Trodahl, M.I., Deslippe, J.R. & Jackson, B.M., 2016. Improving predictions of N & P export to waterways from rural landscapes in New Zealand using LUCI. In: *Integrated nutrient and water management for sustainable farming.* (Eds L.D. Currie and R. Singh). http://flrc.massey.ac.nz/publication.html. Occasional Report No. 29. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 7 pages.

IMPROVING PREDICTIONS OF N & P EXPORT TO WATERWAYS FROM RURAL LANDSCAPES IN NEW ZEALAND USING LUCI

Martha Trodahl[1], Julie Deslippe[2] & Bethanna Jackson[1]

[1]School of Geography, Environment & Earth Sciences, Victoria University of Wellington
PO Box 600, Wellington 6140, New Zealand
[2]School of Biological Sciences, Victoria University of Wellington
PO Box 600, Wellington 6140, New Zealand
Email: Martha.Trodahl@vuw.ac.nz

Introduction

Increased community concern over the impact of rural land management and primary production on water quality in New Zealand has resulted in recent legislative and regulatory changes to limit nutrient export to waterways (MFE 2013). This places farmers and land managers under increased pressure to reduce nutrient losses to the environment, while sustaining enterprise production and profitability. Due to its fine spatial scale and focus on the rural environment, the Land Utilisation & Capability Indicator (LUCI) is well placed to help farm and catchment managers quantify and explore spatially explicit solutions to these issues. A collaboration between LUCI developers and Ravensdown has recently commenced with the aim of developing a bespoke version of LUCI that features improved and spatially explicit detail of farm management. This work aims to improve nutrient export predictions by better representing climate, soil, topographic and management variables that influence nutrient export, and to explore, quantify and better represent mitigation strategies within LUCI. This will assist New Zealand farmers and other land managers with decision making around farm ecosystems, particularly around water quality issues and regulation. This paper introduces LUCI and presents results from LUCI water quality models applied to a catchment in the Bay of Plenty, New Zealand. It also discusses further work in progress developing LUCI nitrogen (N) & phosphorus (P) export to water models to better support farm management in New Zealand.

Land Utilisation & Capability Indicator (LUCI)

LUCI, an extension of the Polyscape framework described in Jackson et al. (2013), is a GIS framework that considers impacts of land use on multiple ecosystem services in a holistic and spatially explicit manner. Embedded with a number of single ecosystem service sub-models, mass transport in LUCI is driven by unique hydrological routing algorithms which operate at the underlying digital elevation model (DEM) scale. This allows modelling of the entire range of scales, from the sub-field to nationally, to occur simultaneously. LUCI uses readily available national data that can be easily supplemented with local knowledge.

Eight ecosystem service tools are currently available for general use within the framework, including exports of N and P to waterways. Ecosystem service tools can be run for individual ecosystem service analysis and to analyse interrelationships between ecosystem services, identifying trade-offs and synergies among them.

A number of maps and data are generated by the LUCI water quality models allowing exploration of total nitrogen (TN) or total phosphorus (TP) loads and concentrations both in-stream and on land. A ‘traffic-light’ system is the default colour system used in LUCI maps.

Red highlights potential areas for protection because there is high ecosystem service provision already, green highlights areas where a change could significantly improve an ecosystem service, and amber indicates existing provision is not high, but there is also little opportunity to significantly improve it.

LUCI water quality models use an enhanced, spatially representative export coefficient approach to model TN and TP exports to water. Annual total nutrient exports, or export coefficients (EC), are spatially positioned and cascaded through the landscape as water and sediment accumulate and move through the catchment. For every point in the landscape and stream network, cumulative annual nutrient load and annual average concentration is calculated. Identification of current and potential intercepting nutrient sinks is fundamental to the model. Particulate and dissolved nutrient are considered.

A particular focus of current work to improve LUCI water quality models involves developing export coefficients for use in New Zealand. ECs are defined as the "mass of a [contaminant] per unit area per unit time" (White et al. 2015), commonly quantified in kg $ha^{-1}yr^{-1}$, and they are generally used in catchment scale water quality models to represent diffuse pollution associated with specific land covers and/or uses. ECs are most commonly described in association with export coefficient models (ECM), the simplest forms of which calculate the total catchment contaminant load by summing the loads from individual sources within the catchment. However, export coefficients are also sometimes used in more complex, mechanistic models to represent diffuse pollution from various sources (Lu et al. 2013; Shrestha et al. 2008).

