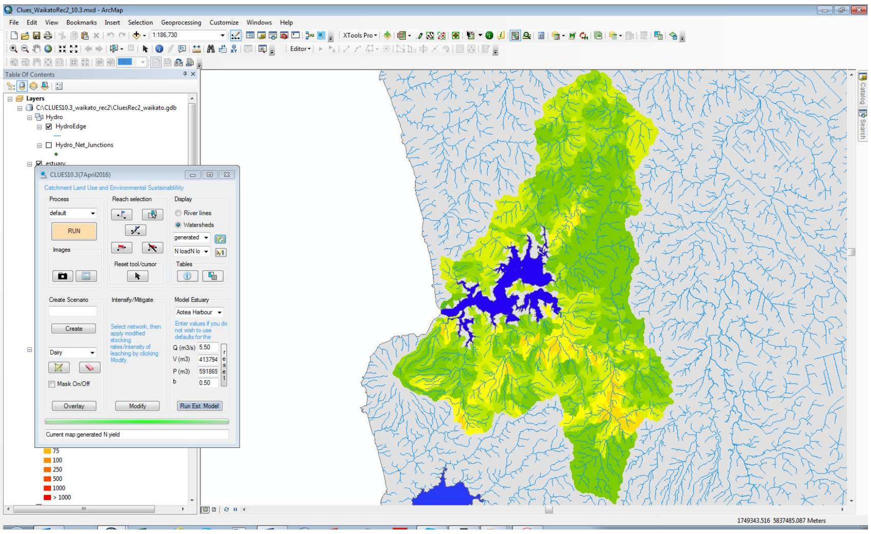


11. The scenario table will have been updated for the selected reaches.

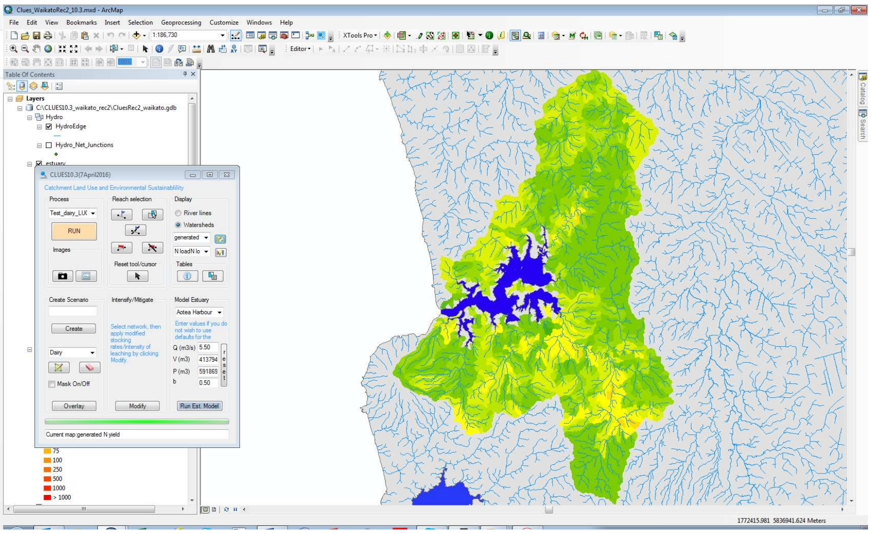


srDairyX	srSheepX	srBeefX	srDeerX	Imp_loadN	Imp_loadP	STRTREACH	SRdairy	SRsheep	SRbeef	SRdeer	pcTND	pcTPD
0	0	0	0	0	0	0	100	100	100	100	70	100
0	0	0	0	0	0	0	100	100	100	100	70	100
0	0	0	0	0	0	0	100	100	100	100	70	100
0	0	0	0	0	0	0	100	100	100	100	70	100
0	0	0	0	0	0	0	100	100	100	100	70	100
0	0	0	0	0	0	0	100	100	100	100	70	100
0	0	0	0	0	0	0	100	100	100	100	70	100
0	0	0	0	0	0	0	100	100	100	100	70	100
0	0	0	0	0	0	0	100	100	100	100	70	100
0	0	0	0	0	0	0	100	100	100	100	70	100
0	0	0	0	0	0	0	100	100	100	100	70	100

12. Select the reaches to be simulated and run the model for the default and modified scenarios.



Default TN generated yield



30% reduction of TN from dairy farming in reaches intersecting land with an LUC of 1-4.

8.1.3 Direct field calculation

Like land use scenarios, the farm practice modification factors can be changed directly in the scenario table using the ARCGIS selection tools and field calculator. Again, this method should only be attempted by users with a good knowledge of GIS.

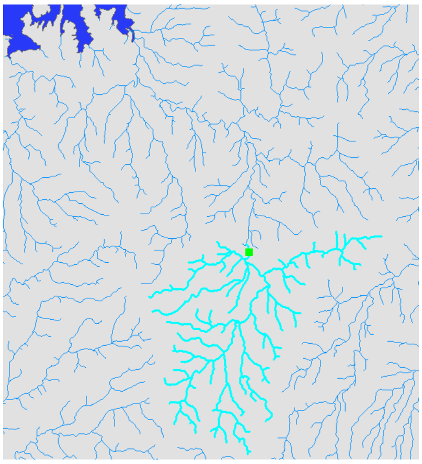
8.2 Forest harvest scenarios

The forest harvest scenario tool was added to CLUES in 2015 as the result of an Envirolink project undertaken for the Tasman District Council (Semadeni-Davies et al., 2015; see Appendix D for more information). The tool is intended to allow users to estimate the short term effects of forest harvest on instream sediment loads. The scenarios should not be used for nutrients or *E. coli*. A forest harvest scenario is only intended to cover the two to three year period after harvest when the soil is exposed and has not yet stabilised following replanting. The long term impact has to be tempered by also considering the reduction of erosion following afforestation. The scenarios are similar in application to farm practice scenarios. They effectively increase the sediment yields from harvested forest by a scalar of sediment yields from pastoral land.

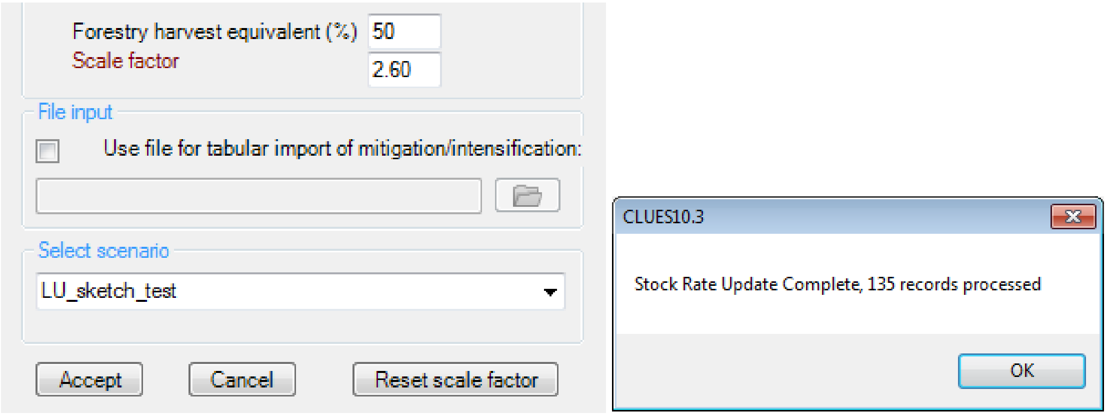
The steps to setting up and running a forestry scenario are illustrated here for the Waituna River that drains into the Raglan Harbour. The scenario is applied to the land use sketch scenario created earlier (LU_sketch_test; see Section 7.1) that replaced all existing land uses to the south of the harbour with plantation forest. The scenario is for half of the plantation forest in the upper reaches of the catchment to be harvested.

1. Create a new scenario or alternatively, use an existing land use change scenario to determine the combined effects of forest planting and harvest.

2. Select the reaches where the forestry harvest scenario is to be applied using the CLUES selection and barrier tools (see the instructions for interactive farm practice scenarios in Section 8.1.1).

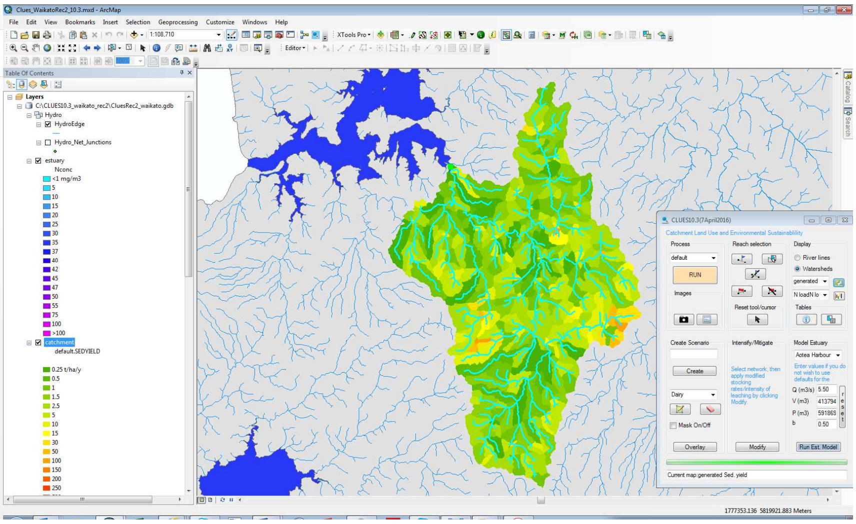


3. Open the Modify tool and set the forest harvest percentage equivalent (0-100%) for the scenario to be modified. Here, half of the selected plantation forest for the LU_sketch_test scenario is harvested. A notification will appear when the forest harvest overlay is complete.

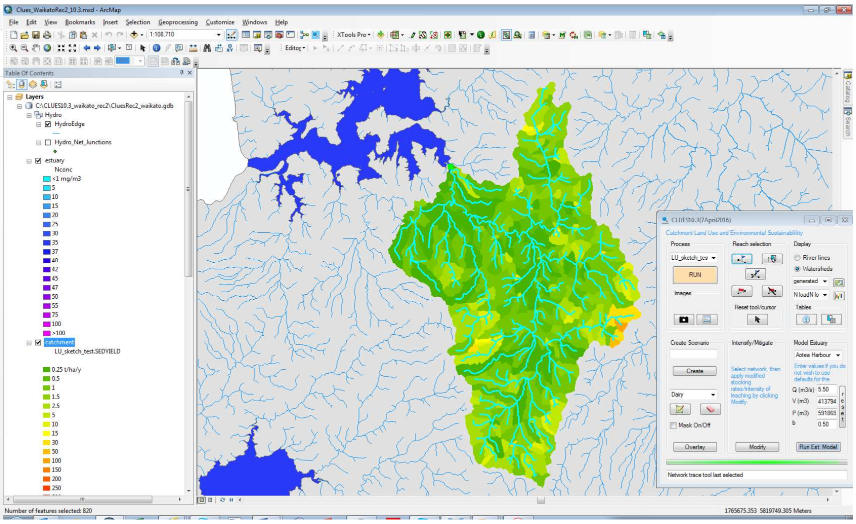


The CLUES default ratio of sediment yields from forested land to the equivalent yield from pasture is 2.60. This scale factor is based on the findings of Fahey et al. (2003b) and Eyles and Fahey (2006) for Hawkes Bay . The factor can be changed by the user if local data are available.

