Jackson, B.M., Metherell, A.K., Roberts, A.H.C., Trodahl, M.I. & White, M., 2016. Adaption of the LUCI framework to account for detailed farm management: a case study exploring potential for nutrient mitigation using data from the Southland Demonstration Farm. 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. 10 pages.

ADAPTION OF THE LUCI FRAMEWORK TO ACCOUNT FOR DETAILED FARM MANAGEMENT: A CASE STUDY EXPLORING POTENTIAL FOR NUTRIENT MITIGATION USING DATA FROM THE SOUTHLAND DEMONSTRATION FARM

Bethanna M. Jackson[1], Alister K. Metherell[2], Ants H.C. Roberts[2], Martha I. Trodahl[1] & Michael White[2]

[1]*School of Geography, Environment & Earth Sciences, Victoria University of Wellington,*
PO Box 600, Wellington 6140
[2]*Ravensdown Ltd, 292 Main South Road, Hornby, Christchurch 8042*
Corresponding author email: bethanna.jackson@vuw.ac.nz

Abstract

This paper discusses recent progress in adapting the Land Utilisation and Capability Indicator (LUCI) framework to take account of the impact of detailed farm management on water, sediment and nutrient delivery to waterways. LUCI is a land management decision support framework which examines the impact of current and potential interventions on a variety of outcomes, including flood mitigation, water supply, greenhouse gas emissions, biodiversity, erosion, sediment and nutrient delivery to waterways, and agricultural production. It searches for “win-win” solutions and cost effective, targeted mitigation options from sub-field level to landscape and/or national scale simultaneously. It is therefore ideally placed to assist with decision making across multiple scales, such as informing the current debates about how best to implement nutrient regulation at farm, catchment and regional scales. However, past applications of LUCI have inferred land management from nationally available land cover categorisations, so historically it lacked the capacity to discriminate between differences in more detailed management (tillage information, type of irrigation system, stocking numbers and type, etc.). Recently a collaboration with Ravensdown Limited has commenced. LUCI is being further developed within New Zealand to take in a range of more detailed management information, which can be entered directly to LUCI or easily integrated via an OVERSEER® farm file. It is anticipated that this enhanced ability, combined with the framework’s existing capacity to support multi-scale decision making, will provide a decision support tool to New Zealand’s farming community that complements OVERSEER® and other available support tools. Example output and ongoing “validation” of LUCI’s performance simulating nutrient loads and concentrations at the farm scale are presented using data from the Southland Demonstration Farm.

Introduction

LUCI is a second generation extension and software implementation of the Polyscape framework described in Jackson *et al* (2013). Development is led by Victoria University of Wellington, with the assistance of a number of international partners. It is specifically tailored to investigate the cumulative impact of individual farm scale interventions within larger catchments, and has been used successfully in England and Wales for this purpose (Jackson *et al.*, 2013, Robinson *et al.*, 2013, McIntyre and Thorne (eds), 2013, Emmett *et al.*, 2014)). LUCI shares a number of features in common with other emergent decision support frameworks, but also has some unique features that make it particularly well suited to evaluating impacts of small-scale farm management at larger scales. Notably, it was the only tool identified in the recent comprehensive international review of generalisable ecosystem service models carried out by Bagstad *et al.* (2013) as being suitable for both "generalisable, landscape-scale modelling" and site-scale modelling. This reflects its focus on accounting for the impacts of fine spatial detail and landscape pattern in its valuations.

As national attention is increasingly focussing on preserving or improving the quality of our waterways, farmers and other land managers are faced with legislative and regulatory demands to reduce nutrient losses while still maintaining profitability. A number of New Zealand farm decision support tools are available and/or being developed to help support farmers and policymakers face the various economic, environmental and social challenges of the coming decades. These tools provide a wide variety of useful information and metrics to support farm and policy decisions, but lack LUCI's ability to represent the cumulative impacts of spatially targeted management at landscape scale. Our goal is therefore to provide a supplementary tool to help guide targeted and cost-effective nutrient mitigation on-farm, and allow policy makers to account for the integrated effects of such mitigation at larger scales.