A common criticism of the EC approach is that often only land cover is considered. However, for an EC to be accurate it must additionally consider climate, soil, topography, and management (White et al. 2015). Developing appropriate ECs for New Zealand that consider all of these variables is a primary aim of the current project and significant progress has recently been made using a Ravensdown dataset derived from OVERSEER®-a New Zealand based agricultural management support tool, designed to analyse nutrient flows associated with farming systems (Selbie et al. 2013).

Catchment Scale Application – Lake Rotorua Catchment

We have initiated catchment scale validation of LUCI's N & P export to water models for New Zealand, with a case-study of the Lake Rotorua catchment, Bay of Plenty, New Zealand. Located in a volcanic caldera, this catchment has very porous allophanic and pumice soils, average annual rainfall of 1353mm (Chappell 2013) and a variety of land covers including agricultural (mostly pastoral), commercial and native forest, and urban areas (Fig. 1). Lake Rotorua has suffered well-documented water quality problems over a number of years (Hoare 1982; Hoare 1984; Morgenstern and Gordon 2006; Rutherford 1984; Rutherford et al. 2009; White et al. 2007). There are a number of unique hydrological and nutrient source variables in this catchment which need consideration. These include spring fed streams, some of which are thought to include significant additions of water and nutrients from outside of the Lake Rotorua surface catchment (White et al. 2014), geothermal sources of ammonium and wastewater irrigation on commercial forestry blocks.

Evaluation of LUCI water quality results were carried out using observed water quality data for 11 sub-catchments within the Lake Rotorua catchment. These data were supplied by Bay of Plenty Regional Council.

