LUCI-Ag Report

Shag River Catchment

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Executive Summary

The Otago Regional Council (ORC) engaged Ravensdown Environmental to model nitrogen (N) and phosphorus (P) losses from the Shag River Catchment using a combination of OverseerFM and LUCI-Ag. Fourteen farms and an effluent disposal site located within the catchment were modelled. Farm OverseerFM and LUCI-Ag modelling was used to inform LUCI-Ag catchment modelling. Each farm was embedded into the catchment model, with the remaining land use in the catchment predicted using aerial photos and data from Land Information New Zealand (NZ Property titles) plus the Land Cover DataBase. The predicted values for average sheep/beef/deer farms in the catchment (e.g. fertiliser inputs, soil test results and revised stock units (RSU)) required for the modelling were based on the average values from the sheep and beef farms in the report. The remaining land use (e.g. Exotic forest, Indigenous forest and Manuka and/or Kanuka) were based off standard LUCI-Ag values.

Modelling identified areas of high N and P load and pathways of high N and P accumulation in the catchment under the likely current land management conditions. These areas of the catchment were then re-modelled using a range of different mitigation scenarios available in LUCI-Ag, to assess their likely impact. Results from the scenario modelling are reported in this LUCI-Ag catchment report.

Results from LUCI-Ag catchment modelling for the Shag River Catchment under current management indicate:

- The highest N load was under winter grazed crops. Current focus by farmers on reducing losses from these hot spots could provide significant benefits.

- The highest P load was found under productive land, on steeper slopes, underlain by Pallic soils (poorer draining soils).

Modelled mitigations and the effects on stream concentration showed:

- Small reductions (~1%) in N and P concentrations, at the Shag River exit, when case study farm mitigations were applied. These farms make up a small part (~18% of the catchment area) of the combined catchment load. If these reductions are extrapolated out to the rest of the catchment (assuming the farms are representative of the catchment), the modelled reductions are a 7% and 2% reduction in N and P concentrations, at the Shag River exit, respectively. The smaller reduction in P losses may be due to the model predicting high P loads from the top of the catchment (due to the annual rainfall layer) and effectively diluting the effect of the case study farm mitigations on reducing in stream P concentration.

- Modelled results suggest that further fencing of low slope land resulted in small reductions (<1%) in N and P concentrations at the Shag River exit. This small reduction is likely due to the small area in the catchment that is low slope land and amount of fencing already completed in that low slope area (it was assumed the high production sheep and beef land from the Manaaki Whenua – Land Cover DataBase was fenced). However, farms saw up to 23% and 71% reductions

in N and P concentrations, respectively, on localised stream exits on their farms due to riparian plantings. The average reductions seen on individual farms (with riparian planting as one of the mitigations) saw average reductions of 13% and 50% of N and P concentrations, respectively, in localised streams leaving the farms.

- Small increases, 2% and <1% in N and P concentrations at the Shag River exit, respectively, were seen when irrigation (~1200 ha – 2% of the catchment) and intensification (~9100 ha – 17% of the catchment) was modelled in the flatter, more productive areas of the catchment. This increase due to intensification could easily be offset by retiring some of their steeper areas of farms into forestry. Reductions in N and P concentrations at the Shag River exit, by 9 and 14%, respectively, were seen when steep pastoral land >25 ° was retired into forestry (~9700 ha – 18% of the catchment). However, LUCI-Ag does not model the effect forestry has on stream flow, only changes in N and P load going into the river. The effect of the harvest phase was also not modelled. It has been seen in previous catchment modelling that recently harvested forest was the sediment loss hotspot.

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Dated: 4 May 2023

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Introduction

The Otago Regional Council (ORC) has engaged Ravensdown Environmental to model nitrogen (N) and phosphorus (P) loss from the Shag River Catchment using LUCI-Ag/OverseerFM. Fourteen farms plus the Waitaki District Council effluent irrigation area located in the catchment were modelled.

The aim of the project was to use modelling to identify areas of high N and P load and pathways of high N and P accumulation under current land management conditions in the Shag River catchment. In areas of the catchment identified as having high N and P loss, a range of different mitigations were then tested using LUCI-Ag scenario modelling to assess their likely impact.

Details of LUCI-Ag/OverseerFM modelling

Each farm was embedded into the catchment model, the remaining land use was predicted using aerial photos and the following databases: Land Information New Zealand – NZ Property titles, Manaaki Whenua – Land Cover DataBase, and ORC land use and irrigated area layers. The predicted values for average sheep/beef/deer farms in the catchment (e.g. fertiliser inputs, soil test results and RSU) were based on the average values from the 12 sheep and beef farms in the report distributed over high and low producing LCDB grassland classes and irrigated and dryland areas. One dairy farm and one arable farm were also modelled in the catchment. The remaining land use (e.g. Exotic forest, Indigenous forest and Manuka and/or Kanuka) were based off standard LUCI-Ag values.