Description of the LUCI model

Most LUCI algorithm calculations and valuations are produced at the resolution of a digital elevation model (DEM): many of its models require this resolution due to its topographical routing capabilities. Applications to date suggest that a 5m by 5m DEM provides more than sufficient resolution for making decisions at the field scale, and this is the scale used in this study. The potential of the landscape to provide benefits is a function of both the biophysical properties of individual landscape elements and their configuration. Both are respected in LUCI where possible. For example, the hydrology, sediment and chemical routing algorithms are based on physical principles of hillslope flow, taking information on the storage and permeability capacity of elements within the landscape from soil and land use data and honoring physical thresholds and mass balance constraints. LUCI discretizes hydrological response units within the landscape according to similarity of their hydraulic properties and preserves spatially explicit topographical routing. Implications of keeping the "status quo" or potential scenarios of land management change can then be evaluated under different meteorological or climatic events (e.g. flood return periods, rainfall events, droughts), cascading water through the hydrological response units using a "fill and spill" approach. These and other component algorithms are designed to be fast-running while maintaining physical consistency and fine spatial detail. This allows it to operate from subfield scale to catchment, or even national scale, simultaneously. It analyses and communicates the spatial pattern of individual service provision and tradeoffs/synergies between desired outcomes at detailed resolutions and provides suggestions on where management change could be most efficiently targeted to meet water quality targets while maintaining production.

Maps, tables and other output are generated by the LUCI water quality models allowing exploration of (among other things) water flow and sediment, total nitrogen (TN) or total phosphorus (TP) loads and concentrations both in-stream and on land. A traffic-light system is generally used to distinguish between categorisations. In the context of water quality, this can seem counter-intuitive as rather than flagging a problem, red implies a significant “good” is present. Specifically, red implies high existing service provision, suggesting to stakeholders and decision makers that they should STOP and think carefully before making any changes to land placed in this categorisation (bright and dark red distinguish between very high and moderately high existing service provision respectively). Orange suggests existing provision is poor but there is also negligible opportunity to significantly improve provision. These areas are flagged as not worthy of significant effort for either preservation or change. Green areas denote a “green light” to proceed with change as there is negligible existing service provision combined with an opportunity to significantly enhance service provision. Bright green suggests a higher opportunity to enhance service provision than dark green (both still being categorised as significant). We are considering a change to a more intuitive colour scheme for farm-scale applications in the future.

As Trodahl *et al.* (2016; this volume) notes, LUCI water quality models use an enhanced, spatially representative export coefficient approach to model TN and TP exports to water. Cumulative exports are computed for every point in the landscape, based on the export associated with each individual grid cell and accumulation and interception processes. Both dissolved and particulate nutrients are considered and tracked separately (bound to water flow and sediment movement respectively). Past applications of LUCI have inferred land management from nationally available land cover categorisations, so historically it lacked the capacity to discriminate between differences in more detailed management (tillage information, type of irrigation system, stocking numbers and type, etc.). A key part of this project is developing more appropriate export coefficients that consider climate, soil, topography, and land management. Another is to link appropriately with complementary knowledge and frameworks to avoid duplication of effort and consistency in advice provided to farmers and other stakeholders. In the first instance, our efforts are directed to integrating appropriately with OVERSEER®, a New Zealand based support tool that among other things simulates nutrient flows associated with farming systems (Selbie *et al.* 2013), due to its importance in the NZ nutrient regulation environment, and to the wealth of information it already holds.

Methodology

The 295 ha Southland Demonstration farm, northwest of Wallacetown near Invercargill (see Figure 1a), was chosen as one of the first case studies for testing and refining the revised version of LUCI at the farm scale. As discussed by Cameron *et al.* (2014), the farm milks ~800 cows on a mix of ryegrass and white clover pasture milking platform of ~260 ha, wintering on farm-grown brassicas and fodder beet. Soils are mostly poorly drained, so a reasonably extensive network of tile and pipe drains is present. See the Southland Demonstration farm’s website (http://www.siddc.org.nz/sthld-demo-farm/sthld-demo-farm/) for further detail on stock numbers, milk production, typical fertiliser application rates, etc.