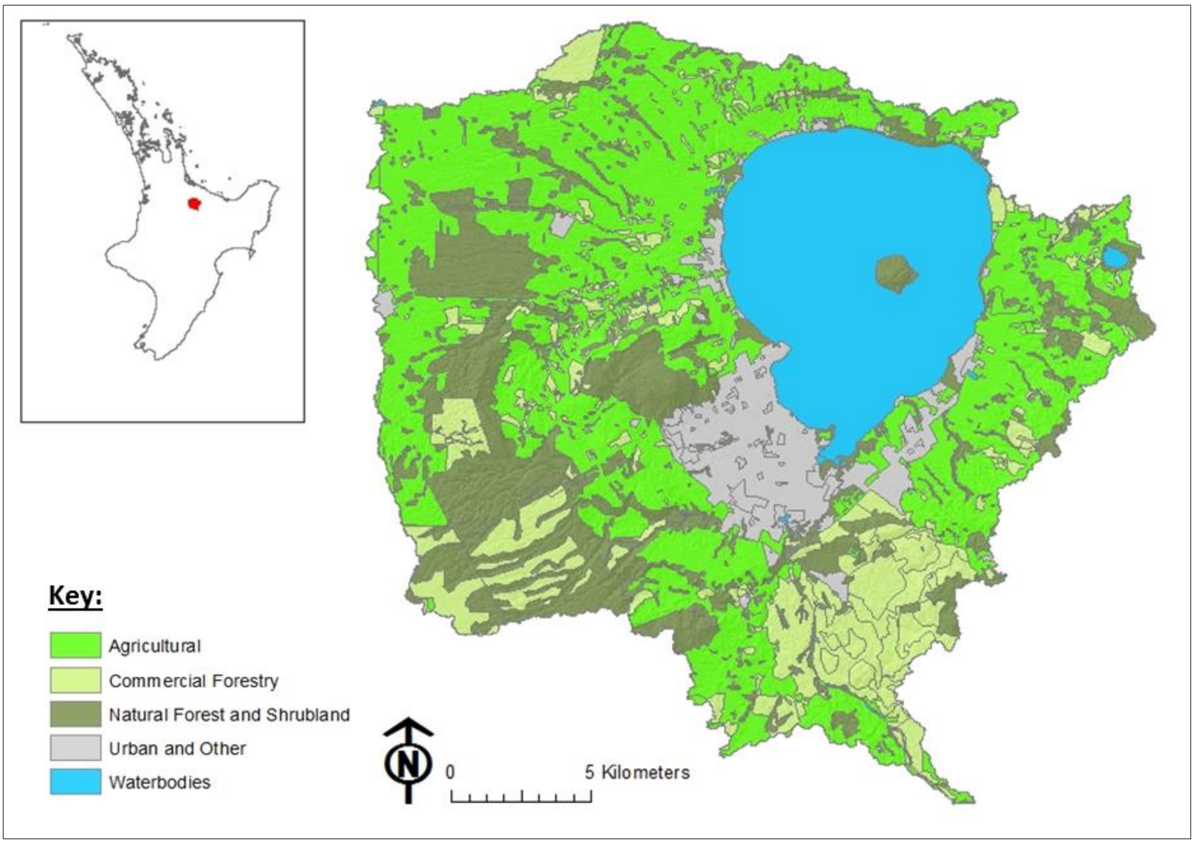

Fig. 1 – Lake Rotorua catchment location and land uses.

Results

Nitrogen

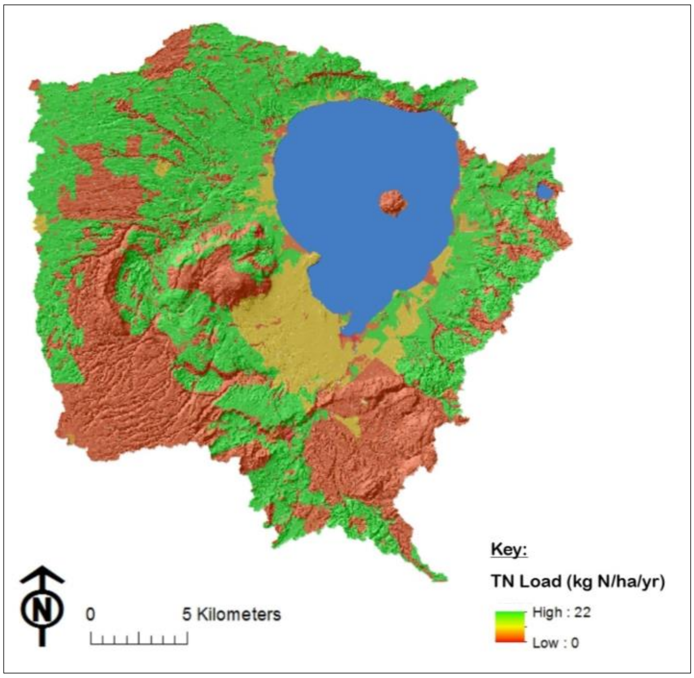

Fig. 2 – Total N load generated in Lake Rotorua catchment

Within the Lake Rotorua catchment, the highest N loads tend to be associated with agricultural land, while the lowest loads are associated with both commercial and natural forest areas within the catchment (Fig 2). When accumulated N load is considered a similar pattern of N loads emerges, with agricultural land associated with high and forested land associated with low accumulated N loads (Fig 3a). However, when accumulated N loads are considered at finer spatial scales (Fig. 3b), it reveals that toe-slope positions in the landscape are significant nutrient pathways. N pathways, where water and nutrients converge and make their way through to the stream network, are depicted in bright green in Fig 3b. These N pathways are where opportunities to intercept nutrients exist.