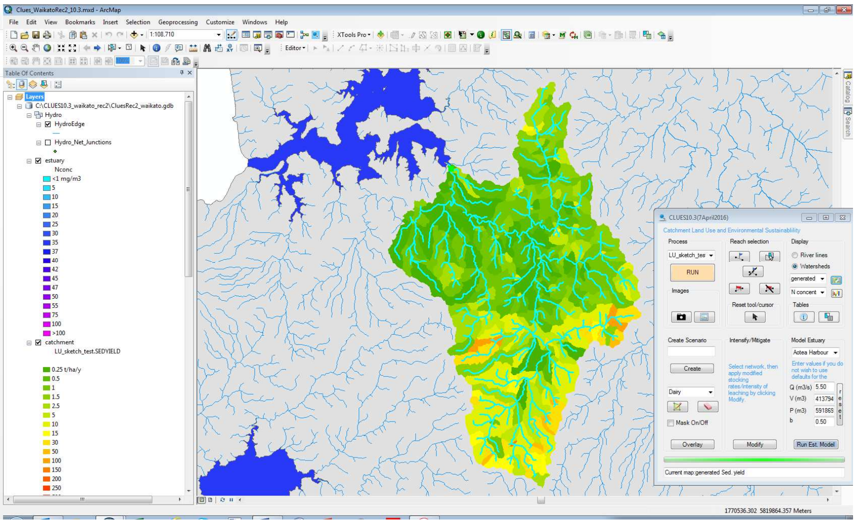
4. Deselect the modified area and select the reaches to be modelled if required. In this example, CLUES is run for the entire Waituna River catchment.



Sediment generated yield simulated using the default scenario



Sediment generated yield simulated for land use change scenario (all land uses replaced by planation forest in the south and intensive sheep and beef in the north) with no forest harvest



Sediment generated yield simulated for land use scenario with half of the forested area in the upper reaches of the catchment harvested.

9 Output reporting and display

This section demonstrates how to use the CLUES mapping and table tools to report and display CLUES outputs and how to compare outputs for different scenarios. When comparing the outputs of a scenario against the default, make sure that CLUES has been run for the same reach selection for both scenarios.

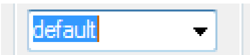
9.1 Maps

The default map when CLUES is run is the TN annual load watershed map. Other water quality outputs can be mapped using the instructions below

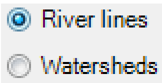
9.1.1 Watershed and river line Maps

In this example, TN concentration is mapped as a river line map for all the streams draining to the Raglan Harbour.

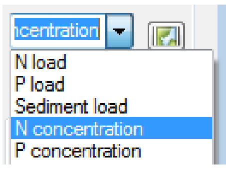
1. Select the scenario to be mapped from the scenario drop-down menu. Here the default scenario is selected

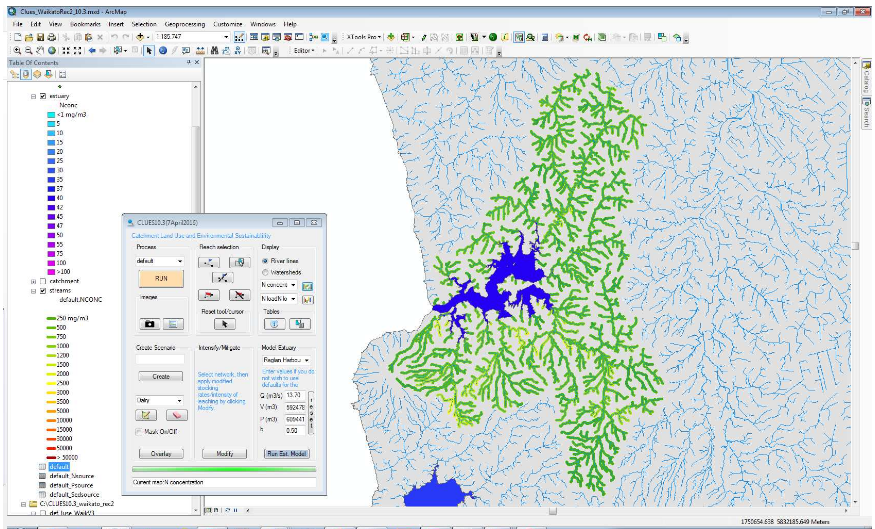


2. Select the type of map to be displayed by checking either the River lines or Watersheds radio buttons. Note that river line maps are not available for generated yields.



5. Select the water quality indicator output to be displayed using the map dropdown menu and click the map display button.





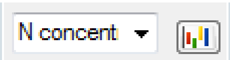
9.1.2 Bar chart maps

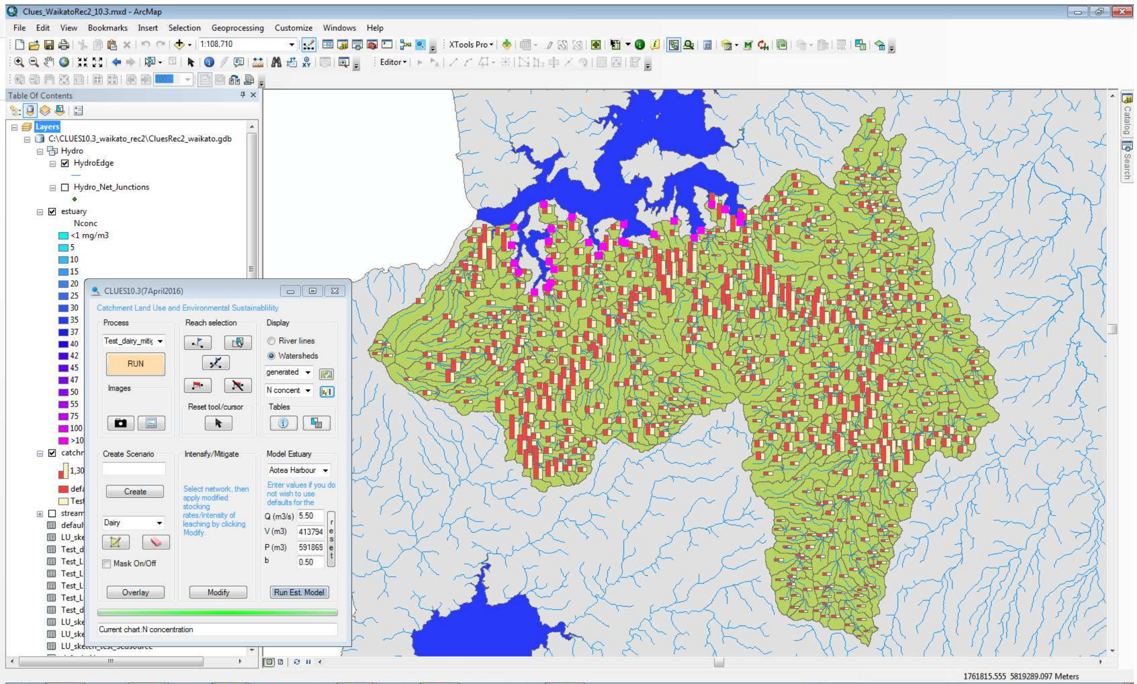
Bar chart maps can only be generated when a scenario other than the default has been created and run. They indicate the difference in the selected model output between the default and selected scenario in map form. In this example, the default scenario is compared to the outputs of the interactive dairy farm mitigation scenario produced in Section 8.1.1.

1. Select the scenario to be compared with the default scenario from the scenario drop-down menu.

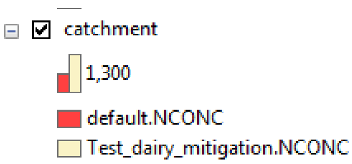
2. Run CLUES for both the selected scenario and the default with the same reach selection.

3. Select the water quality indicator to be compared from the bar chart drop down menu (here TN concentrations are compared) and click the bar chart map button.





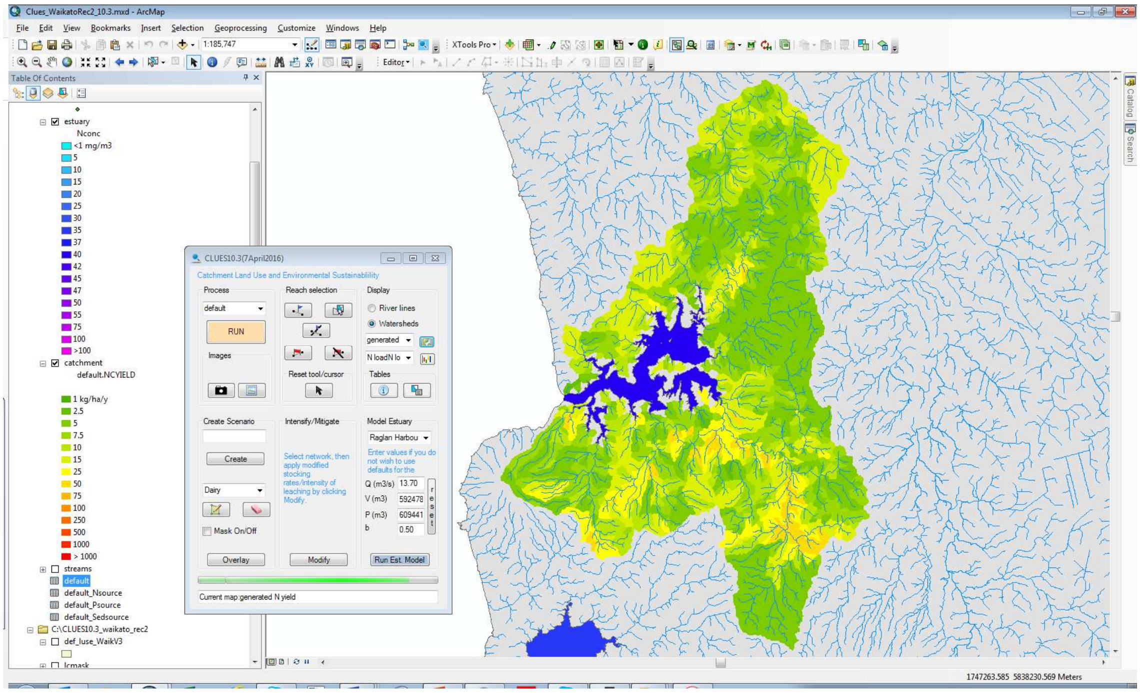
The bar chart symbology is listed in the TOC under the catchment feature class



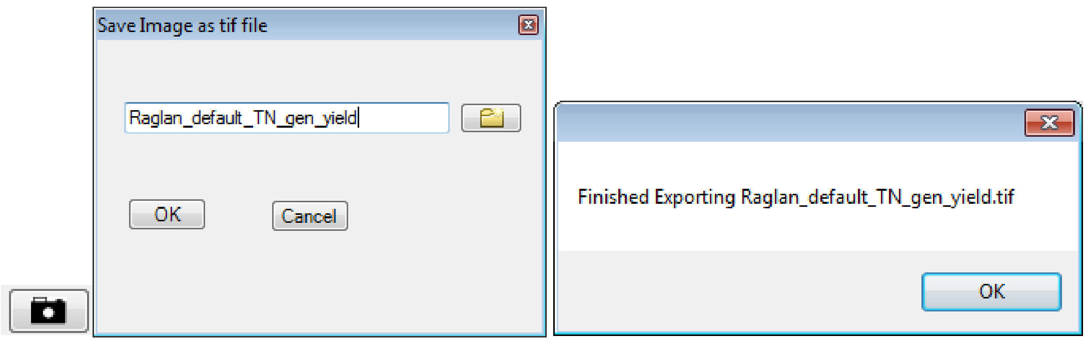
9.1.3 Making a geo-referenced .tif file map image

The results generated by CLUES for a particular river reach selection and scenario are updated after every model run. This means that CLUES cannot toggle between the model outputs for different river reach selections modelled with the same land use scenario. The CLUES Image tools allow result maps or charts of different catchment selections to be compared by creating a geo-referenced .tif file of the display screen. The tif image file is saved for later display within ArcMap or for use in a document. Geo-referencing means that images can be panned or zoomed within ArcMap for the extent covered in the image.

