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EVALUATING THE UNCERTAINTIES IN NEW ZEALAND'S GIS DATASETS; UNDERSTANDING WHERE AND WHEN FRAMEWORKS SUCH AS LUCI CAN ENABLE ROBUST DECISIONS SURROUNDING FARM MANAGEMENT PRACTICES

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Introduction

The connection between agricultural activities and water quality degradation is not new, with many studies identifying forms of diffuse pollution such as nitrogen, phosphorus and sediment emitted from intensive agriculture. While the quantities of nutrients lost from agriculture are not large compared to the total nutrients residing in the soil-plant-animal system, the transfer of nutrients from agricultural land to water causes significant environmental impact (Monaghan et al., 2007). With increasing attention on more sustainable land-use practices and mitigating the impact of agricultural intensification on the environment, decision support tools like the Land Utilisation and Capability Indicator (LUCI) are well suited to aid agricultural management, at both small and large scales (Trodahl et al., 2017).

This paper discusses how the varying quality and resolution of New Zealand's soil and elevation datasets impact LUCI's output. One case study is presented on the application of LUCI's Nitrogen to Water and Phosphorus to Water tools to a farm located on the Canterbury plains. Four different data combinations are carried out, using both freely and nationally available topography and soil data in the form of the NZSoSDEM 15m national digital elevation model (DEM) generated by the Otago School of Surveying (available from koordinates.com) and the Fundamental Soil Layer (FSL- available from https://lris.scinfo.org.nz/). The two remaining datasets are not currently freely available or of full national coverage, with the 2m DEM sourced from Environment Canterbury and S-Map soil data available under license from Landcare Research (smap.landcareresearch.co.nz/).

LUCI

LUCI, described in detail in Jackson et al. (2013); Sharps et al. (2017); and Trodahl et al. (2017) is a GIS-based framework that explores land management scenarios to identify locations where changes in land use might deliver improvements in ecosystem services, or where trade-offs between services are present (Sharps et al., 2017). The algorithms in LUCI include an exploration of the impacts of land management changes on flood risk, habitat connectivity, erosion and sedimentation, nutrient movements, carbon sequestration and agricultural productivity. This research is solely focused on LUCI's ability to model and track the flow of nitrogen, phosphorus and sediment across the landscape to waterways.

A benefit of using LUCI to model and understand the complex interaction between nutrients, sediment and water quality on a farm system is that it is spatially explicit. Using the different tools within the framework the user can track changes across the entire farm, or within smaller blocks, enabling mitigation strategies that improve water quality to be effectively targeted. Minimum base data required for LUCI is a DEM, soil and land cover data. These can be sourced from nationally available datasets. However, the addition of further national or local data along with stakeholder consultation can improve the accuracy of LUCI's output (Figure 1).