Our study benefits from a range of previous work carried out at the site, and particularly from the study described by Cameron *et al.* (2014), which collected a range of valuable data including a detailed topographical survey with >5,000 individual GPS survey points, groundwater and other hydrological surveys and continuous (15 minute) monitoring of nitrate-N at two sites on a creek running through the farm (the Tomoporakau Creek). We supplement the information from this study further through collecting monthly water samples near both the original monitoring sites. These are professionally analyzed by Analytical Research Laboratories for a number of water quality measurands, including nitrate-N. Specifically, we collect pH, conductivity, total dissolved and total suspended solids, turbidity, total and dissolved carbon, ammoniacal-, nitrate- and total Kjeldahl- N, total, total dissolved, and dissolved reactive P.

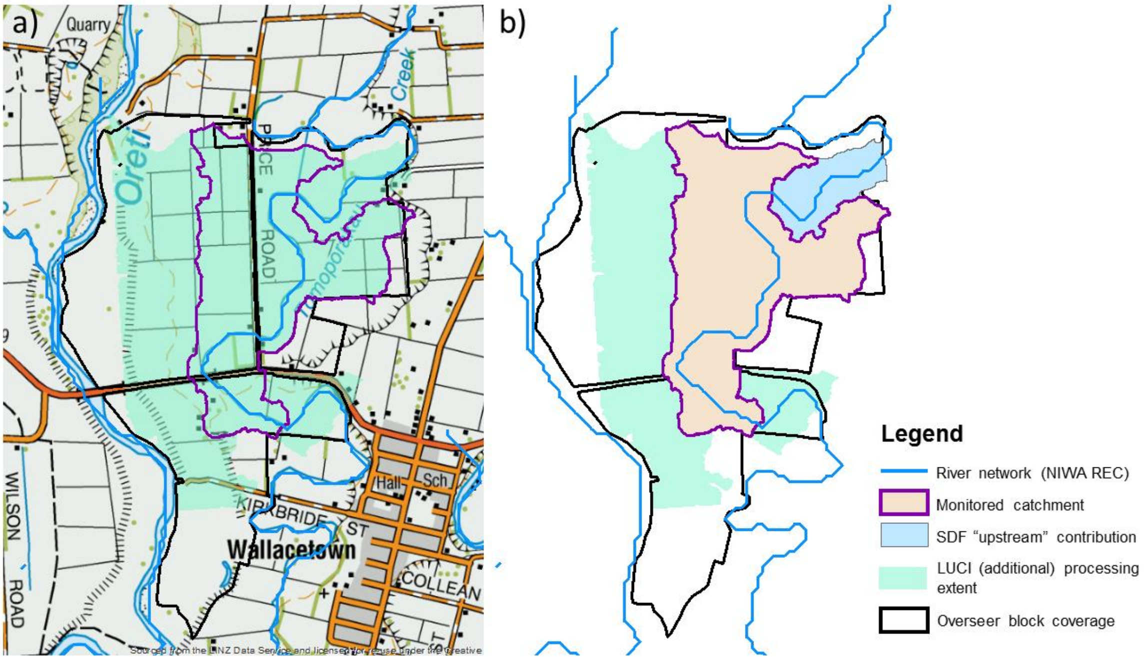


Figure 1: Location of the Southland Demonstration farm with data and LUCI processing extents.

As the farm topography is flat to gently rolling (aside from the presence of flood defence stop banks), we required reasonably accurate topographical data to drive the LUCI model. We used the spot height data collected as part of the study described by Cameron *et al*. (2014) to construct a 5m by 5m DEM; i.e., gridded height data. The survey coverage was not sufficient to construct this detailed DEM over the whole farm, but did cover most of it, including the full extent of the area contributing water, sediment and nutrients to the monitored portion of the farm (i.e., contributing between the upstream and downstream monitoring points). The light green shading in Figure 1a shows the extent of the DEM we created, which in turn constrains the extent of the LUCI processing. The spatial extent of the farm's OVERSEER® blocks, as a surrogate for the farm boundaries, can be seen in Figure 1b. Some parts of the farm had to be excluded due to the lack of spot height coverage; we also did an analysis of all "basins" contained in the DEM and chose to exclude those where only small fractions of a basin lay within the DEM to avoid artefacts and edge effects. This was particularly important towards the north-east portion of the farm, where the Tomoporakau Creek entered and exited the available DEM coverage several times.