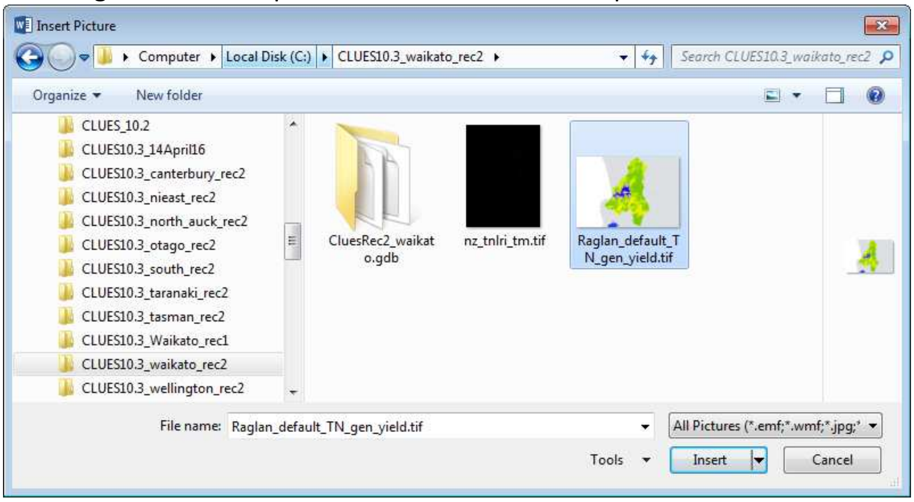
1. Run CLUES for the selected river reaches and display the outputs to be saved. In this example, a .tif file is created for the default TN generated yield watershed map for Raglan Harbour.

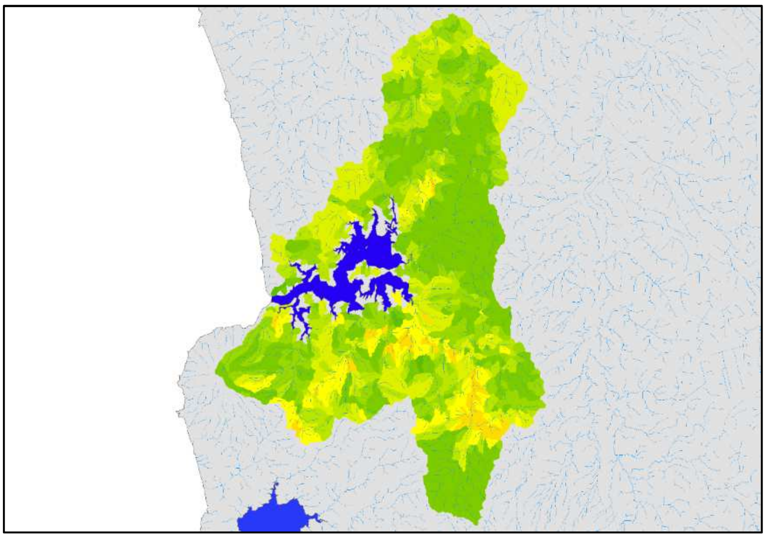


6. Click the CLUES imaging tool and save the image with a suitable name (use underscores rather than spaces in the file name). The default file location is the CLUES regional directory (i.e., the map document home directory). To choose another location, browse and save accordingly.

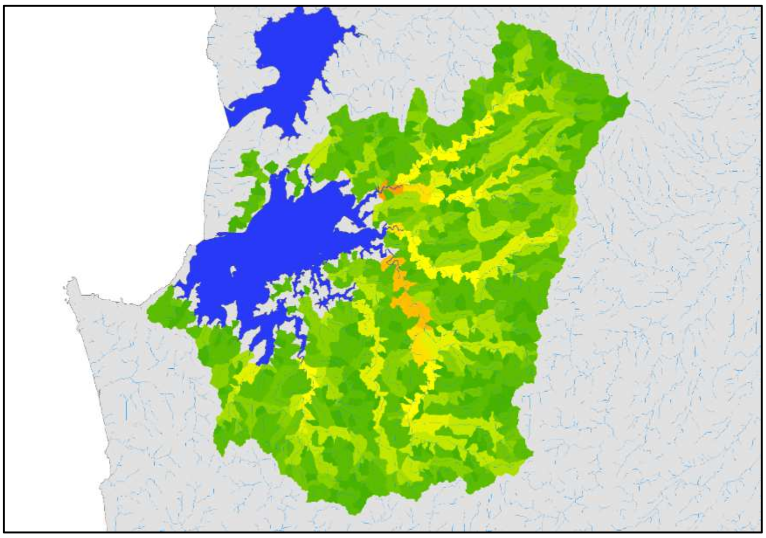


7. The image will be saved into the directory and can be imported into other documents, here the image has been imported into this manual as a picture file.

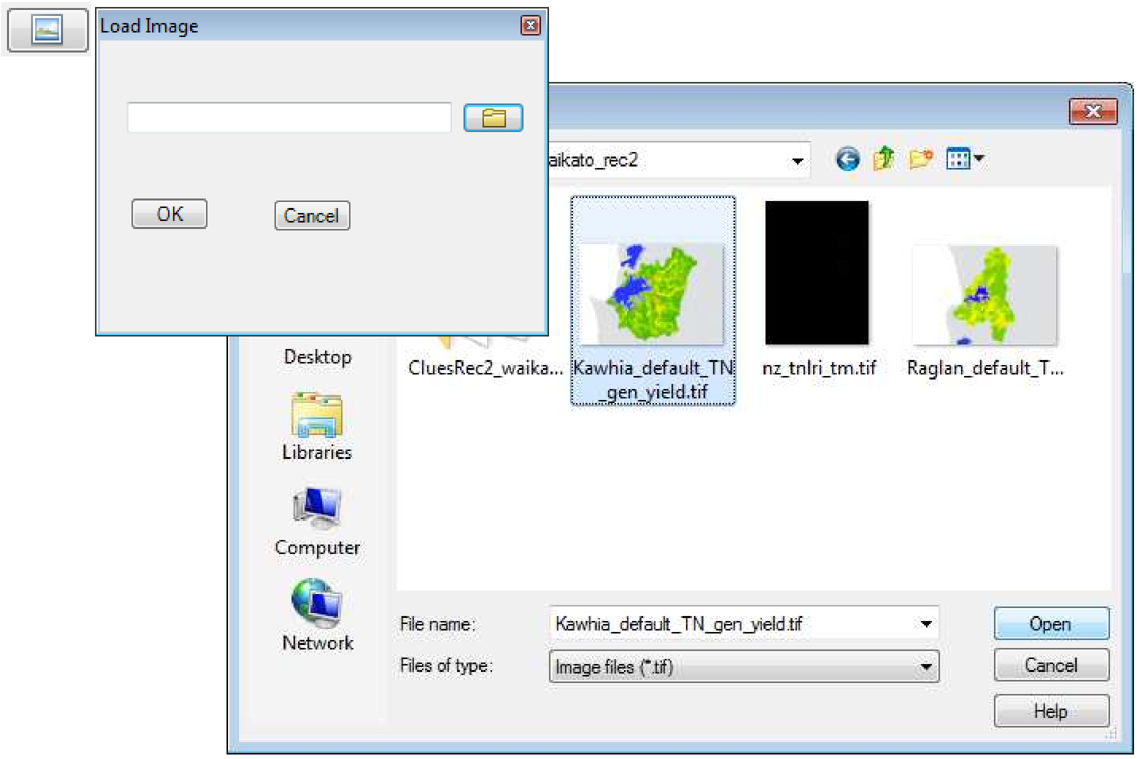


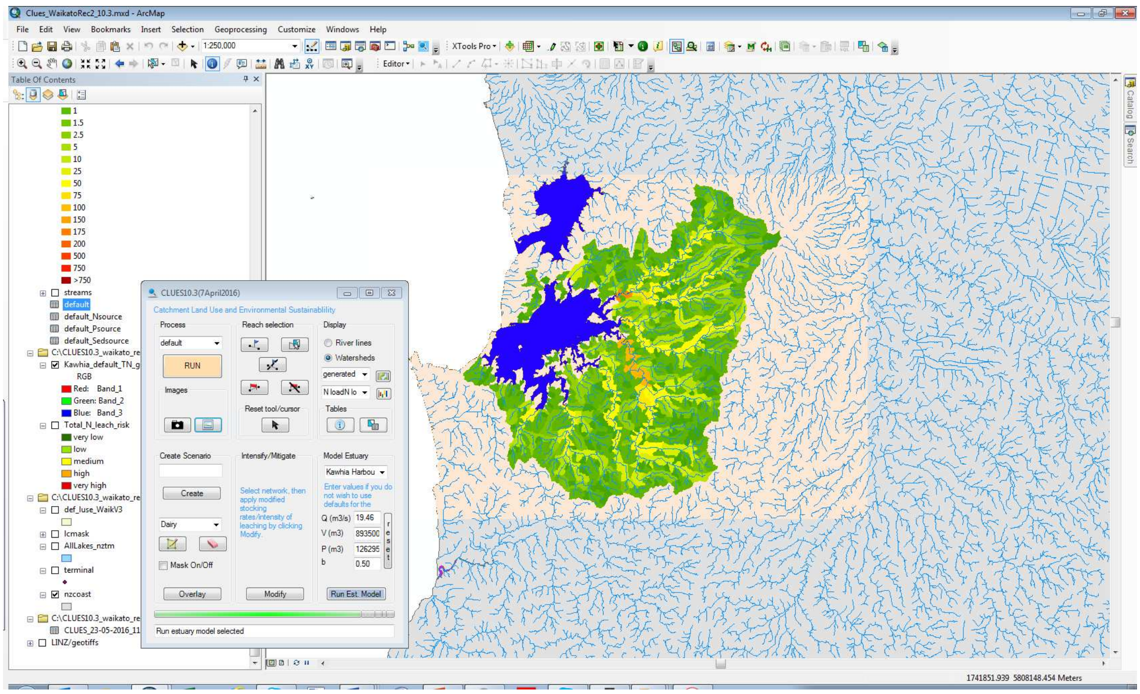


8. The .tif files can be used to compare the outputs from different locations. In this example, another .tif file image has been created for the Kawhia Harbour default TN generated yields.

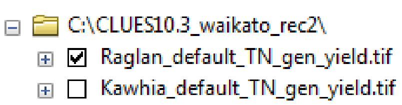


9. The .tif file images can be imported into back into CLUES by clicking the load image button. Browse and select the image to display.





The image will be displayed for the extent of the image. Since the image is geo-referenced, it can be zoomed and panned within its extent. To turn the image off, ensure that the TOC source tab is open and uncheck the image. Multiple .tif file images can be displayed.

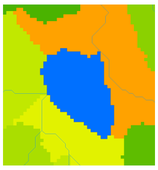


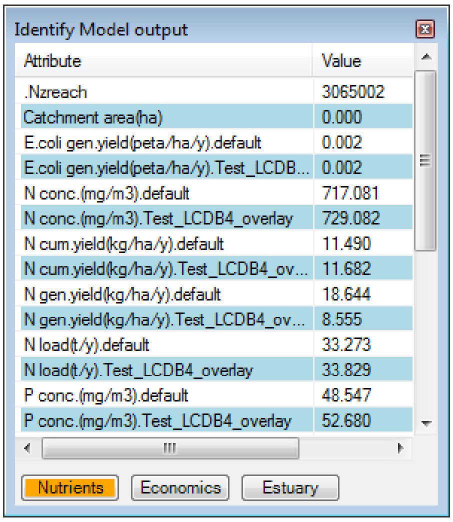
9.2 ID table tool

The ID table tool is used to report the water quality and socio-economic indicators for a single sub-catchment or to report the TN and TP concentrations for a selected estuary. In this example, the outputs generated by the imported LCDB4 land use scenario (see Section 7.2) are examined.