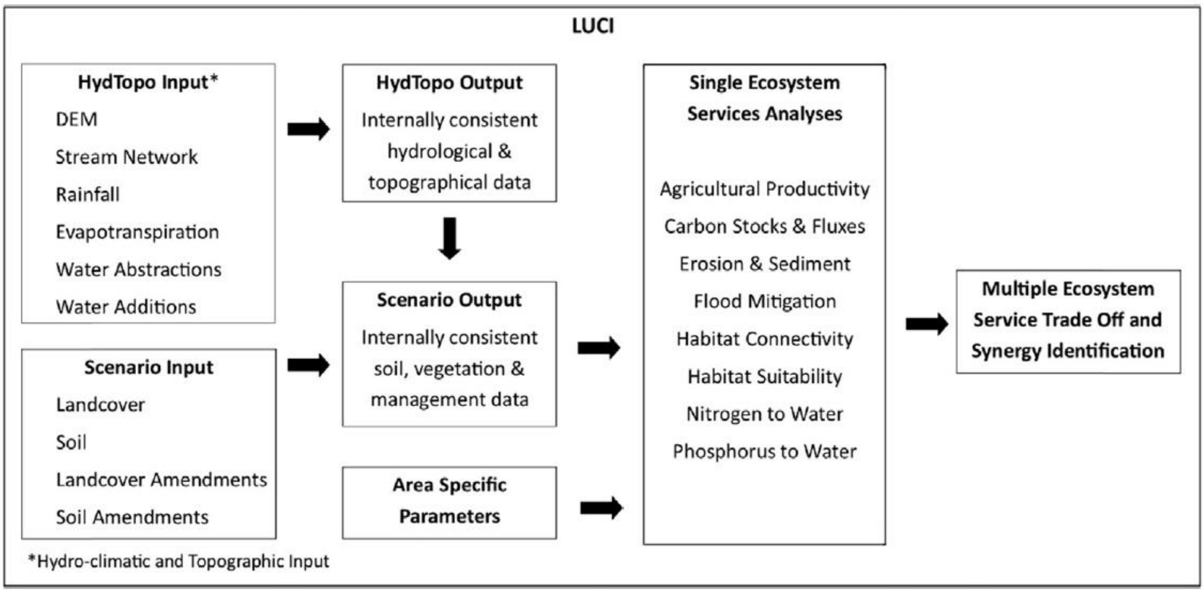

Figure 1- LUCI process diagram, based on Figure 1 in Trodahl et al. (2017)

The Nitrogen to Water and Phosphorus to Water tools use an export coefficient approach to model nitrogen and phosphorus lost to water in kg/ha/yr. The export coefficient approach describes the rate at which a contaminant is input into a water body per unit of source area, in this case, the unit area is one DEM grid cell (White et al. 2015). These export coefficients are linked to land cover classification, climate and region being modelled and are commonly used to represent the movement of diffuse pollution in the landscape (Trodahl et al., 2017).

Soil Data

To test how varying quality and resolution of New Zealand's soil data effects LUCI's output, two soil maps were used to produce estimates of nitrogen and phosphorus lost from one site. The Fundamental Soil Layer combines the polygons in the New Zealand Land Resource Inventory (NZLRI) with the soil data from the National Soil Database (NSD). In the Canterbury region, this information was based on the original Plains and Downs Survey at a scale of 1:126 720 (Kear et al. 1967). Expert knowledge along with consultation with stakeholders merged the existing soil profiles and determined the seventeen soil attributes that the FSL describes (Barringer et al., 2016). The second dataset used, S-map, has been under development since 2003 and is the newest soil database covering New Zealand. This dataset incorporates the historic data held within the NSD with new soil surveys and fills in data gaps with an inference engine which uses rule-based validation to infer soil properties if unavailable from the measured data (Lilburne et al., 2012). S-Map is designed to be used at scales between 1:50 000 and 1:20 000 and users need to consider the implications of using this dataset outside of the scale of analysis it was designed for (S-MapOnline, 2018).

Topographic Data

The only nationally available DEMs are derived from the LINZ NZTopo50 database with 20 m contours. Columbus et al. (2011) interpolated a 15m^2 DEM from this data choosing this resolution as a balance providing a DEM of reasonable spatial resolution, without creating a file so large that it would often be impractical to be used in research. National coverage of LiDAR (Light Detecting and Ranging) data is not yet available. However, regional councils hold LiDAR data over some or (in the case of Greater Wellington) all of their region, which can be used to create fine resolution DEMs if researchers are allowed access. LINZ is actively procuring LiDAR data from the separate databases held by councils and private companies to facilitate access (LINZ, 2018).

Case Study: North Canterbury

The study site is a 309ha sheep and beef farm located in North Canterbury in the Ashley watershed (Figure 2). The terrain is mostly flat, with a mix of brown, pallic and recent soil orders (Figure 3). There is a steep escarpment and one permanent stream on the property. FSL and S-Map soil datasets and DEMs at 15m and 2m resolution are available for this study site. For the results presented in this paper land cover data is taken from the national LCDB4 database which classed 67% of the farm area as high producing grassland and 23% as rotational cropland (Figure 4). The other smaller areas classified were exotic forest, gorse and deciduous hardwoods.

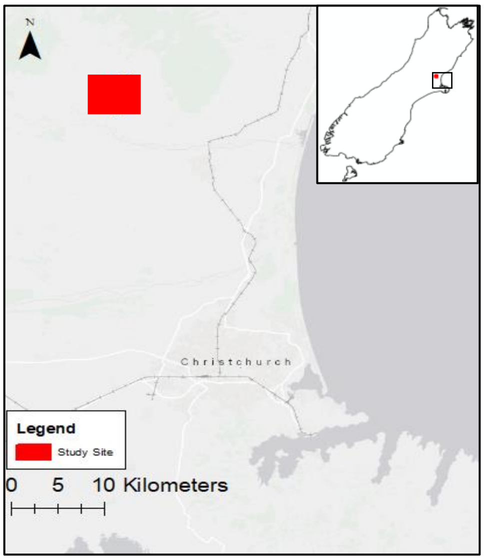

Figure 2- Location of study site.