Figure 1b distinguishes between three key areas of the resultant LUCI processing extent. The monitored contributing area is shown in tan; with an area of 110.0 ha (1.1 km^2). An additional 19.7ha of contributing area, upstream of the monitoring area, passes through the Southland Demonstration farm before it reaches the upstream monitoring site, shown in blue. As a small portion of the northeast of the farm is excluded from our watershed area analysis, this value of ~130ha is broadly consistent with Cameron *et al*. (2014)'s estimate that 138 ha of the farm potentially contributes drainage water into the Tomoporakau Stream.

The total area contributing to the downstream monitoring points was also calculated, using the nationally available 15m by 15m DEM described by Colombus *et al*. (2013). A value of 19.01 km^2 was obtained, suggesting an area approximately 18 times larger than the monitored catchment contributes the water received at the upstream monitoring site.

The remaining light green shaded areas consist of the area contributing to the Tomoporakau Creek below the downstream monitoring site, and (to the west) a reasonable portion of the farm that drains south and eventually west to the Oreti River. Although we do not have data to assist with ground-truthing of how well LUCI represents these non-monitored areas, we still model them for the purposes of checking that a larger variety of blocks are modelled and that results are sensible and/or consistent with OVERSEER®.

As previously discussed, LUCI's export coefficient approach within New Zealand is being modified to better consider climate, soil, topography, and land management. Preliminary representations accounting for a number of variables including rainfall and irrigation, various N and P inputs, Olsen P levels, soil order, anion storage capacity, etc. have been generated, based on a dataset derived from a large number of Ravensdown OVERSEER® files. Refinement of these representations is ongoing, but the preliminary set was considered appropriate for generation of indicative results for this paper.

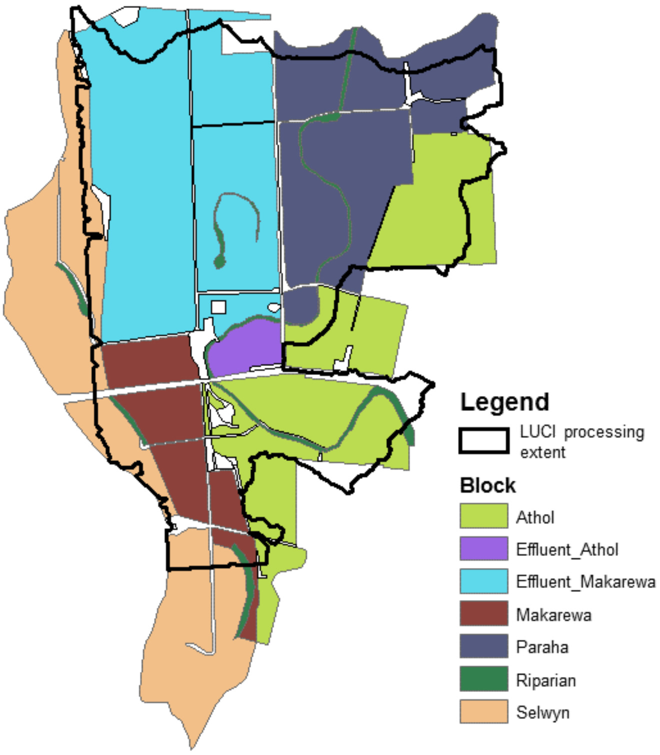
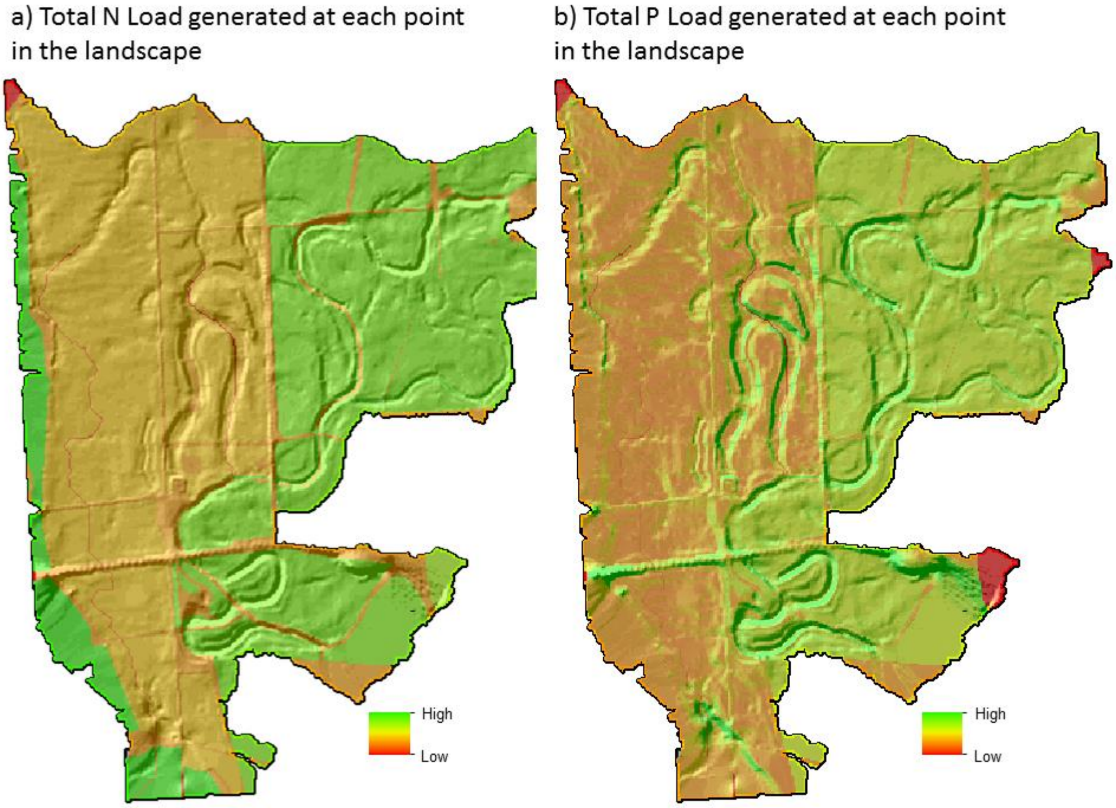