Catchment details and description

The Shag River/Waihemo in east Otago has a catchment area of approximately 550 km^2. The river is approximately 90 km long and flows from the slopes of the Kakanui Peak, past the town of Palmerston, before entering the Pacific Ocean south of Shag Point/Matakaea. The main Shag valley follows the geologically active Waihemo Fault system; the fault system separates weakly cleaved greywacke ranges on the northeast side, from rolling schist uplands on the southwest side (Black *et al.* 2004). A significant sub catchment of Deepdell Creek is located on the southwest side of the catchment.

The catchment is largely used for sheep and beef, with some exotic forest and tussock/scrubland (Figure 4). The catchment was modelled as 14% forestry and 83% pastoral/cropping land. A large part of the catchment is rolling/hill country, with most of the flat land found in the valley at the lower end of the catchment. The catchment also contains the Macraes gold mine.

The average annual rainfall is approximately 600 mm. The river is relatively low flow and water quality is generally good (Olsen 2014) (Table 1).

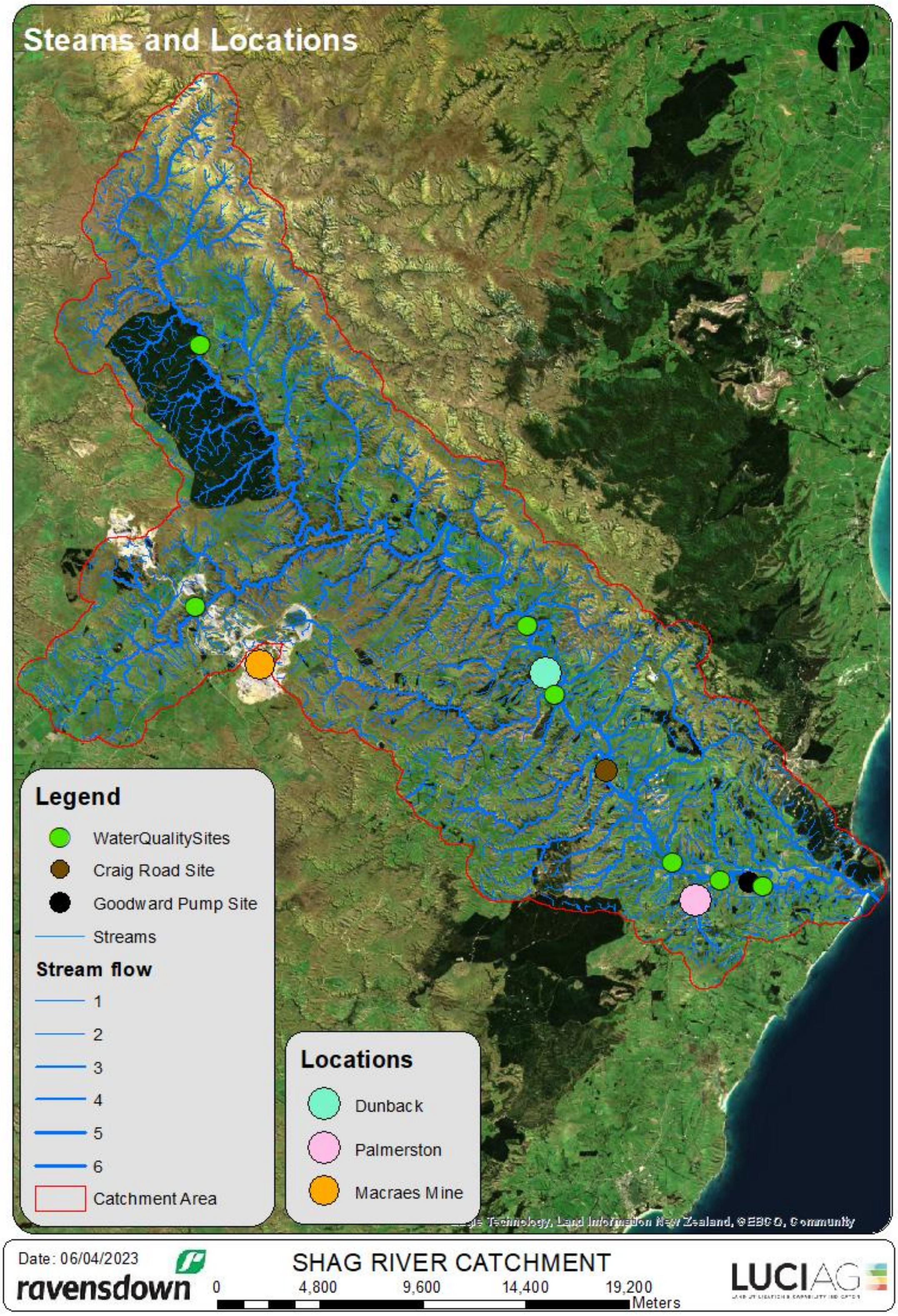

Figure 1. Catchment area, key locations and waterways (may include ephemeral streams) in the catchment. Please note that waterways are generated by LUCI-Ag based on a digital elevation model (DEM) using topography and rainfall. Due to the resolution of the DEM, waterways may not be in exactly the correct location on the map.