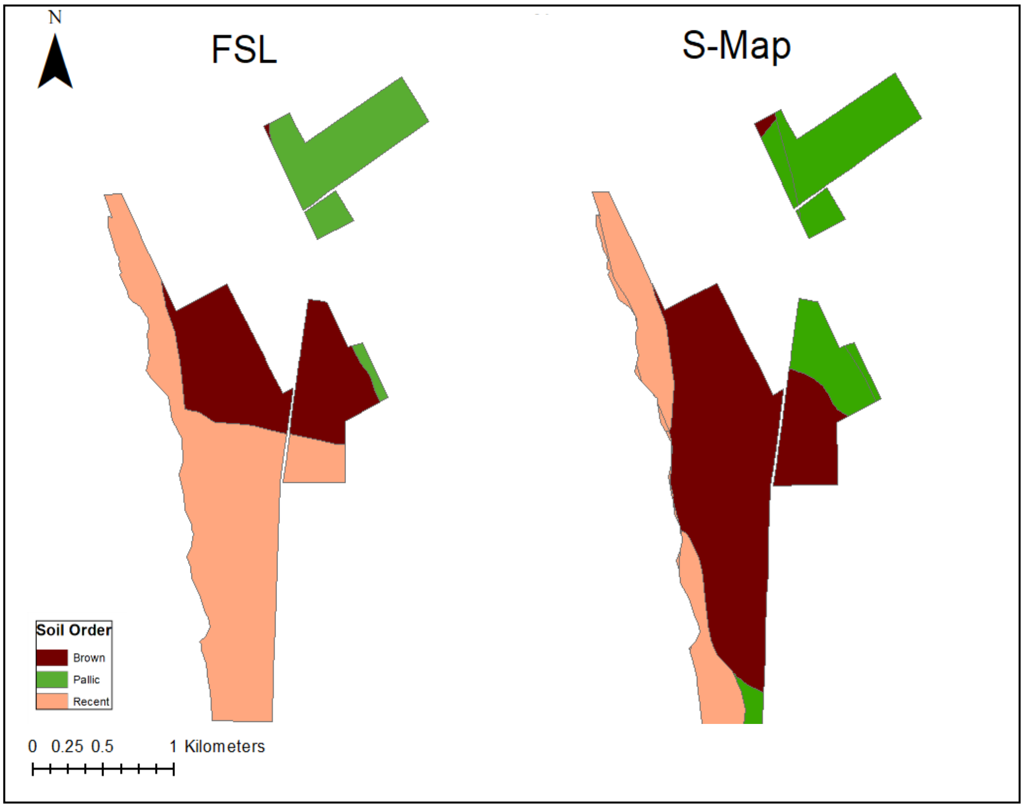

Figure 3- Soil order classification in FSL and S-Map.

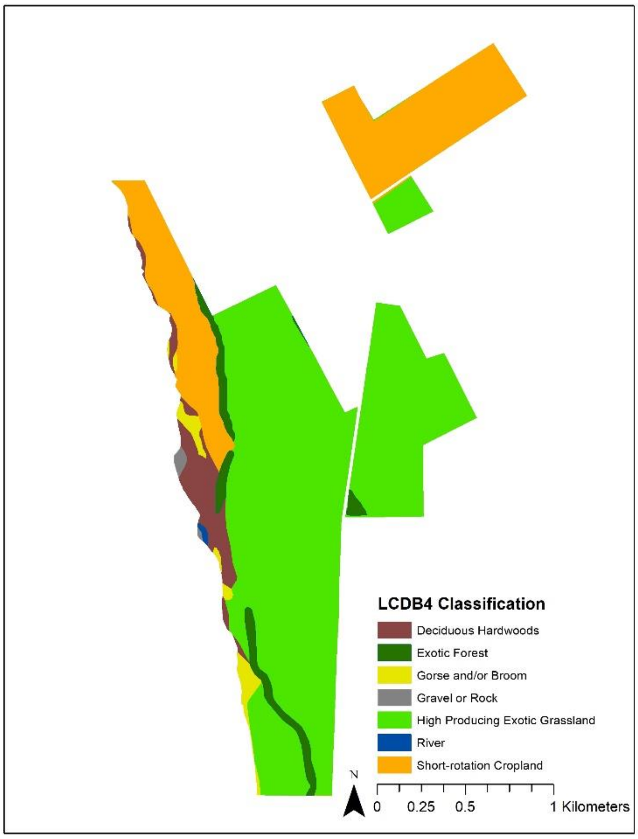

Figure 4- Land use classification in the LCDB4

Method

LUCI water quality models (Nitrogen to Water and Phosphorus to Water) were run using four combinations of soil and topographic data (Table 1). In general, default parameters were used, except when the default values clearly showed a deviation from the real word characteristic of the landscape. The nitrogen and phosphorus load estimates were then analysed in Matlab to understand the distribution of load estimates and the probability of a loads occurrence on the landscape. In Matlab the load results from each cell were then summed across the landscape to calculate the total load on the farm in kg N(P)/yr.