Figure 2: Block coverage over LUCI processing extent.

LUCI has now been modified to include the ability to read in information from an OVERSEER® output (xml) file, which is associated with a GIS block layer to allow it to allocate the OVERSEER® information spatially. It extracts values as appropriate (e.g. N and P inputs, irrigation type, Olsen P level, soil order etc.) and overwrites national baseline information wherever block information is present. Where OVERSEER® block information is not present, LUCI infills information from national soil (S-map or Fundamental Soils Layer) and land cover information (LCDB products) along with regional estimates of average nitrogen and phosphorus inputs, irrigation use, etc. Figure 2 shows the block extent for the Southland Demonstration farm application.

Results and Discussion

Results are indicative only, due to the preliminary nature of our recently derived functions relating load exported from points in the landscape to various factors such as soil type and land management. Overall, qualitative results seem very promising; LUCI patterns in space and its variations according to soil characteristics, topography, nutrient input and management type look reasonable and consistent with learnings from OVERSEER® and other national and international studies. Figure 3a shows LUCI's qualitative predictions of total N load (total amount of N exiting from any point in the landscape via surface or subsurface processes) generated over the Southland Demonstration farm landscape. Figure 3b shows the corresponding total estimated P loading. Soil type has a dominant effect in both cases, with the Makarewa soil (top left of the farm) much less prone to lose nutrients to the stream. It is worth noting that the Makarewa soils receive most of the effluent generated on the farm and the load estimates in Figure 3 include consideration of this additional input; an indication of good practice at the farm. The P loading is more nuanced than the N loading, indicating the increased dependence of P loss estimates on non-soil property factors such as slope and intense climatic drivers.


a) Total N Load generated at each point in the landscape

b) Total P Load generated at each point in the landscape

Figure 3: Total N (left) and total P (right) loading generated at individual points in the Southland Demonstration far landscape, as estimated from LUCI using OVERSEER® farm information.

Not all the nutrients lost from individual points in the landscape actually exit the farm. LUCI tracks their progress through the landscape via dissolved and particulate pathways, and accounts for interception, retention and loss processes that may prevent the nutrients ending up in waterways. Figure 4 shows the predicted accumulated loading for N (Figure 4a) and P (Figure 4b) in the landscape. Green areas show where particularly high loads can be intercepted, and are priority targets for mitigation. Due to the flat nature of the Southland

Demonstration farm landscape, the accumulated N load is very similar to the individual landscape N loading (although some subtle differences occur where topographic variation is high). The loading of nitrogen remains relatively diffuse and opportunities to make major reductions through fine-scale targeted interventions are low. However, significant opportunities to spatially target P mitigation is evident. Small patches of green indicate hot spots where interception could substantially reduce loss to waterways.