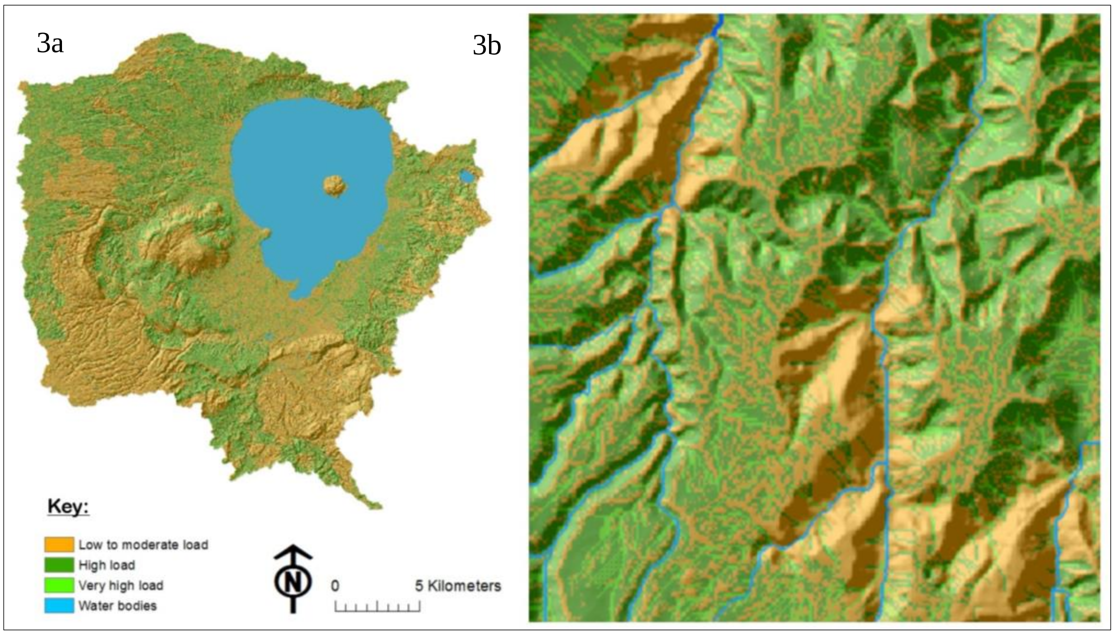

Fig. 3a and b - Accumulated total N load for the whole Lake Rotorua catchment (3a) and a close up of a pastoral area within the catchment (3b).

Phosphorus

Total P loads within the Lake Rotorua catchment also vary with land use type. Based on current export coefficients, highest P loads occur on areas of recently harvested commercial forest, while agricultural land covers generated slightly lower total P and areas of intact native and productive forest generate the lowest TP loads (Fig 4). Analysis of accumulated TP load within the catchment, reveals similar patterns to accumulated TN load. Again, highest loads are associated with agricultural land and lowest loads are associated with forested land. However, considering the data at higher spatial resolution it becomes clear that, as with TN loads, there are fine scale patterns of TP within land-use types, and that convergence areas are significant nutrient pathways for both N and P (Fig. 5b).