Table 1- Data input for the four LUCI applications

LUCI Application	**Soil Data**	**Topographic Data**
S-Map 2m	S-Map (1:50 000)	LiDAR (2m)
S-Map 15m	S-Map (1:50 000)	National DEM (15m)
FSL 2m	FSL (1:126 720)	LiDAR (2m)
FSL 15m	FSL (1:126 720)	National DEM (15m)

Results and Discussion

LUCI Nitrogen to Water and Phosphorus to water tools produce a variety of outputs that allow the user to explore total nitrogen and phosphorus loads on the landscape (kg nutrient/ha/yr) and accumulated total loads (kg nutrient/yr). Accumulated load considers the nutrient load at any point plus the contribution to that cell from "uphill" sources (Jackson et al., 2013). The results are represented by a traffic light colour scheme where red indicates high nutrient loads and green indicates low nutrient loads (note this is a reversal of the original colour scheme presented in Jackson et al. (2013), in use until a change in 2017).

Nitrogen loads from the four applications are shown in Figure 5 and nitrogen accumulated load is shown in Figure 6. The distribution of high and low nitrogen loads can be seen to follow the pattern of each applications input soil data (Figure 3). The changing ratio of brown, pallic and recent soil order classifications across the farm when using the newer, S-Map dataset, resulted in the reduction in the high load estimates classified as recent soil in the FSL as this area was reclassified as a brown soil. The area classified as pallic soil remained as a low nitrogen load. This was expected as pallic soils leach less nitrogen due to increased denitrification and lower drainage rates compared to well drained recent and brown soils (Pollacco et al., 2014).

While the highest estimates of total nitrogen load remain the same for the applications using identical soil data, the two FSL applications estimated a higher total nitrogen load, as shown in Table 2. The highest total nitrogen load was 4,443 kg N/yr calculated from FSL 15m, with the second highest estimate from FSL 2m, this pattern is present in the total estimates of phosphorus as well. This indicates that the source of soil data plays a more significant role on the results of total nutrient loads then the resolution of the DEM.

However, when looking at the outputs of accumulated nutrient load on the landscape, the effect of the different soil datasets is not apparent and instead, the changing resolution of the DEM is the main cause of difference between the applications. When looking at the accumulated loads of S-Map 2m and S-Map 15m, it is apparent that the 15m DEM is estimating different pathways to the 2m DEM and this is the same when comparing FSL 2m and FSL 15m. Since LUCI estimates accumulated load using a topographic routing algorithm that associates soil, climate, slope based on the grid size of the DEM provided, when using a lower resolution DEM, the microtopography present on the farm is not picked up by the algorithm and the accumulated load patterns are not realistic in this relatively flat landscape. LUCI's estimates of accumulated load differ between DEM resolution regardless of what soil dataset is used.