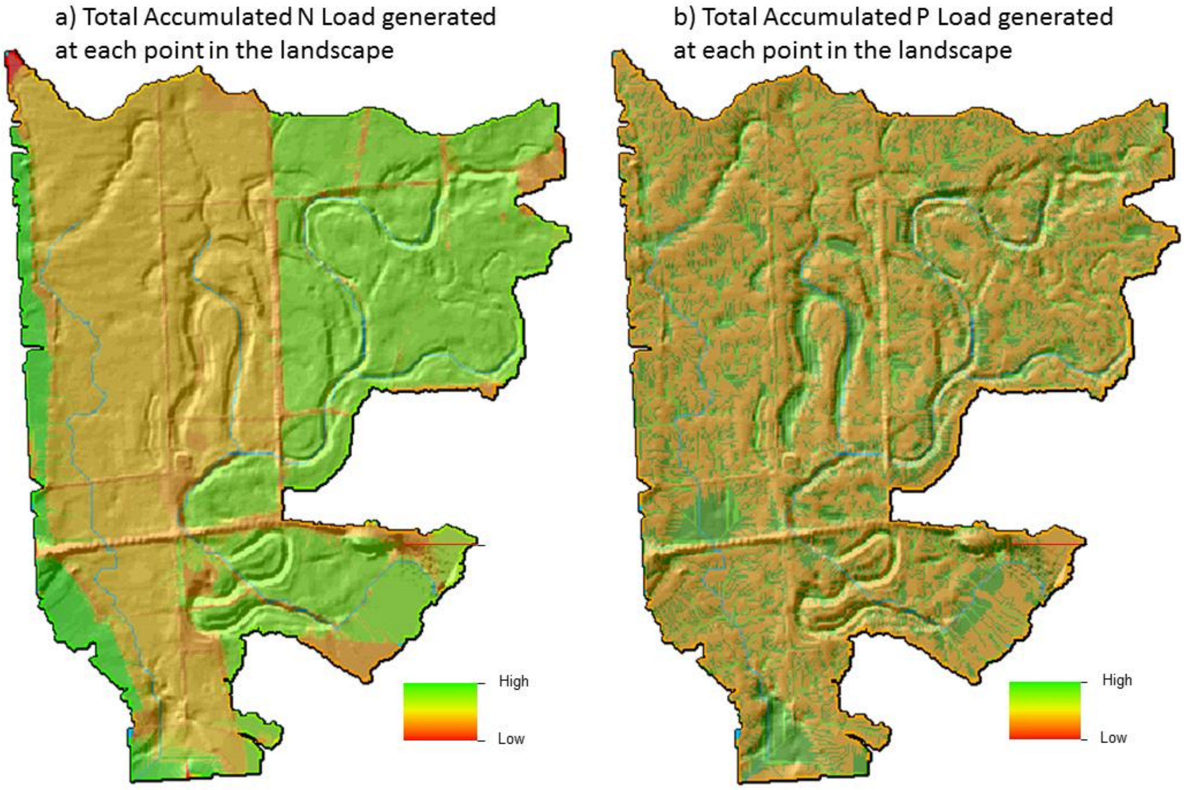


Figure 4: Total accumulated N loading (left) and total accumulated P loading (right) generated over the Southland Demonstration far landscape, as estimated from LUCI using OVERSEER® farm information.