1. Select the scenario to be displayed and click on the ID table button on the CLUES interface to activate the ID table tool.

2. Click on a REC sub-catchment to open the table. The default display is the Nutrient tab. Notice that the sub-catchment will flash in a contrasting colour when it is selected. The NZREACH gives the NZ reach number for REC1 or the NZ segment number for REC2.

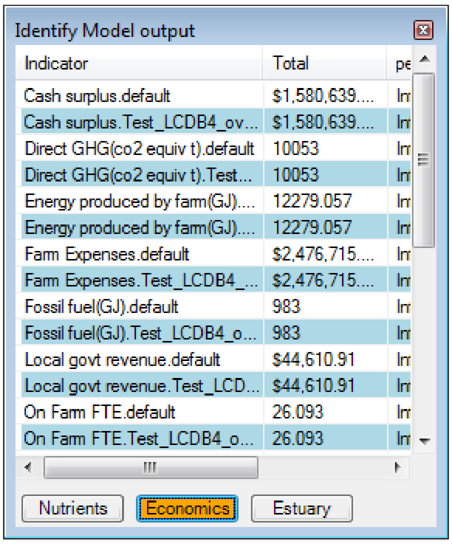



Identify Model output

Attribute	Value
.Nzreach	3065002
Catchment area(ha)	0.000
E.coli gen.yield(peta/ha/y).default	0.002
E.coli gen.yield(peta/ha/y).Test_LCDB...	0.002
N conc.(mg/m3).default	717.081
N conc.(mg/m3).Test_LCDB4_overlay	729.082
N cum.yield(kg/ha/y).default	11.490
N cum.yield(kg/ha/y).Test_LCDB4_ov...	11.682
N gen.yield(kg/ha/y).default	18.644
N gen.yield(kg/ha/y).Test_LCDB4_ov...	8.555
N load(t/y).default	33.273
N load(t/y).Test_LCDB4_overlay	33.829
P conc.(mg/m3).default	48.547
P conc.(mg/m3).Test_LCDB4_overlay	52.680

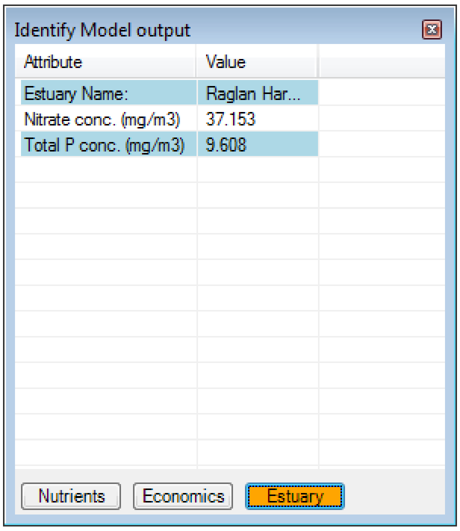
If a scenario other than the default is selected for display, the ID table will show the outputs for both the default and selected scenarios. A values of -0.1 indicates that the reach was not selected for the model run.

3. To display the socio-economic indicators, activate the Economics button and reselect the sub-catchment by clicking on it. Again, the ID table will show the outputs for both the default scenario and the selected scenario.

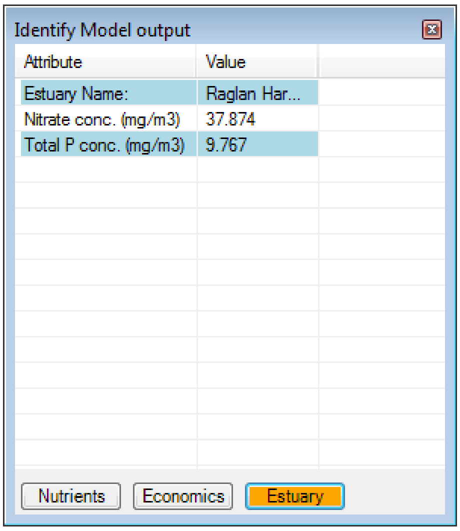

Identify Model output

Indicator	Total	pe
Cash surplus.default	$1,580,639....	In
Cash surplus.Test_LCDB4_ov...	$1,580,639....	In
Direct GHG(co2 equiv t).default	10053	In
Direct GHG(co2 equiv t).Test...	10053	In
Energy produced by farm(GJ)....	12279.057	In
Energy produced by farm(GJ)....	12279.057	In
Farm Expenses.default	$2,476,715....	In
Farm Expenses.Test_LCDB4_...	$2,476,715....	In
Fossil fuel(GJ).default	983	In
Fossil fuel(GJ).Test_LCDB4_o...	983	In
Local govt revenue.default	$44,610.91	In
Local govt revenue.Test_LCD...	$44,610.91	In
On Farm FTE.default	26.093	In
On Farm FTE.Test_LCDB4_o...	26.093	In

4. To view the estuary nutrient concentrations, run CLUES Estuary for the selected estuary. Open the ID table for any reach then activate the estuary button and then click on the estuary. Note that only the outputs for the most recent CLUES Estuary model run are displayed for estuaries as the model outputs are saved directly into the Estuary attribute table and replace the outputs for the selected estuary of any previous model run. Here CLUES Estuary outputs for the default and imported land use scenario are displayed. They were generated successively by running CLUES Estuary for the default scenario, recording the results and then rerunning the model for the land use scenario.



Default scenario

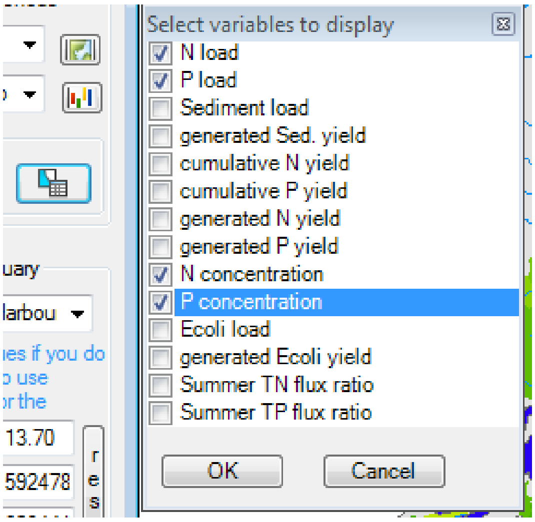


LCDB4 imported land use scenario

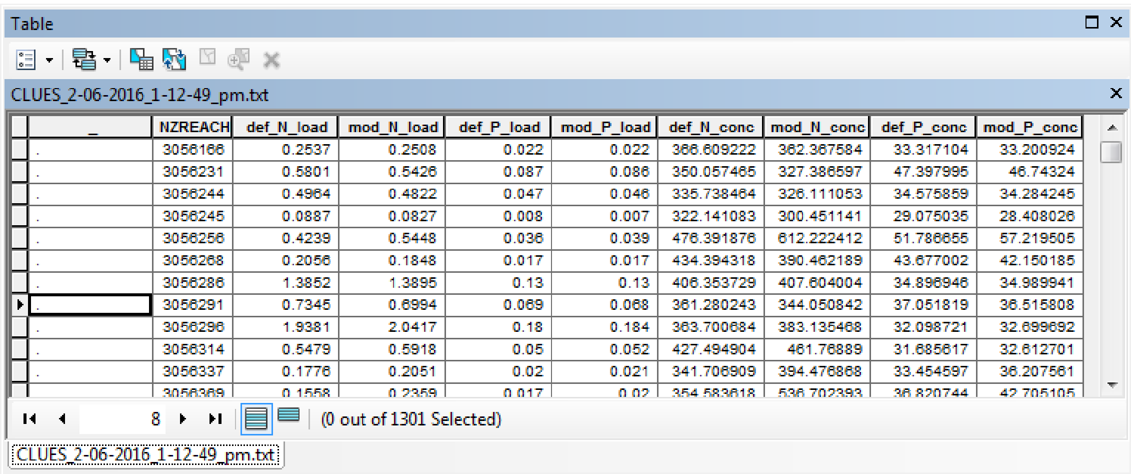
9.3 Run summary tables

The run summary table tool reports user selected water quality outputs for all the reaches simulated in a model run. The model outputs are listed for each reach selected identified by river reach ID number (NZ reach for REC1 or NZ segment for REC2) in the NZREACH field. The summary table is saved as a text file which means it can be opened directly in another package such as Excel for further analysis or plotting. The inclusion of the reach number as an identifier means the table can be joined to the geodatabase feature classes for later analysis or display. Here a summary table is created to compare the nutrient loads and concentrations estimated for the default and the imported land use scenarios

1. Select the scenario to be displayed and click on the summary table button on the CLUES interface to activate the ID table tool. This will open a list of water quality indicators available for reporting. Click on the radio buttons to select the results of interest.

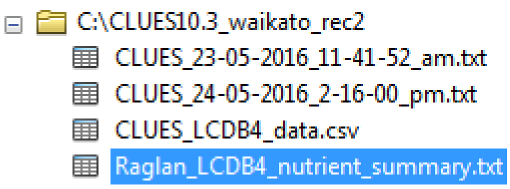


2. The summary table will report the checked outputs for each reach selected for the model run. Note that if a scenario other than the default is selected, the table shows the outputs for both this scenario and the default. A value of -0.1 for the default indicates that the reach was not selected for the default run (it is always a good idea to run both the default and the scenario for each reach selection).

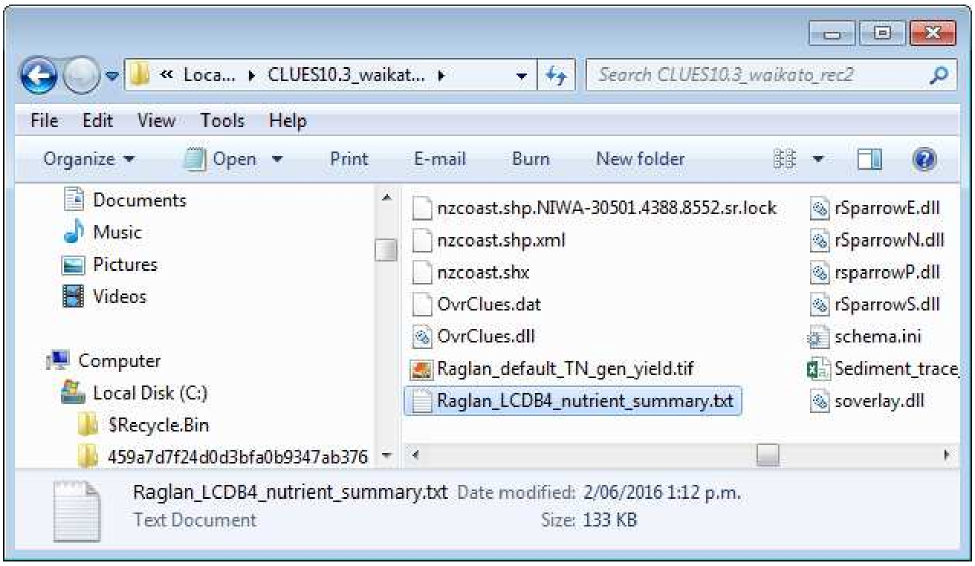


_	NZREACH	def_N_load	mod_N_load	def_P_load	mod_P_load	def_N_conc	mod_N_conc	def_P_conc	mod_P_conc
.	3056166	0.2537	0.2508	0.022	0.022	366.609222	362.367584	33.317104	33.200924
.	3056231	0.5801	0.5426	0.087	0.086	350.057465	327.386597	47.397995	46.74324
.	3056244	0.4964	0.4822	0.047	0.046	335.738464	326.111053	34.575859	34.284245
.	3056245	0.0887	0.0827	0.008	0.007	322.141083	300.451141	29.075035	28.408026
.	3056256	0.4239	0.5448	0.036	0.039	476.391876	612.222412	51.786655	57.219505
.	3056268	0.2056	0.1848	0.017	0.017	434.394318	390.462189	43.677002	42.150185
.	3056286	1.3852	1.3895	0.13	0.13	406.353729	407.604004	34.896946	34.989941
.	3056291	0.7345	0.6994	0.069	0.068	361.280243	344.050842	37.051819	36.515808
.	3056296	1.9381	2.0417	0.18	0.184	363.700684	383.135468	32.098721	32.699692
.	3056314	0.5479	0.5918	0.05	0.052	427.494904	461.76889	31.685617	32.612701
.	3056337	0.1776	0.2051	0.02	0.021	341.706909	394.476868	33.454597	36.207561
	3056369	0.1558	0.2359	0.017	0.02	354.583618	536.702393	36.820744	42.705105

3. The table is saved automatically by CLUES in the regional geodatabase directory as a text file and will be listed in the TOC under the Source tab which will be activated automatically. The naming convention of the table and file is CLUES_datetime.txt, in this example, the table was created on 2nd June 2016 at 1:12:49 pm.