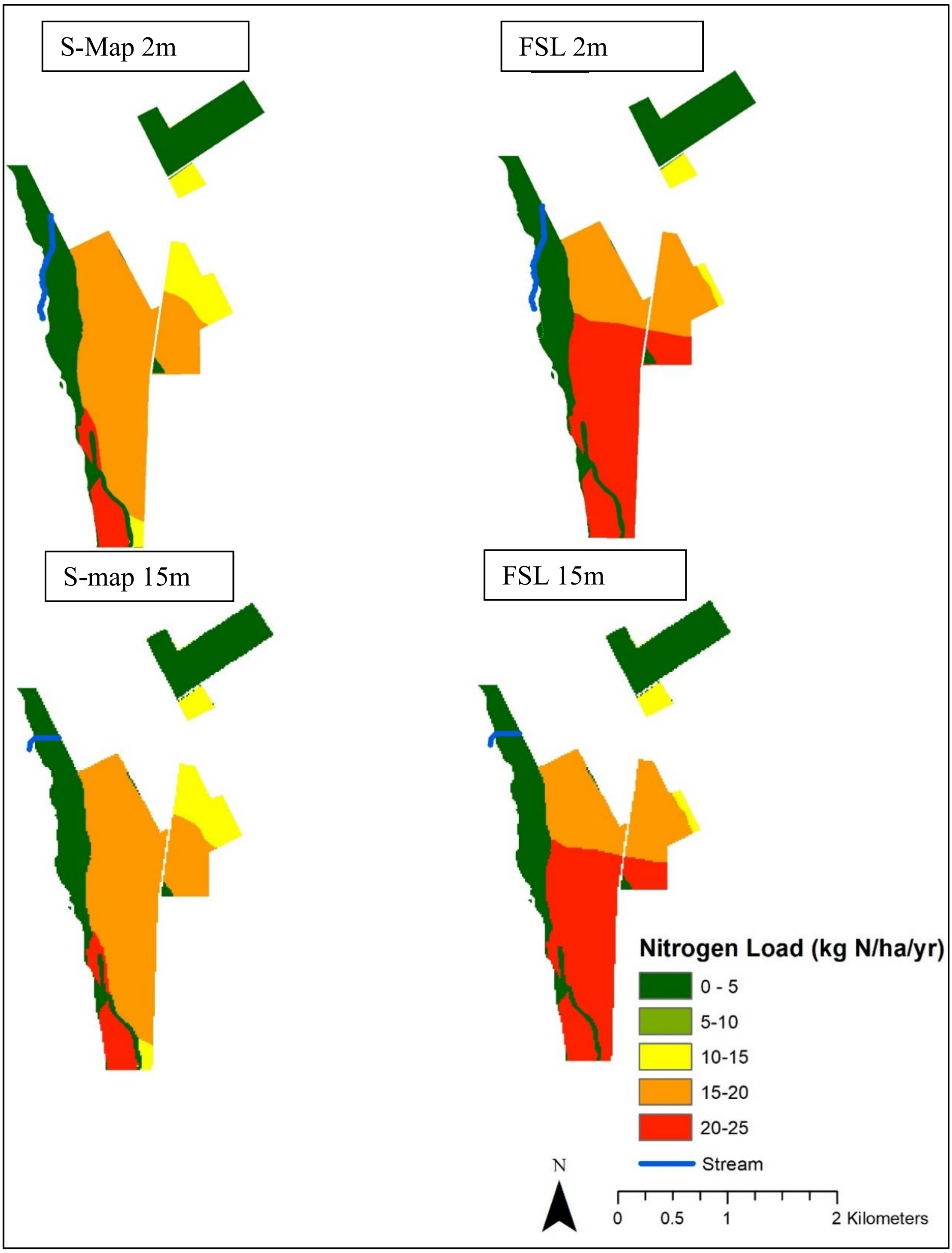

Figure 5- LUCI's estimates of Nitrogen Load using all data input scenarios.