Quantitatively, however, there is still significant work to do. When compared to observed data our preliminary functions are currently over-predicting total P and total N concentrations at both upstream and downstream sites (under the assumption that the monthly stream sampling is representative of an average mean, which is by no means safe as significant intra-monthly variance in stream nutrient concentrations has been observed at this site (Cameron *et al.*, 2014) as well as at many others). It is worth noting that previous stream outputs simulated by LUCI using standard export coefficients have shown no tendency to consistently over or under predict; i.e. there has never been such a strong bias observed between simulated and observed concentrations. This is perhaps not unexpected; the “classic” export coefficients we used previously have a degree of attenuation built into them by default due to their derivation from stream concentration data, while OVERSEER® explicitly sets out to output loads and concentrations exiting the soil zone, omitting consideration of any further attenuation through processes such as redox conditions, plant uptake of nutrients in-stream, etc. We are currently working on options to modify the OVERSEER® coefficients to account for processes occurring between the root zone and the stream. LUCI has options to include in-stream and/or subsurface denitrification and also travel time distributions to account for lags in responses to change; however multiple competing hypotheses can produce similar reductions and resolving which processes are actually causing the "attenuation" is a priority for further work. Our preliminary functions predicting P export, relationships mined from Ravensdown OVERSEER® farm records, also have a heavy dependence on slope. While this dependence is reasonable, it is probable that there are scaling issues related to using relationships with slope derived from results at OVERSEER® block scale at the 5m by 5m pixel scale used by our LUCI results. Downscaling the OVERSEER® results such that they can be applied without bias at our sub-block level scale is another research priority.

Statistics from our monthly monitoring to date at the upstream site and downstream sites, which commenced in May 2015, are shown in Table 1. We also refer readers to the paper by Cameron *et al*. (2014), which shows high resolution patterns in nitrate concentrations and loadings over the 2012 calendar year.

Measured	Units	Mean	Standard Deviation	Min	Max
Nitrate-N upstream	mg/L	5.434	2.350	1.580	9.640
Nitrate – N downstream	mg/L	5.065	2.234	1.140	9.020
Ammonium-N upstream	mg/L	0.067	0.052	<0.02	0.170
Ammonium-N downstream	mg/L	0.118	0.147	<0.02	0.520
Total Kjeldahl N upstream	mg/L	0.754	0.243	0.410	1.100
Total Kjeldahl N downstream	mg/L	0.739	0.331	0.300	1.210
Total P upstream	mg/L	0.046	0.031	<0.02	0.103
Total P downstream	mg/L	0.055	0.035	<0.02	0.111
Total dissolved P upstream	mg/L	0.031	0.019	<0.02	0.065
Total dissolved P downstream	mg/L	0.030	0.012	<0.02	0.044
DRP upstream	mg/L	0.029	0.013	0.010	0.047
DRP downstream	mg/L	0.025	0.010	0.010	0.040
Conductivity upstream	mS/m	26.283	1.482	23.850	28.020
Conductivity downstream	mS/m	26.969	1.331	24.170	28.590
Total suspended solids upstream	mg/L	3.200	3.765	0.000	13.00
Total suspended solids downstream	mg/L	4.500	5.622	0.000	14.000

Table 1: Statistics from upstream and downstream site monitoring to date (May 2015 through February 2016). Note the statistics for those variables where values fell below the minimum detection limit are not exact; in those cases we assumed a value of half the minimum detection limit for estimation of overall means and standard deviations.

It is notable that in both the previous and current studies, there is often a significant dilution and/or other reduction (perhaps in-stream processing or denitrification in the subsurface) in nitrate-N levels occurring between the upstream and downstream site. The magnitude of the reduction is extremely significant given the relative contributing areas; as previously mentioned the upstream site has a catchment area of ~18 times the additional monitored area captured at the downstream site. The presence of this effect makes the Southland Demonstration farm, and specifically the monitored sites, a very valuable case study to better understand attenuation processes.

Conclusions

Significant progress has been made in adapting LUCI to better represent detail in New Zealand farm management, and to link it to information on farm management and best practice science contained in other relevant decision support tools such as Overseer. Initial results are promising, with qualitative patterns in response appearing sensible and in-line with both NZ and international understandings. To allow LUCI and other models predicting catchment-wide water quality patterns to properly integrate predictions derived either directly or indirectly from OVERSEER® or other models predicting to the bottom of the root zone only, there is a need to better understand and represent attenuation (loss and/or transformations) of nutrients as they move between the root zone and the waterways in which they are measured. In the interim, an adjustment factor to account for attenuation will be added; however such factors significantly compromise prediction accuracy so going forward we are determined to instead include (and resolve, where possible), competing hypotheses of process response. There are also challenges in relating OVERSEER® block and farm scale predictions to the finer 5m by 5m scale used by LUCI, which will be overcome via a downscaling exercise to remove bias in predictions between scales. The Southland Demonstration farm is only one of our test sites, but provides a particularly interesting opportunity to consider attenuation and loss processes due to the significant reduction in nitrate concentrations that has been observed during many incidences of both previous and current sampling.