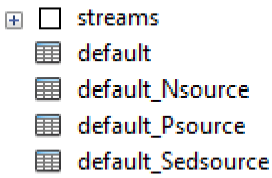
4. The summary tables can be reopened in ArcGIS or viewed in other software packages that can read text files for reporting or post processing. It is a good idea for future reference to rename the tables according to the run selection or scenario. While tables can be renamed for display in the TOC, the original file name will remain unchanged. The filename can be changed using Windows Explorer or ArcCatalog (you will have to remove it from the map document first and then re-import it under the new name).



9.4 Contaminant tracing tables

Nutrient and sediment tracing tables are created automatically for each scenario after a model run. They can be used to determine the loads and yields generated by each land use with a sub-catchment at any point in the drainage network. The model outputs are listed for each reach selected identified by river reach ID number (NZ reach for REC1 or NZ segment for REC2) in the NZREACH field. The tables are updated for the current reach selection each time CLUES is run. Since the tables are overwritten each time the scenario is run, users should save or export them under new names if multiple runs (e.g. with different reach selections) are made for the same scenario using different reach selections.

1. The tracing tables can be seen in the TOC when the source tab is active and are saved as geodatabase tables in the CLUES geodatabase.

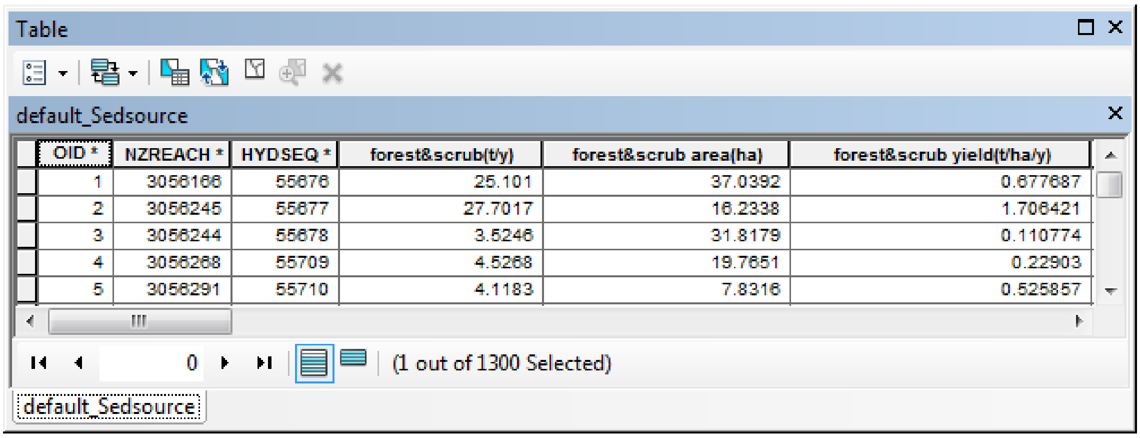


5. The tracing tables for the different contaminants are slightly different with regard to the land use classes they contain due to the way in which CLUES aggregates land use data for load calculation (see Appendix C for the land use classes supplied for each contaminant).

6. Two sets of results are provided for each reach and land use class. The first set of outputs are the loads and yields generated within each reach. That is, for each land use class, the yields represent the amount of contaminant generated by that land use class per unit area and the load is the product of the yield and the area covered by the land use class.

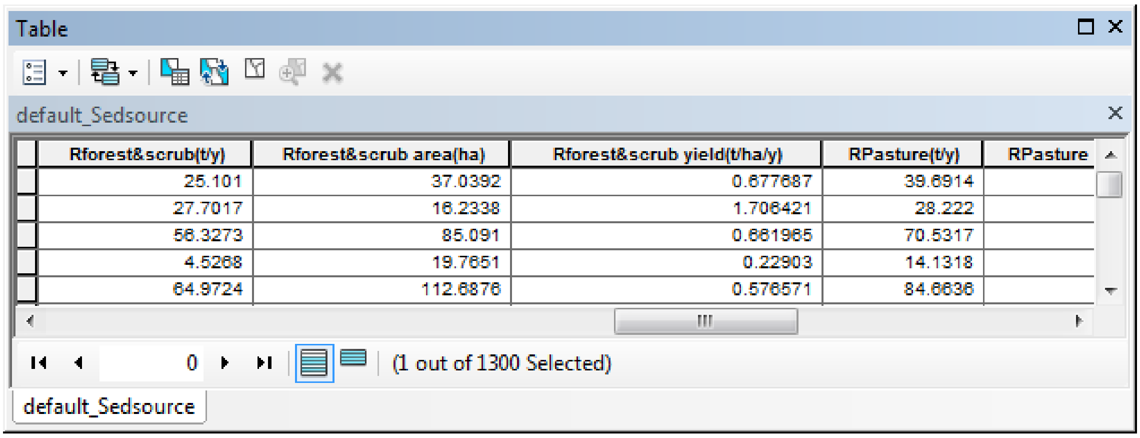
   The second set of outputs are prefixed by the letter R and represent the instream (i.e., cumulative) load or yield for each land use. The instream load is the sum of the load generated within the catchment and the load from upstream for each land use less any reservoir attenuation. The cumulative yield for each land use class is the instream load for that land use class divided by the total upstream area covered in by the land use class.

   For example, from the sediment tracing table for the default scenario shown below, the headwater reaches 3056166 (37.04ha) and 3056245 (16.23 ha) flow into reach 3056244 (31.82 ha). These reaches have sediment loads generated by their respective sub-catchments of 25.10, 27.70 and 3.52 t/yr and their generated yields are 0.68, 1.71 and 0.11 t/ha/y. Since they are headwater streams with no reservoirs, reaches 3056166 and 3056245 have the same instream loads and cumulative yields as their generated loads and yields. However, the instream load for 305644 is the sum of the upstream loads and the generated load from the reach (56.33 t/y) while the cumulative yield is the instream load divided by the total upstream area (85.09 ha), which is 0.66 t/ha/y.

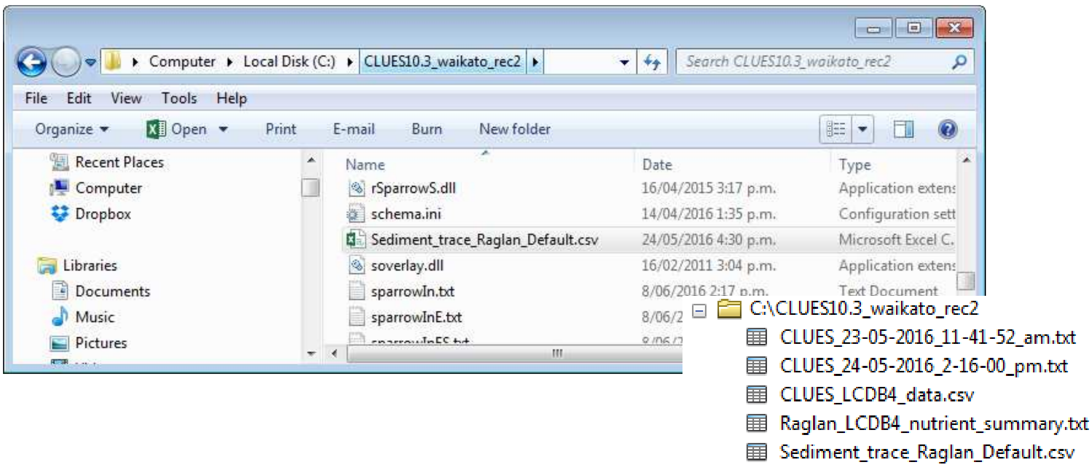


▲ Generated sediment loads, area and yields by reach calculated for the forest and scrub (trees) land use aggregate.

▼ Instream (cumulative) loads, areas and yields for the forest and scrub land use aggregate calculated for the same selection of reaches.



7. Since the tracing tables are automatically updated after every CLUES run for a particular scenario, if they are required for future reference, export them to a new file under a new name. In this example, the default sediment table has been exported from the tracing table as a text file saved to the regional directory and then imported back into ArcMap.



9.5 Comparing results for scenarios other than the default

CLUES does not have tools that allow the outputs of a scenario to be compared to scenarios other than the default scenario. However, the outputs from different scenarios can be compared using ArcGIS geo-visualisation and spatial analyst tools (see below) or by exporting result tables (e.g., run summary and contaminant tracing tables) to another software package for post processing.

9.6 Geo-visualisation, spatial analysis and customised symbology

Geo-visualisation is a defining part of any spatial decision support system as it improves understanding and facilitates communication between different sets of stakeholders. The GIS platform means that the suite of mapping tools supplied with ArcGIS can be used to further explore CLUES input and output data. Users are also able to add their own feature classes to the CLUES map document to enhance display.

When CLUES displays a map of a particular water quality variable, the scenario table for the selected scenario is automatically joined to either the stream (riverline maps) or catchment (watershed and bar chart maps) layers. The symbology for these layers is automatic and is updated each time a water quality variable or scenario is mapped. The symbology is based on a Natural Jenks distribution for CLUES default output at a national level. It is possible to customise the model output directly for the CLUES catchment and stream feature classes, however, it is recommended that these layers are exported as new feature classes first. Exporting these layers as new feature classes preserves the spatial relationship between the model results for a specific scenario and the spatial geometry held in CLUES geodatabase.

In addition to customised symbology, creating new feature classes for different scenarios opens the possibility of undertaking spatial analysis of the model results to derive new data sets such as changes in yields between scenarios or sub-catchment rankings. Two examples are shown in Figure 9-1. In the first (Figure 9-1 left), CLUES-estimated TN concentrations were split into three bands according to Waikato Regional Council's water quality classification for nitrogen. Median annual TN concentration data derived from Waikato State of Environment reporting are also displayed. The second example (Figure 9-1 right) shows the change in estimated TN generated yields between pre-European (1770) and contemporary (2002, i.e., LCDB2) land use scenarios simulated for the Kaipara Harbour (Semadeni-Davies, 2012). The inset shows contemporary forested areas and sheep and beef, and dairy farming based on LCDB2. The location of marae and catchment boundaries are also mapped and labelled.