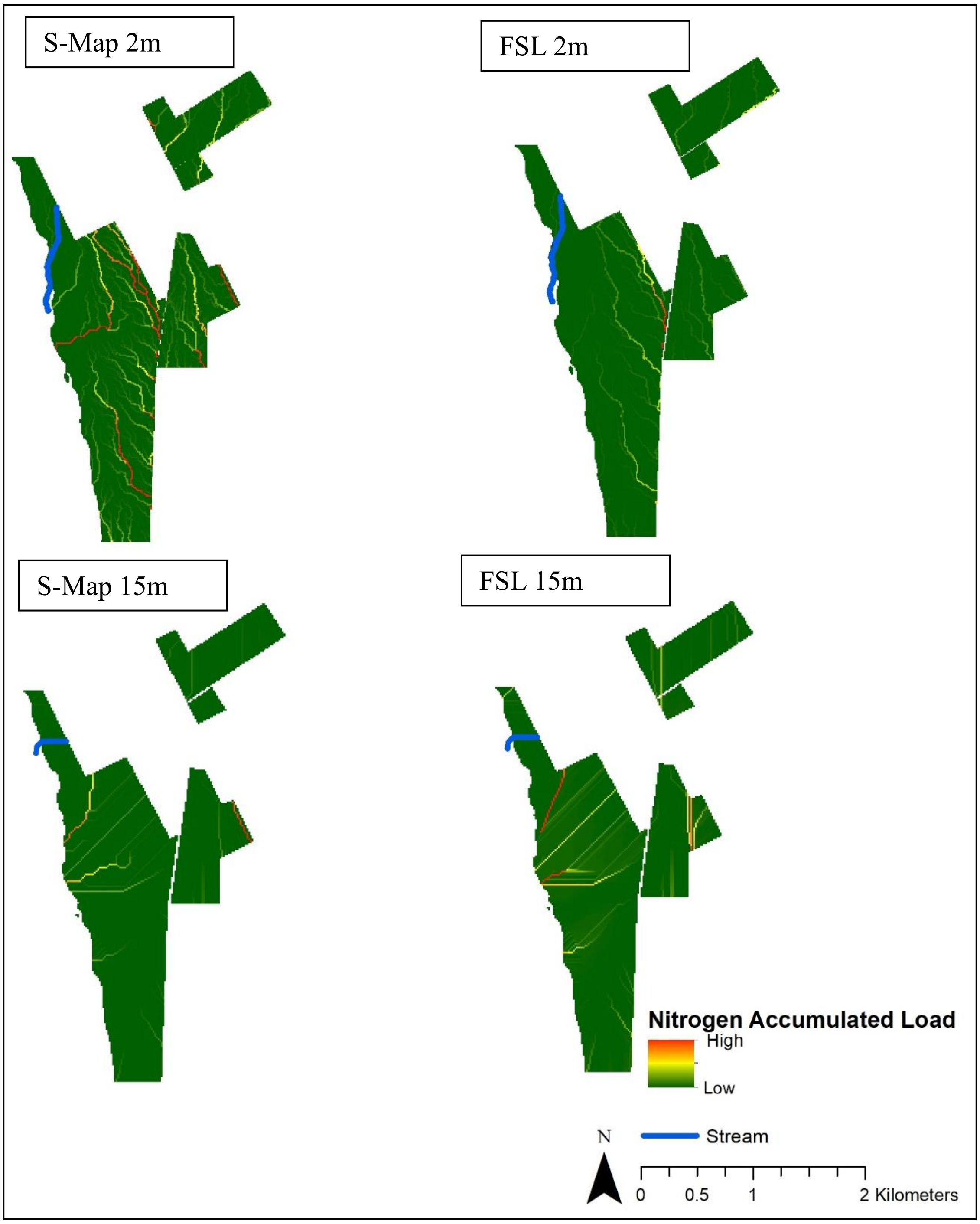

Figure 6- LUCI's estimates of Nitrogen Accumulated Load using all data input scenarios.

Table 2- Total Nitrogen Loads calculated from all applications

LUCI Application	Total Nitrogen Load (kg N/yr)	Total Phosphorus Load (kg P/yr)
S-Map 2m	3,691	57.2
S-Map 15m	3,713	57.8
FSL 15m	4,401	89.2
FSL 15m	4,443	90.1

Not only is soil classification effecting LUCI's estimates of nitrogen loads but the land cover classification in the LCDB4 has resulted in load inconsistencies. The estimates of nitrogen loads along the river flat on the western edge of the farm vary despite being classed as recent soils in both FSL and S-Map datasets. The reason for the different loading estimates along this block is the classification of the upper northern part as cropland and the southern half as high producing grassland (Figure 4). In reality, the entire river flat is covered by high producing grassland, showing the importance of understanding the underlying data used in models such as LUCI, and if available, the importance of using high resolution, site specific land cover data. For farm scale use land use information would normally be derived from an Overseer nutrient budget and associated farm management block map as these provide LUCI with information on the cropping practices, fertiliser and irrigation management present on this farm.

Phosphorus load estimates also follow the pattern in soil input data (Figure 7). Again, FSL 2m and FSL 15m estimate higher phosphorus loads then their S-map counterparts, with FSL 2m estimating 89.2 kg P/yr and S-Map 2m estimating 57.2 kg P/yr (Table 2). Comparing the load of individual cells with the same soil order between applications, the values are similar, so the reason for the 32 kg P/yr difference between S-Map and FSL applications can be attributed to the classification change from recent to brown soil over the main block of the farm (this is the most significant area of difference between the two soil maps). The accumulated phosphorus load results show a similar pattern to the accumulated nitrogen load output, where the effect of the lower resolution DEM results in a different representation of accumulated load across the landscape (Figure 8).