Acknowledgements

The authors would like to acknowledge and thank Ravensdown for funding for this project and the Southland Demonstration Farm and the South Island Dairying Development Centre for additional data provision and permission to use the farm as a case study site. Particular thanks to Ron Pellow (SIDDC) and Stacey McNaught (Southland Demonstration Farm) for helpful assistance and feedback, and to Lauren Carter (Victoria University of Wellington) for assistance transcribing and formatting data records. Thanks also to the Centre for Soil and Environmental Research, Lincoln University and Aurecon for provision of DEM spot height data and Chris Smith (AgResearch) for provision of monthly sampling. We also acknowledge our international partners, with particular thanks to the Centre for Ecology and Hydrology (UK), for ongoing contributions to broader LUCI development.

References

Bagstad, K.J., Semmens, D.J., Waage, S and Winthrop, R. (2013). A comparative assessment of decision support tools for ecosystem services quantification and valuation. *Ecosystem Services*, 5: e27-e39.

Cameron, K., Di, H., Roberts, A., Beale, N., Weir, J. and Borrie, N. (2014). “Monitoring effects of Southland Demonstration Farm on stream water nitrate.” In: *Nutrient management for the farm, catchment and community*. (Eds L.D. Currie and C L. Christensen). http://flrc.massey.ac.nz/publications.html. Occasional Report No. 27. Fertilizer and Lime Research Centre, Massey University, Palmerston North, New Zealand. 9 pages.

Columbus, J.; Sirguey, P. and Tenzer, R. (2011). A free, fully assessed 15-m DEM for New Zealand, *Survey Quarterly*, 66: 16-19.

Emmett, B., Abdalla, M., Anthony, S., Astbury S., August, T., Barrett, G., Biggs, J., Botham, M., Bradley, D., Brown, M., Carter, H., Chadwick, D., Cigna, F., Cooper, D., Cooper, J., Cosby, B., Creer, S., Cross, P., Edwards, F., Edwards, M., Evans, C., Ewald, N., Fitton, A., Garbutt, A., Grebby, S., Greene, S., Halfpenney, I., Hall, J., Harrison, S., Harrower, C., Henrys, P., Hobson, R., Hughes, S., Isaac, N., Jackson, B., Jarvis, S., Jones, D., Keith, A., Kelly, M., Korenko, J., Lallias, D., Leaver, D., Lebron, I., Malcolm, H., Maskell, L., McDonald, J., Moxley, J., Norton, L., O'Hare, M., Owen, A., Pereira, M., Peyton, J., Powney, G., Pywell, R., Rawlins, B., Robinson, D., Rorke, S., Rowland, C., Roy, D., Scarlett, P., Scholefield, P., Scott, A., Scott, L., Scott, R., Siriwardena, G., Smart, S., Smith, P., Swetnam, R., Taylor, R., Tordoff, G., Van Breda, J., Vincent, H., Wagner, M., Waters, E., Watkins, J., White, J., Williams, B., Wood, C., Wright, S. (2014*)* Glastir Monitoring & Evaluation Programme. First year annual report. Bangor, NERC/Centre for Ecology & Hydrology, 242pp. (CEH Project no. NEC04780)

Jackson, B.M., Pagella, T., Sinclair, F., Orellana, B.A., Henshaw, A., Reynolds, B., Mcintyre, N.R., Wheater, H.S. and Eycott, A. (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.

McIntyre, N. and Thorne, C (eds), 2013. Land use management effects on flood flows and sediments- guidance on prediction, CIRIA, London, ISBN: 978-0-86017-722-7.

Robinson, D.A., Jackson, B.M., Clothier, B.E., Dominati, E.J., Marchant, S.C., Cooper, D.M., & Bristow, K.L. (2013). Advances in Soil Ecosystem Services: Concepts, Models, and Applications for Earth System Life Support. *Vadose Zone Journal, 12(2).*

Selbie, D. R., N. L. Watkins, D. M. Wheeler and 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.

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.