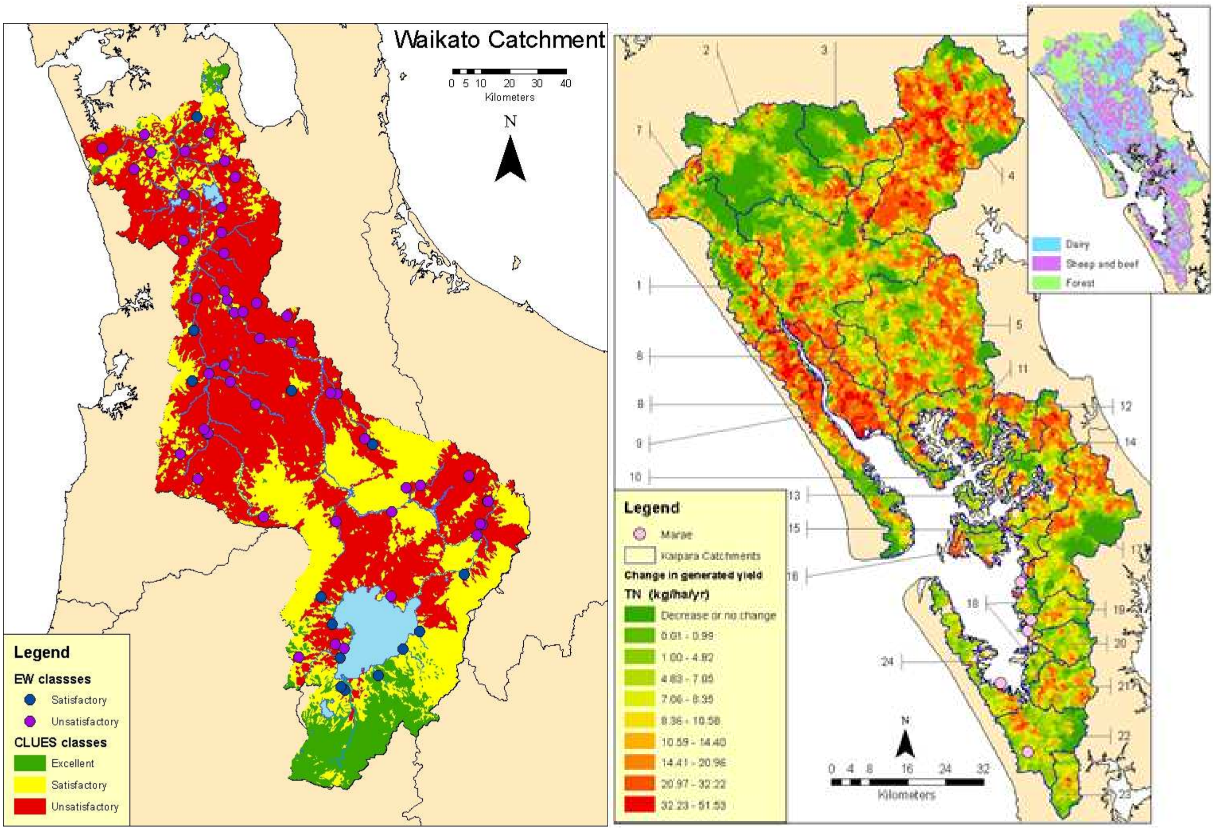


Figure 9-1: Customised display of CLUES output demonstrating the potential for geo-visualisation.
Left: TN concentrations classified according to Waikato Regional Council water quality bands compared to 5-year SOE median concentrations (2003-2007). Semadeni-Davies et al. (2009), prepared using CLUES 2.0.6.
Right: Change in estimated TN generated yields between 1770 and 2002. Inset shows primary land uses in the study area derived from LCDB2. Marae locations are labelled. Semadeni-Davies (2012), prepared using CLUES 3.1.

Acknowledgements

This manual has been prepared as part of NIWA's CLUES core funding project (FWWQ1605). Special thanks to Dan Borman at the Waikato Regional Council for the use of the council's LCDB4 land use data.

References

Argent, R.M., Perraud, J.M., Rahman, J.M., Grayson, R.B. and Podger, G.M. (2009) A new approach to water quality modelling and environmental decision support systems. *Environmental Modelling & Software*, 24(7): 809-818. http://dx.doi.org/10.1016/j.envsoft.2008.12.010

Armstrong, M.P., Densham, P.J. and Ruston, G. (1986) Architecture for a microcomputer-based decision support system. *Proceedings 2nd International Symposium on Spatial Data Handling*, Williamsville.

AsureQuality (2008 base-line year) AgriBase ™ Rural properties database. http://www.asurequality.co.nz/capturing-information-technology-across-the-food-supply-chain/agribase-database-of-new-zealand-rural-properties.cfm

Croke, J.C. and Hairsine, P.B. (2006) Sediment delivery in managed forests: a review. *Environmental Reviews*, 14: 59-87. 0.1139/A05-016

CSIRO (2011) CSIRO Atlas of Regional Seas (CARS). www.cmar.csiro.au/cars

Densham, P.J. (1991) Spatial decision support systems In: D.J. Maguire, M.F. Goodchild & R. D.W. (Eds). *Geographical Information Systems: Principles and Applications*. Harlow, Longman, John Wiley & Sons Inc., New York.

Elliott, A., Alexander, R., Schwarz, G., Shankar, U., Sukias, J. and McBride, G. (2005a) Estimation of nutrient sources and transport for New Zealand using the hybrid mechanistic-statistical model SPARROW. *Journal of Hydrology (New Zealand)*, 44(1): 1.

Elliott, A.H., Alexander, R.B., Schwarz, G.E., Shankar, U., Sukias, J.P.S. and McBride, G.B. (2005b) Estimation of Nutrient Sources and Transport for New Zealand using the Hybrid Mechanistic-Statistical Model SPARROW. *Journal of Hydrology (New Zealand)*, 44(1): 1-27.

Elliott, S. and Oehler, F. (Year) Prediction of nutrient concentrations from mean annual loads. *New Zealand Hydrological & Freshwater Science Societies Joint Conference, Whangarei, Northland, 23-27 November 2009*.

Elliott, S., Oehler, F. and Booker, D. (Year) Regression alchemy for temporal disaggregation of mean annual loads. *21st Century Watershed Technology Conference and Workshop*, University of Waikato, New Zealand.

Eyles, G. and Fahey, B. (2006) The Pakuratahi land use study: a 12-year paired catchment study of the Environmental effects study of Pinus Radiata Forestry, Hawke's Bay Regional Council Plan No. 3868.: 128.

Fahey, B., Marden, M. and Phillips, C. (2003a) Sediment yields from plantation forestry and pastoral farming, coastal Hawke's Bay, North Island, New Zealand. *Journal of Hydrology (NZ)*, 42(1): 27 - 38.

Fahey, B.D. and Marden, M. (2000) Sediment yields from a forested and a pasture catchment, coastal Hawke's Bay, North Island, New Zealand. *Journal of Hydrology (NZ)*, 39(1): 49-63.

Fahey, B.D., Marden, M. and Phillips, C.J. (2003b) Sediment yields from plantation forestry and pastoral farming, coastal Hawke's Bay, North Island, New Zealand. *Journal of Hydrology (NZ)*, 42(1): 27-38.

Geertman, S. and Stillwell, J. (2003) Interactive support systems for participatory planning. In: S. Geertman & J. Stillwell (Eds). *Planning support systems in practice. Advances in Spatial Science*. Springer-Verlag, Berlin, Heidelberg, New York.

Gillibrand, P.A., Inall, M.E., Portilla, E. and Tett, P. (2013) A box model of the seasonal exchange and mixing in regions of restricted exchange: application to two contrasting Scottish inlets. *Environmental Modelling & Software*, 43: 144-159.

Harris, S., Elliott, S., McBride, G., Shankar, U., Quinn, J., Wheeler, D., Wedderburn, L., Hewitt, A., Gibb, R. and Parfitt, R. (Year) Integrated assessment of the environmental, economic and social impacts of land use change using a GIS format–the CLUES model. *New Zealand Agricultural and Resource Economics Society Conference August*.

Hughes, A., Semadeni-Davies, A. and Tanner, C. (2013a) Nutrient and sediment attenuation potential of wetlands in Southland and South Otago dairying areas. NIWA Client Report prepared for the Pastoral 21 Research Programme under subcontract to AgResearch, HAM2013-016 (under review).

Hughes, A., Semadeni-Davies, A. and Tanner, C. (2013b) The water quality attenuation potential of wetlands in Southland and south Otago dairying areas.

Hughes, A.O., Quinn, J.M. and McKergow, L.A. (2012) Land use influences on suspended sediment yields and event sediment dynamics within two headwater catchments, Waikato, New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 46(3): 315-333.

Hume, T.M., Snelder, T., Weatherhead, M. and Liefting, R. (2007a) A controlling factor approach to estuary classification. *Ocean & Coastal Management*, 50(11–12): 905-929. http://dx.doi.org/10.1016/j.ocecoaman.2007.05.009

Hume, T.M., Snelder, T., Weatherhead, M. and Liefting, R. (2007b) A controlling factor approach to estuary classification. *Ocean Coast Management*, 50(11-12): 905-929.

Landcare Research ltd (2013) Land Cover Database - version 3 (LCDB3). https://lris.scinfo.org.nz/layer/304-lcdb-v30-land-cover-database-version-3-deprecated/

Leathwick, J.R., Morgan, F., Wilson, G., Rutledge, D., Mcleod, M. and Johnston, K. (2002) Land Environments of New Zealand: Technical Guide, Prepared by Landcare Research Ltd for the Ministry for the Environment. http://www.landcareresearch.co.nz/resources/maps-satellites/lenz http://www.mwpress.co.nz/soil/land-environments-of-new-zealand

Litschert, S.E. and MacDonald, L.H. (2009) Frequency and characteristics of sediment delivery pathways from forest harvest units to streams. *Forest Ecology and Management*, 259(2): 143-150. http://dx.doi.org/10.1016/j.foreco.2009.09.038

Luketina, D. (1998) Simple tidal prism models revisited. *Estuarine, Coastal and Shelf Science*, 46(1): 77-84.

Marden, M. and Rowan, D. (1993) Protective value of vegetation on tertiary terrain before and during Cyclone Bola, east coast, North Island, New Zealand. *New Zealand Journal of Forestry Science*, 23: 255-263.

Monaghan, R.M., Semadeni-Davies, A., Muirhead, R.W., Elliott, S. and Shankar, U. (2010) Land use and land management risks to water quality in Southland. Report prepared for Environment Southland by AgResearch.,

Motha, J.A., Wallbrink, P.J., Hairsine, P.B. and Grayson, R.B. (2003) Determining the sources of suspended sediment in a forested catchment in southeastern Australia. *Water Resources Research*, 39(3): doi:10.1029/2001WR000794.

Newsome, P.F.J., Wilde, R.H. and Willoughby, E.J. (2008) Land Resource Information System spatial data layers: Data Dictionary, Landcare Research New Zealand Ltd.

Oehler, F. and Elliott, A.H. (2011) Predicting stream N and P concentrations from loads and catchment characteristics at regional scale: A concentration ratio method. *Science of the Total Environment*(409): 5392-5402.

Phillips, C., Marden, M. and Basher, L. (2007) Review of sediment generation processes in exotic forestry and the applicability of using compound-specific isotopes to understand sediment movement, Landcare Research Contract Report: LC0607/151.

Plew, D.R., Zeldis, J.R., Shankar, U. and Elliott, S. (2015) CLUES Estuary - a tool for predicting estuary water quality. *Australasian Coasts & Ports Conference*, Auckland, New Zealand, 15-18 September 2015.

Ridgway, K.R., Dunn, J.R. and Wilkin, J.L. (2002) Ocean interpolation by four-dimensional least squares - application to the waters around Australia. *Journal Atmospheric and Oceanic Technology* 19(9): 1357-1375.