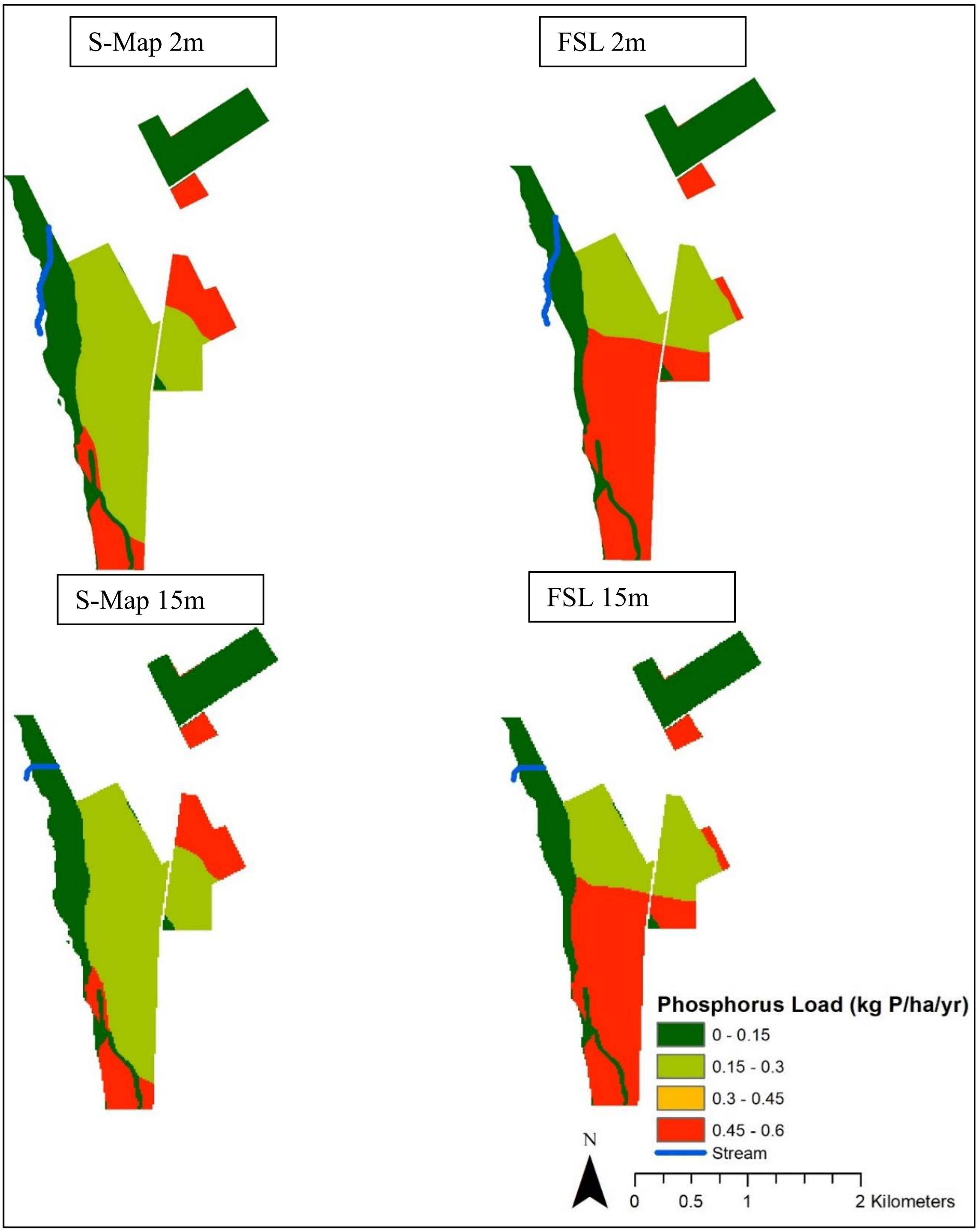

Figure 7-LUCI's estimates of Phosphorus Load using all data input scenarios.