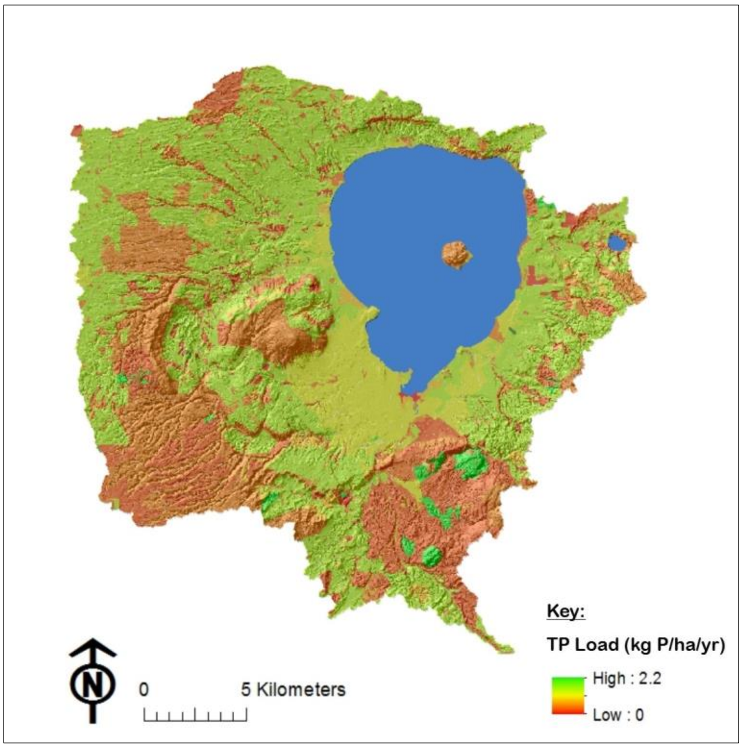

Fig. 4 – Total P load generated in Lake Rotorua catchment

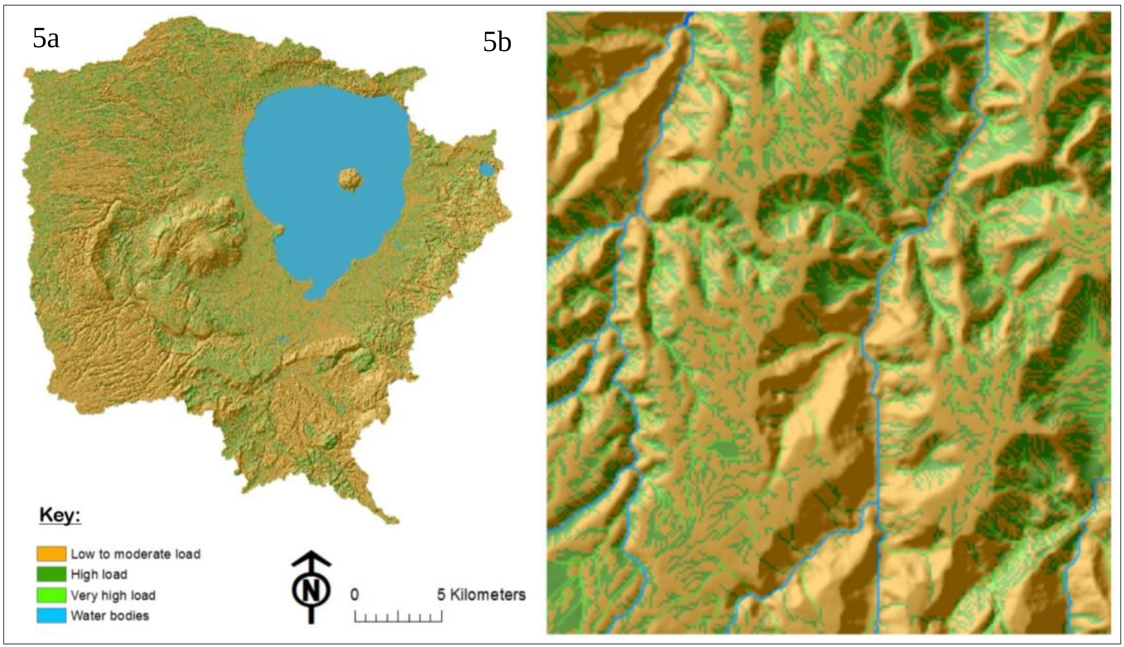

Fig. 5a and b - Accumulated TP load for the whole Lake Rotorua catchment (5a) and a close up of a pastoral area within the catchment (5b).

Recent modifications to the LUCI N & P models that are incorporated into the above results include refinements to ECs for each land cover category that are derived from New Zealand literature. Additions of water to the stream network of the catchment from springs are also now accounted for. This has resulted in significantly improved agreement among observed and simulated stream discharge for the 11 Lake Rotorua sub-catchments (Fig. 6 & 7).

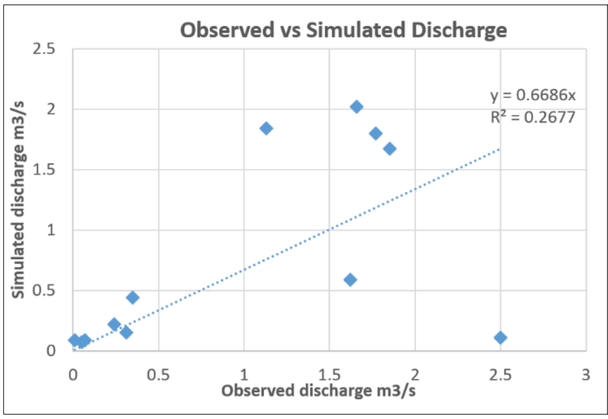

Fig. 6 – Initial observed against simulated discharge

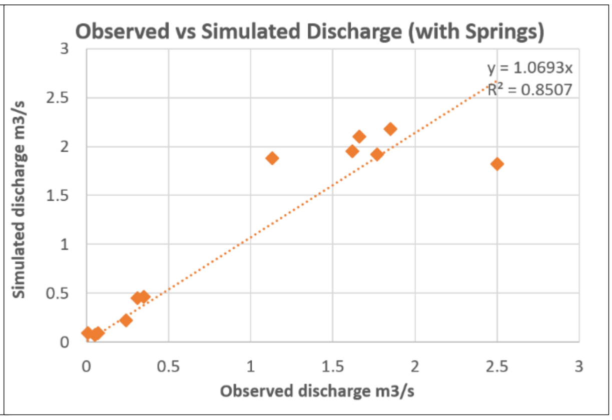

Fig. 7 – Improved observed against simulated discharge

Discussion

Comparison of observed vs simulated TN and TP concentrations for the 11 Lake Rotorua sub-catchments for the models as applied above make it clear that further work is required to constrain uncertainty in nutrient export estimates (Fig. 8 & 9). National scale application of the LUCI N model in Wales resulted in an R^2 value of 0.86 for observed vs simulated TN concentrations, and similar congruency of LUCI outputs in the New Zealand context is our aim. To achieve a better representation of N and P loads in the Lake Rotorua context, we are quantifying and incorporating within LUCI some of the unique nutrient sources within the catchment (ie. nutrients in spring water, geothermal sources and wastewater irrigation).