Roberts, A.H.C. and Watkins, N. (2014) One nutrient budget to rule them all – the OVERSEER® best practice data input standards. In: L.D. Currie & C.L. Christensen (Eds). *Nutrient Management for the Farm, Catchment and Community, Occasional Report No. 27*. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. http://flrc.massey.ac.nz/publications.html
Rosen, M.R., Reeves, R.R., Green, S., Clothier, B. and Ironside, N. (2004) Prediction of groundwater nitrate contamination after closure of an unlined sheep feedlot. *Vadose Zone Journal*, 3(3): 990-1006.
Schwarz, G.E., Hoos, A.B., Alexander, R.B. and Smith, R.A. (2006) *The SPARROW Surface Water-Quality Model – Theory, Application, and User Documentation. U.S. Geological Survey Techniques and Methods, Book 6, Section B. Chapter 3*. USGS, Reston, Virginia.
Semadeni-Davies, A. (2012) CLUES for Kaipara Harbour Drainage Area Land use comparison 1770-2002. Prepared for AgResearch (sub-contract to MSI). NIWA Client Report: AKL2012-003.
Semadeni-Davies, A. and Elliot, S. (2013) Impact of stock exclusion on E. coli concentrations: Application of the CLUES model to the lower Waikato River catchment, Prepared for Minsitry for the Environment, NIWA Client Report No: HAM2013-108 (under client review).
Semadeni-Davies, A. and Elliott, A.H. (Year) CLUES modelling of E. coli in the upper Waikato River catchment. *21st Century Watershed Technology Conference and Workshop*, University of Waikato, Hamilton, New Zealand, 3-6 November 2014.
Semadeni-Davies, A., Elliott, S., McBride, G. and Shankar, U. (2009) Using CLUES to identify impact catchments - Waikato River Catchment Pilot Study.
Semadeni-Davies, A., Shankar, U. and Hughes, A. (2015) Modification of the CLUES model: Addition of forestry management tools and contaminant tracing tools Prepared for Envirolink / Tasman District Council. NIWA Client report: AKL2015-011.
Shepherd, M. and Wheeler, D. (2013) How nitrogen is accounted for in OVERSEER® Nutrient Budgets. In: L.D. Currie & C.L. Christensen (Eds). *Accurate and efficient use of nutrients on farms. Occasional Report No. 26.* . Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. http://flrc.massey.ac.nz/publications.html
Shepherd, M., Wheeler, D., Selbie, D., L., B. and Freeman, M. (2013) OVERSEER®: Accuracy, precision, error and uncertainity. In: L.D. Currie & C.L. Christensen (Eds). *Accurate and efficient use of nutrients on farms. Occasional Report No. 26.* . Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. http://flrc.massey.ac.nz/publications.html
Snelder, T., Biggs, B. and Weatherhead, M. (2010) New Zealand River Environment Classification User Guide. March 2004 (Updated June 2010), ME Number 499.
van Delden, H., Seppelt, R., White, R. and Jakeman, A.J. (2011) A methodology for the design and development of integrated models for policy support. *Environmental Modelling & Software*, 26(3): 266-279. http://dx.doi.org/10.1016/j.envsoft.2010.03.021
Vant, B. (2014) Sources of nitrogen and phosphorus in the Waikato and Waipa Rivers, 2003–12, Waikato Regional Council Technical Report 2014/56.
Wheeler, D., Shepherd, M., Freeman, M. and Selbie, D. (2014) OVERSEER® nutrient budgets: selecting appropriate timescales for inputting farm management and climate information. In: L.D. Currie & C.L. Christensen (Eds). *Nutrient Management for the Farm, Catchment and Community, Occasional Report No. 27*. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. http://flrc.massey.ac.nz/publications.html
Woods, R., Elliott, S., Shankar, U., Bidwell, V., Harris, S., Wheeler, D., Clothier, B., Green, S., Hewitt, A., Gibb, R. and Parfitt, R. (2006) The CLUES Project: Predicting the Effects of Land-use on Water Quality – Stage II. NIWA Client Report HAM2006-096.
Woods, R., Hendrikx, J., Henderson, R. and Tait, A. (2006) Estimating Mean flow of New Zealand rivers. *Journal of Hydrology (NZ)*, 45(2): 95-110.
Zeldis, J., Shankar, U., Plew, D., Unwin, M. and Hoyle, J. (2012) Potential nutrient concentrations of Waikato Region Estuaries and preliminary estimates of their trophic state. Prepared for Waikato Regional Council.

Appendix A CLUES software terms and conditions for use

CAREFULLY READ THE TERMS AND CONDITIONS OF THIS LICENCE BEFORE YOU INSTALL, EXECUTE OR USE THE CLUES SOFTWARE. BY INSTALLING, EXECUTING OR USING CLUES YOU BECOME THE LICENSEE TO THIS LICENCE AND CONSENT TO BE BOUND BY ITS TERMS AND CONDITIONS. IF YOU DO NOT WISH TO ACCEPT THE TERMS PROMPTLY RETURN THE UNINSTALLED/UNEXECUTED CLUES SOFTWARE TO NIWA.

1. LICENCE

1.1 National Institute of Water & Atmospheric Research Limited, a duly incorporated company having its registered office in New Zealand ("NIWA"), is the owner, and/or licensee, of copyright and other intellectual property in software to, amongst other things, predict the impacts of land-use changes on water quality and socio-economic indicators and the cumulative effects of multiple nutrient and sediment inputs at a larger catchment scale and any associated user documentation (collectively "CLUES"). Upon installation, execution and/or use of CLUES you accept a non-exclusive, non-transferable licence to use CLUES upon the terms and conditions contained herein. You do not receive title to, or any interest or other proprietary rights in, CLUES whatsoever.

1.2 This licence does not include any support services in relation to CLUES ("Software Support Services"). Any Software Support Services that you may require must first be agreed with NIWA and shall be provided pursuant to a separate agreement with NIWA.

2. PERMISSIBLE USES

2.1 You may:

a. Use CLUES, on your internal systems, solely as an end user and only for your Internal Purposes. For the purposes of this licence "Internal Purpose" means your usual internal operational and planning functions, which where you have a public safety or interest function, includes use for public good purposes such as issuing public safety warnings, or carrying out your prescribed regulatory functions. However, for the avoidance of doubt expressly excludes undertaking or providing catchment modelling or other environmental research or consultancy services to third parties, on a contract or revenue generating basis;

b. Copy CLUES into any machine-readable or printed form for the purposes of transferring CLUES between internal systems and for archive or back-up purposes.

3. YOUR UNDERTAKINGS

3.1 You undertake not to perform any of the acts referred to in this clause and sub-clauses, except to the extent expressly permitted in this licence or with NIWA's prior written consent. You may not:

1.1.1 Distribute, supply or sub-licence CLUES (or any component thereof) to any third party;

1.1.2 Translate, adapt, modify, develop or alter CLUES or any part of it;

1.1.3 Disassemble, decompile or reverse engineer CLUES or directly or indirectly allow a third party to disassemble, decompile, or reverse engineer the whole or any part of CLUES.

1.1.4 Merge all or any part of CLUES with any other software;

1.1.5 Remove or obliterate from CLUES any copyright notice applied by NIWA;

1.1.6 Disclose to, provide or otherwise make CLUES available, in whole or in part, to any person other than your employees;

1.1.7 Use CLUES except in accordance with the provisions of this licence; and/or

1.1.8 Sell, assign, licence or otherwise transfer your rights under this licence.

3.2 You shall ensure your employees, and any permitted agents, contractors, assignees or licensees agree to be bound by the terms of this licence.

3.3 If you want to use CLUES for a commercial purpose, or any purpose other than your Internal Purpose, you shall seek NIWA's consent and enter into an appropriate agreement with NIWA prior to any such use.

4. TERMS

4.1 Unless you receive NIWA's express written permission, the licence is effective for a two (2) year term, commencing on the date of first installation, execution or use of CLUES, unless terminated earlier in accordance with the terms of this licence. The licence may be renewed as of right, but upon written request, for a further two (2) year concurrent term.

4.2 This licence shall automatically terminate if you breach any of the terms or conditions of the licence. NIWA may terminate the licence, in its sole discretion, upon two (2) weeks written notice.

4.3 NIWA may, in its sole discretion, terminate this licence at any time upon six (6) months notice.

4.4 CLUES contains integral third party components. If a third party terminates, or otherwise withdraws or suspends, NIWA's access to any such component, then NIWA may suspend a your access to CLUES and/or terminate this licence immediately.

4.5 Upon termination or expiration or this licence, you agree to immediately cease use of and delete/destroy CLUES and any copies thereof (in whatever form). If you are bound by the Public Records Act 2005 to retain a copy of CLUES, then you may do so, solely for record keeping purposes, but only to the extent necessary for you to meet your obligations under that Act.

5. EXCLUSION OF WARRANTIES

5.1 CLUES is provided “as is” without warranty of any kind, either express or implied, including, but not limited to, the implied warranties of merchantability and/or fitness for a particular purpose.

5.2 NIWA does not warrant that the functions contained in CLUES will meet your requirements or that the operation of CLUES will be uninterrupted or error free, or that CLUES will not infringe a third party’s intellectual property rights. If you, or a third party through your use of CLUES, suffered damage, or incurs liability or cost as a result of your use of CLUES, you (and not NIWA) agree to assume the entire cost of all necessary services, repair or correction.

5.3 You agree that you are using CLUES for the purpose of a business and therefore any warranties expressed or implied by the Consumer Guarantees Act 1993 shall not apply to this licence or your use of CLUES.

6. LIMITATION OF LIABILITY / INDEMNITY

6.1 NIWA shall not be liable to you or to any other party for any loss, cost or damage, whatsoever or howsoever caused, arising directly or indirectly in connection with CLUES or your use thereof.

6.2 Notwithstanding the generality of clause 6.1, NIWA expressly excludes liability for indirect, special, incidental or consequential loss or damage, which may arise in respect of this licence, CLUES, its use or otherwise, or for loss of profit, business, production, revenue, goodwill or anticipated savings.

6.3 In the event that NIWA incurs any liability whatsoever, such liability will under no circumstances exceed in aggregate, the lesser of the licence fee paid by you for the use of CLUES or $500.

6.4 You agree to fully indemnify, and keep indemnified, NIWA against any claim, proceeding, loss, cost (including legal costs on a solicitor/own client basis), damage, liability or expense incurred or suffered by it, whether arising in contract, tort (including negligence) or otherwise and arising out of, or in connection with:

a. your use of CLUES;

b. use of CLUES by any third party who has receive CLUE from, or through you; or

c. a breach of this agreement by you.

7. INTELLECTUAL PROPERTY

7.1 You acknowledge that any and all copyright, trade marks, patents, design reMaptrations, trade-secrets, know-how and other intellectual property, subsisting in or used in connection with, CLUES (including but not limited to all code, images, photographs, animations, video, audio, music, text, data incorporated in CLUES) are and remain the sole property of NIWA (or any other third party owner NIWA licences intellectual property from).

7.2 Any modifications or alterations of CLUES shall remain the property of NIWA in all respects, whether modified or altered by you, NIWA or a third party, and whether or not such modifications or alterations are authorised by NIWA.

8. CONFIDENTIAL INFORMATION

8.1 You agree that all software, information, data, drawing, specifications, documentation, software listings, source or object code, which NIWA may have imparted, or may from time to time impart, to you or you gain access to, relating to CLUES or associated procedures (the "Confidential Information"), is proprietary and confidential.

8.2 You agree that you shall use the Confidential Information solely in accordance with the provisions of this licence and shall not at any time during the licence or after its termination disclose the Confidential Information, either directly or indirectly, to any third party without NIWA's prior written consent.

8.3 You may only disclose such Confidential Information to those employees who require the information to use CLUES. Prior to disclosing such Confidential Information, you will advise those employees of the confidential nature of that information, and ensure they agree to be bound by the obligations under this licence.

8.4 Upon the expiry or termination of this licence you will immediately deliver up to NIWA all copies of CLUES and all associated documentation and all other Confidential Information within your power, possession or control. You may retain one copy, for solely record keeping purposes, if required to do so by the Public Records Act 2005.