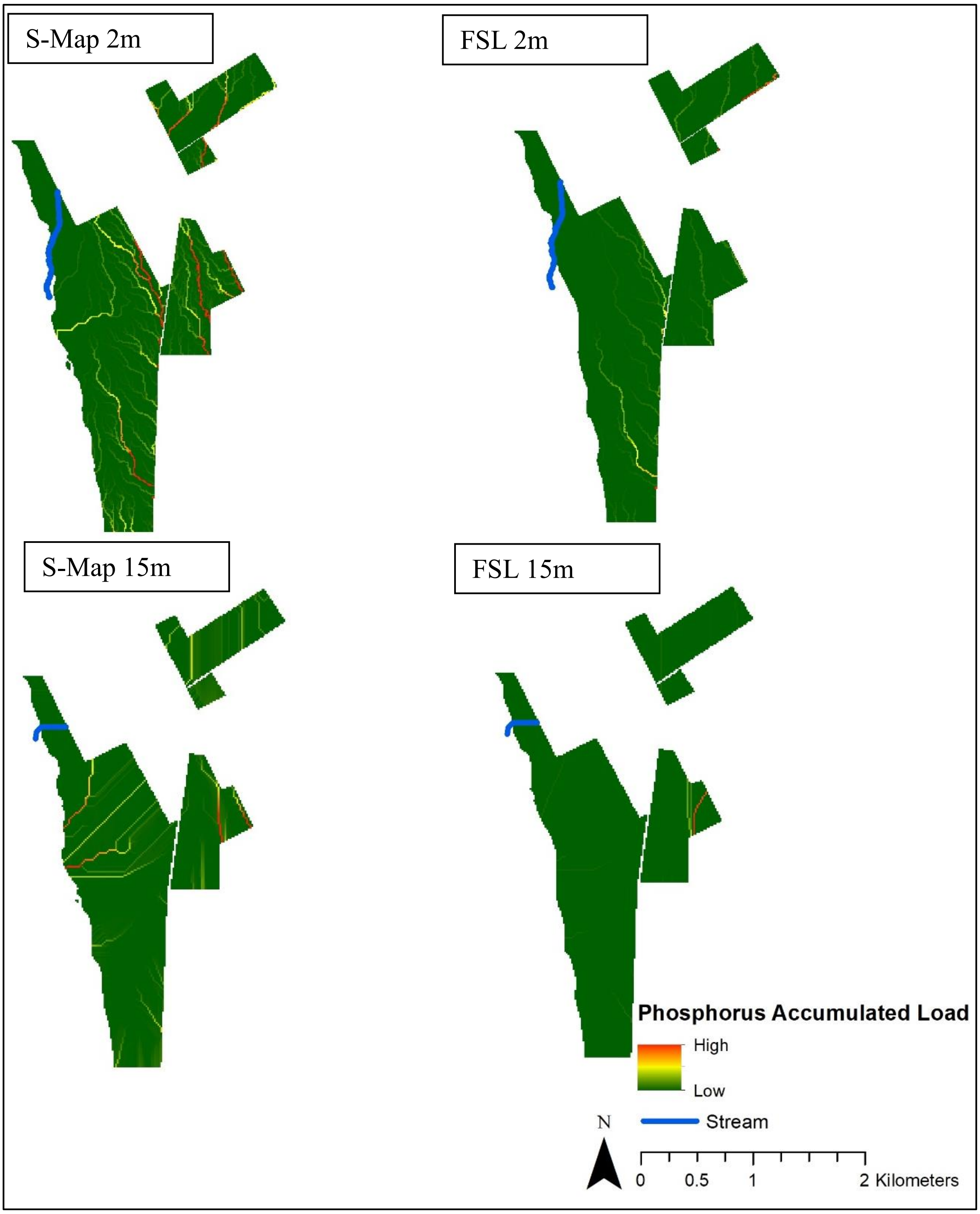

Figure 8-LUCI's estimates of Phosphorus Accumulated Load using all data input scenarios.

It is important to note the different pathways of nutrient movement through a farm system. Nitrogen is easily lost by leaching to ground water, whereas, phosphorus is mainly lost through runoff and erosion (McDowell and Condron, 2004). While phosphorus loss from farm is in smaller quantities then the total amount present in the soil, only a small quantity of phosphorus entering a water body causes significant environmental damage through the enhanced growth of aquatic weeds and algae (McDowell and Condron, 2004). The area of pallic soil has been classified as cropland in the LCDB4, resulting in low predicted phosphorus losses on this site, again highlighting the importance of site specific landcover data. Pallic soils are naturally prone to pugging due to the impermeable nature of the soil, this means that surface water rich in phosphorus can be lost to water bodies via surface runoff (FLRC, 2016). Pallic soils have low P retention meaning that little phosphorus is removed from the soil solution and held on the surface of soil colloids. Given this case study has a flat topography, with the only area of major elevation change (the river escarpment) covered in forest, phosphorus loss on this site is not as large or complex as expected loss from a site with rolling, steep hill topography.

Conclusion

In this case study, LUCI's estimates of nitrogen and phosphorus load lost from the landscape are affected by the soil data used as input to the model. The changing classification from recent to brown soil with the newer, S-Map dataset, results in reduced estimates of nitrogen and phosphorus loads on this farm. Load estimates are also dependant on land use. Accumulated load patterns however, are not sensitive to changing the source of the soil data and instead, the resolution of the DEM used in each application had the most pronounced effect. These relationships between difference soil datasets and DEM resolutions are being explored further in five other case studies. These sites are located in both the North and South Island, ensuring different climates, land management practices, soil datasets and topography are incorporated this analysis of the LUCI model.

Acknowledgements

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