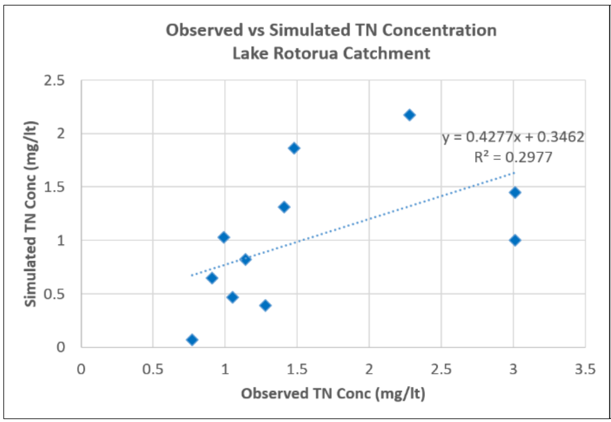

Fig. 8 – Observed against simulated TN concentration

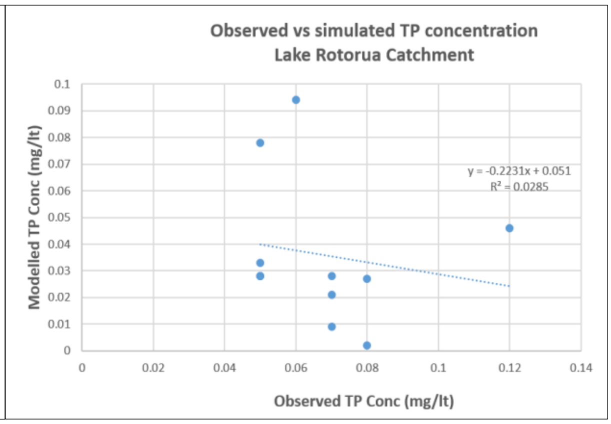

Fig. 9 – Observed against simulated TP concentration

Also of particular importance is further work refining ECs, and recent progress has been made using a dataset covering a wide variety of environments and farm systems that is derived from Ravensdown OVERSEER® records. This has resulted in the development of new N and P ECs for pastoral land covers. For catchment scale applications, these ECs take account of broad regional climate and management variables, and more detailed soil and topographic variables. For example, we compared TN loads from the model used above and the model using the new ECs for the Lake Rotorua catchment (Fig. 10a, b). This example makes clear that the new ECs provide a more nuanced and detailed representation of nutrient exports from pastoral land covers. Application of these new ECs at the farm scale will account for climate, management and soil variables in more detail. For more information on these farm scale improvements see Jackson et al, in this volume. Evaluation and refinement of these ECs is on-going at both the catchment and farm scales. Similar work and development of New Zealand appropriate export coefficients for a wider variety of land cover categories is also planned in the near future.