9. GENERAL

9.1 You must not assign, licence, transfer or otherwise deal with, either in whole or in part, the benefit or burden of this Agreement without the prior written consent of NIWA, who's consent may be withheld in its absolute discretion.

9.2 NIWA may from time to time, in its discretion and without notice to you, vary the terms of this licence and your access to CLUES.

9.3 Failure or delay by NIWA in enforcing any right or provision of this licence is not to be construed or deemed a waiver of such provision or right, and shall not in any way prejudice NIWA's right to take subsequent action.

9.4 If any provision of this licence is void or unenforceable for any reason that provision shall, to that extent, be severed from the remaining provisions, which will remain in full force and effect.

9.5 This licence will be governed by and construed in all respects in accordance with the laws of New Zealand and you agree to submit to the jurisdiction of the New Zealand Courts.

Appendix B SPARROW *E. coli* model

The SPARROW *E. coli* model incorporated into CLUES was recalibrated to make use of newly available water quality data in October 2015. Here we provide more details of the form and parameterisation of the *E. coli* model than for other constituents, because the model has not been documented previously.

The model divides source terms into diffuse sources (i.e., pastoral, urban and other land uses) and point sources. The source loads from pasture and other rural areas is give in equation 1:

$$S_i = A_i\, c_i \exp[1.3(R - 1.85) - 0.46(D - 4.2) + 0.14(T - 10.1)] \qquad (1)$$

where S_i is the source load (organisms/day) for land use i (pasture or non-pasture), A_i is the area of land use i (km^2), c_i is the source coefficient or yield associated with the source, R is mean annual rainfall (m/y), D is the LRI drainage class (dimensionless indicator ranging between 1-5, increasing from poorly drained to well drained), and T is the mean annual air temperature (°C). The source coefficients determined through calibration are:

- 88×10^{12} (standard error or s.e. 31×10^{12}) organisms/km^2/year for pasture,
- 0.52×10^{12} (s.e. 0.031×10^{12}) organisms/km^2/year for other rural sources and,
- 147×10^{12} (s.e. 97×10^{12}) organisms/km^2/year for urban areas irrespective of rainfall or drainage.

The source coefficients were determined by calibration to measured loads from 128 sites, with an adjusted R^2 of 0.82 for load and 0.73 for yield, and a RMSE of 1.0, all in natural log space.

The effective settling velocity in lakes and reservoirs is 3200 (s.e. 2200) m/year. Decay in streams is modelled as a first-order function of stream length, with a decay coefficient, k (km^{-1}) of $0.048Q^{-0.77}$ (s.e. 0.024 and 0.19 for the coefficient and exponent respectively) where Q is the stream discharge in m^3/s.

Appendix C Contaminant tracing tables

Contaminant tracing tables were added to CLUES in 2015 as part of an Envirolink project for Tasman District Council (Semadeni-Davies et al., 2015). CLUES 10.3 returns tracing tables for each of TN, TP and sediment. No table is produced at this stage for *E. coli*. Contaminant tables contain the generated and cumulative loads and yields for each corresponding contaminant by land use class for all the REC reaches selected for the model run. The tables enable users to determine which land use classes contribute the greatest loads of TN, TP and sediment within each REC catchment as well as the instream loads and cumulative yields for each reach and for the catchment as a whole. They can be displayed as maps by joining the table to either the catchment or stream feature classes using the NZREACH[10] identifier. The tables can also be exported to other software packages as text files.

Due to the way in which CLUES has been calibrated and simulates aggregated contaminant loads from different land uses for some of the contaminants modelled, the tables for the different contaminants are slightly different with regard to the land use classes they contain. For example, the high country sheep and beef and other pastoral land use classes are not included in the TP summary table as these land use classes have a minimal effect on estimated TP loads. Instead, these land uses have been added to the Other Non-pasture land use class. Similarly, the native forest, forestry and scrub land use classes all have separate source-yield parameters for TN simulation but are aggregated in the TP and sediment tracing tables. The aggregated land use classes for TN, TP and sediments are as follows:

- TN tracing table (scenario_Nsource)
  - Native forest (*native forest*)
  - Forestry (*exotic forest*)
  - Scrub (*scrub*)
  - Urban (*urban*)
  - Dairy (*dairy*)
  - Deer (*deer*)
  - Sheep and beef, intensive (*sbi*)
  - Sheep and beef, hill country (*sbhill*)
  - Sheep and beef, high country (*sbhigh*)
  - Other pasture (*otherPast*)
  - Tussock (*tussock*)
  - Other non-pasture (*othernonPast*)
- TP tracing table (scenario_Psource)
  - Native and exotic forest and scrub (*forest&scrub*)
  - Dairy (*dairy*)
  - Sheep and beef, intensive (*sbi*)
  - Sheep and beef, hill country (*sbhill*)
  - Deer (*deer*)
  - Other non-pasture (*othernonPast)*
- Sediment tracing table (scenario_Sedsource)
  - Native and exotic forest and scrub (*forest&scrub*)
  - All live stock (*pasture*)
  - Tussock (*tussock*)
  - All other land uses (*other*)

[10] NZREACH in the contaminant tracing tables refers to the NZ reach (REC1) or NZ segment (REC2) number depending on the version of CLUES downloaded.

For each land use class and REC reach, the tables provide two sets of results; these are the sub-catchment and accumulated loads, areas and yields, respectively. The latter are denoted by an *R*-prefix in the table field heading. For each land use class within a reach sub-catchment, the sub-catchment area is the area covered by that land use class, the sub-catchment load is the load generated by the land use class in the sub-catchment and the sub-catchment generated yield is calculated as the sub-catchment load divided by the sub-catchment area. The accumulated loads and areas for each land use class are the sums of the upstream loads and areas for each land use class respectively. That is, the loads determined for each REC sub-catchment and land use class are added to the load from upstream reaches progressively down the network. Cumulative areas for each land use type are similarly added progressively downstream. Note that instream attenuation is applied as loads are routed downstream. The cumulative yield is the instream cumulative load divided by the area of the REC sub-catchment and the upstream area for each land use class.

Appendix D Scenario table output fields

The table below gives the field names and aliases of model outputs held in a scenario table. All the socio-economic indicators are cumulative values.

Field name	Alias (with units)	Description
Water quality indicators		
NLOAD	N load(t/y)	Mean annual TN cumulative (instream) load
PLOAD	P load(t/y)	Mean annual TP cumulative (instream) load
OVRNLOSS*	N leach(kg)	OVERSEER TN leaching losses Note: intermediate value not reported by CLUES
OVRPLOSS*	P leach(kg)	OVERSEER TP leaching losses Note: intermediate value not reported by CLUES
NYIELD	N cum.yield(kg/ha/y)	Mean annual TN cumulative (instream) yield
PYIELD	P cum.yield(kg/ha/y)	Mean annual TP cumulative (instream) yield
NCYIELD	N gen.yield(kg/ha/y)	Mean annual TN generated yield for sub-catchment
PCYIELD	P gen.yield(kg/ha/y)	Mean annual TP generated yield for sub-catchment
SED	Sediment load(kt/y)	Mean annual TSS instream load
SEDYIELD	Sed. gen.yield(t/ha/y)	Mean annual TSS generated yield for sub-catchment
NCONC	N conc.(mg/m3)	Median annual TN instream concentration
PCONC	P conc.(mg/m3)	Median annual TP instream concentration
ECOLI	peta E.coli per year	Mean annual *E. coli* instream load
ECOLIYLD	E.coli gen.yield(peta/ha/y)	Mean annual *E. coli* generated yield for sub-catchment
Socio-economic indicators (cumulative values)		
OUTPUT	Revenue($)	Farm revenue
FTE	Total_FTE	Total full-time equivalent employment
OF_FTE	OnFarmFTE	On-farm full-time equivalent employment
FWE	Expenses($)	Farm expenses
CFS	Cash_surplus($)	Cash flow surplus
GDP	Total_GDP($)	Total gross domestic product
Foss_fuel	Fossil_Fuel(GJ)	Fossil fuel
Oth_Enrgy	Tot_Energy_use(GJ)	Total energy use
Energy	Farm_Energy(GJ)	Energy produced by farm (
Protein	Farm_Protein(kg protein)	Farm protein output
D-GHG	Direct_GHG(CO2 equiv kg)	Direct greenhouse gas emissions
T_GHG	Total_GHG(CO2 equiv kg)	Total greenhouse gas emissions
Trasp	Transport($)	Total activity in the transport sector
RateTx	Local_gov_rev($)	Government revenue

* Reference value, not reported in outputs

Appendix E Forest harvest

The ability to model of the impacts of forest harvest on sediment loads in freshwater streams was added to CLUES as part of an Envirolink project undertaken for Tasman District Council (Semadeni-Davies et al., 2015). The following information has been summarised from that study.

CLUES has the same sediment yield parameters for both plantation and native forest and represents mature forest with stable soils. This is because for most of the growth period of a plantation forest (20-25 years) the rates of erosion and sediment delivery are similar to those for native forest within locations with comparable geology, terrain and climate (Phillips et al., 2007).

The retention of a vegetative cover on hillslopes provides protection against erosion processes such as sheet-wash and rill erosion (commonly referred to as *hillslope erosion*) and mass movement (e.g. landslides and earthflows). The establishment of plantation forests has been demonstrated to provide effective protection in erosion-prone areas in New Zealand and overseas (e.g., Marden and Rowan, 1993; Motha et al., 2003). Although erosion rates and sediment delivery rates from plantation forests are often generally less than from pastoral-based land uses in the long-term (Fahey and Marden, 2000; Hughes et al., 2012), the disturbance associated with forestry management operations (particularly harvesting) can be significant (Croke and Hairsine, 2006; Litschert and MacDonald, 2009). The harvesting period is, however, only a small part of a full forest rotation and this needs to be considered when assessing the significance of forestry land cover as a source of sediment.

The forest harvest scenario tool in CLUES is similar in application to the tools developed for creating farm practice scenarios, but operates differently. While the latter tools change the source yields associated with stock, the new forest harvest modification tool effectively applies a land use change scenario that replaces plantation forest with pasture for sediment. The method is based on the findings of Fahey et al. (2003a); Fahey et al. (2003b); and Eyles and Fahey (2006) for a study in Hawkes Bay. This study was identified in a review of New Zealand literature as being the most comprehensive catchment-scale investigation of post-harvest sediment generation effects in New Zealand. The study compared sediment loads generated over a decade (1995-2005) from two head-water catchments; one in pasture and one initially forested with mature *P. radiate* that was harvested in 1997. They found that following harvest, sediment loads from the forested catchment were elevated for two to three years before new growth was established and the soils stabilised. The ratio of sediment loads from the forested catchment compared to the pastoral catchment rose from around 0.3 initially to 2.6 for the three years following harvest, before returning to the pre-harvest levels. Much of the increased sediment load was associated with up-grading and construction of roads and landings prior to harvest, which is consistent with other forest studies in New Zealand. Phillips et al. (2007) suggest that the results from this study are generally applicable to forestry catchments throughout New Zealand.

CLUES has applied the same relationship between forest sediment yields and pastoral yields by replacing the harvested forest with an increase in the area of pastoral land[11] equivalent to 2.6 times the harvested area. This has the effect of increasing the sediment yield from harvested forest to 2.6 times the yield for pastoral land. This method was adopted as it requires a relatively simple modification of CLUES. In contrast, creating a new harvested forest land use class would have major

[11] Note that CLUES applies the same sediment yields to all stock types.

implications for the model structure. However, users are able to change the forest harvest parameter if local data are available.

The forest harvest modification is only valid for sediment and should not be used to simulate changes in nutrients or *E. coli*. Since CLUES is a steady-state model, it does not simulate changes in yields over time as forestry land is harvested and replanted. Thus, the results of a forest harvest scenario refer only to the two- to three-year period during and immediately following harvest.