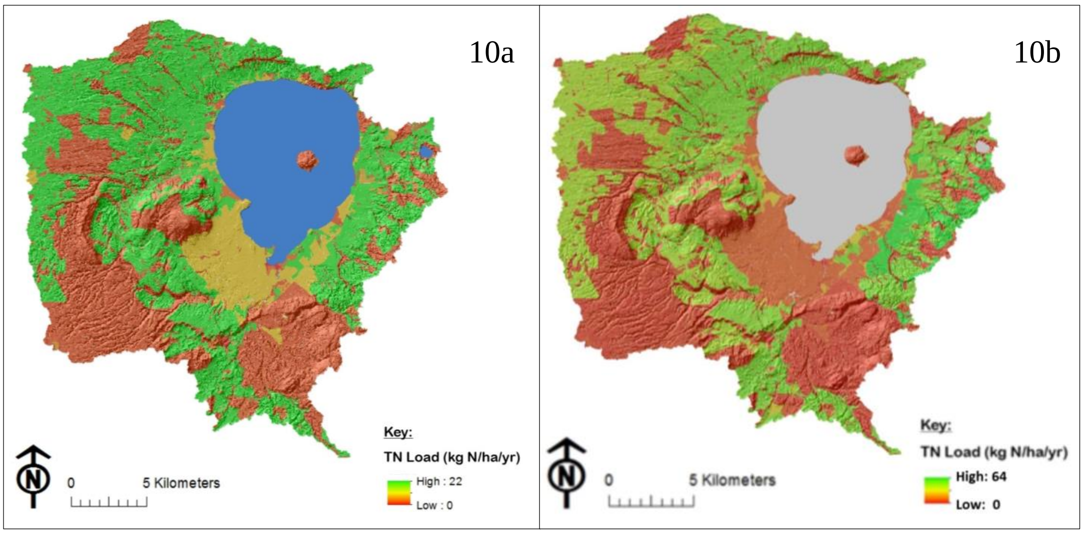

Fig. 10a and b – Total N load generated in Lake Rotorua catchment based on initial literature based ECs for pastoral land cover (10a) and improved ECs based on data covering a wide variety of environments and farm systems that is derived from OVERSEER® (10b).

Acknowledgements

The authors would like to acknowledge and thank Ravensdown and Callaghan Innovation for funding for this project and Ravensdown and Bay of Plenty Regional Council for data provision. Particular thanks to Alistair MacCormick from Bay of Plenty Regional Council and Alister Metherell, Ants Roberts and Mike White from Ravensdown for helpful assistance and feedback.

References

Chappell, P. R., 2013. The Climate and Weather of Bay of Plenty. NIWA, 40.

Hoare, R. A., 1982. Nitrogen and phosphorus in the Ngongotaha Stream. New Zealand Journal of Marine and Freshwater Research 16:339-349.

Hoare, R. A., 1984. Nitrogen and phosphorus in Rotorua urban streams. New Zealand Journal of Marine and Freshwater Research 18:451-454.

Jackson, B., T. Pagella, F. Sinclair, B. Orellana, A. Henshaw, B. Reynolds, N. Mcintyre, H. Wheater & A. Eycott, 2013. Polyscape: A GIS mapping framework providing efficient and spatially explicit landscape-scale valuation of multiple ecosystem services. Landscape and Urban Planning 112:74-88.

Lu, J., D. Gong, Y. Shen, M. Liu & D. Chen, 2013. An inversed Bayesian modeling approach for estimating nitrogen export coefficients and uncertainty assessment in an agricultural watershed in eastern China. Agricultural Water management 116:79-88.

MFE, 2013. Freshwater reform 2013 and beyond. Ministry for the Environment, Wellington.

Morgenstern, U. & D. Gordon, 2006. Prediction of Future Nitrogen Loading to Lake Rotorua. GNS Science Report, 28.

Rutherford, J., 1984. Trends in Lake Rotorua water quality. New Zealand Journal of Marine and Freshwater Research 18:355-365.

Rutherford, K., C. Palliser & S. Wadhwa, 2009. Nitrogen exports for the Lake Rotorua catchment - calibration of the ROTAN model. National Institute of Water and Atmospheric Research, Hamilton.

Selbie, D. R., N. L. Watkins, D. M. Wheeler & M. A. Shepherd, 2013. Understanding the distribution and fate of nitrogen and phosphorus in OVERSEER. Proceedings of the New Zealand Grassland Association 75:113-118.

Shrestha, S., F. Kazama & L. T. H. Newham, 2008. A framework for estimating pollutant export coefficients from long-term in-stream water quality monitoring data. Environmental Modelling and Software 23:182-194.

White, M., D. Harmel, H. Yen, J. G. Arnold, M. Gambone & R. Haney, 2015. Development of sediment and nutrient export coefficients for U.S. Ecoregions. Journal of the American Water Resources Association 51(3):758-775.

White, P. A., G. N. Kilgour, T. Hong, G. Zemansky & M. Wall, 2007. Lake Rotorua groundwater and Lake Rotorua nutrients Phase 3 science programme technical report. Institute of Geoglogical and Nuclear Sciences, Wairakei.

White, P. A., A. Lovett, C. Tschrittler & M. Cusi, 2014. Lake Rotorua catchment boundary relevant to Bay of Plenty regional Council's water and land management policies. GNS Science, 99.