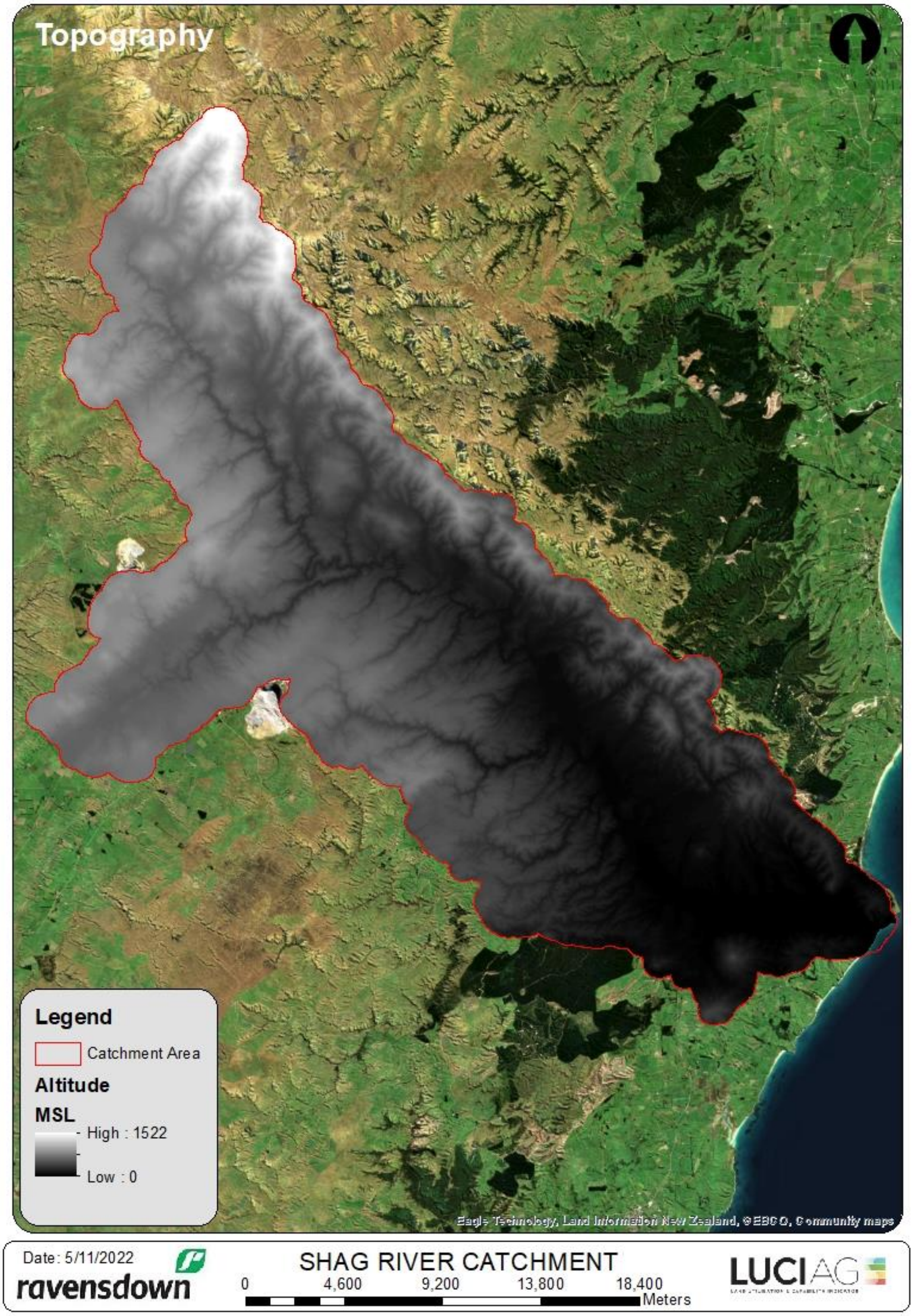

Figure 2. Topography of the Shag River catchment. A 5m*5m DEM was mosaiced from a 1m LiDAR DEM downloaded from OpenTopography (NZ16_Otago) resampled to 5m and the NZ 15m*15m DEM from Otago Survey school (NZSoSDEM v1).

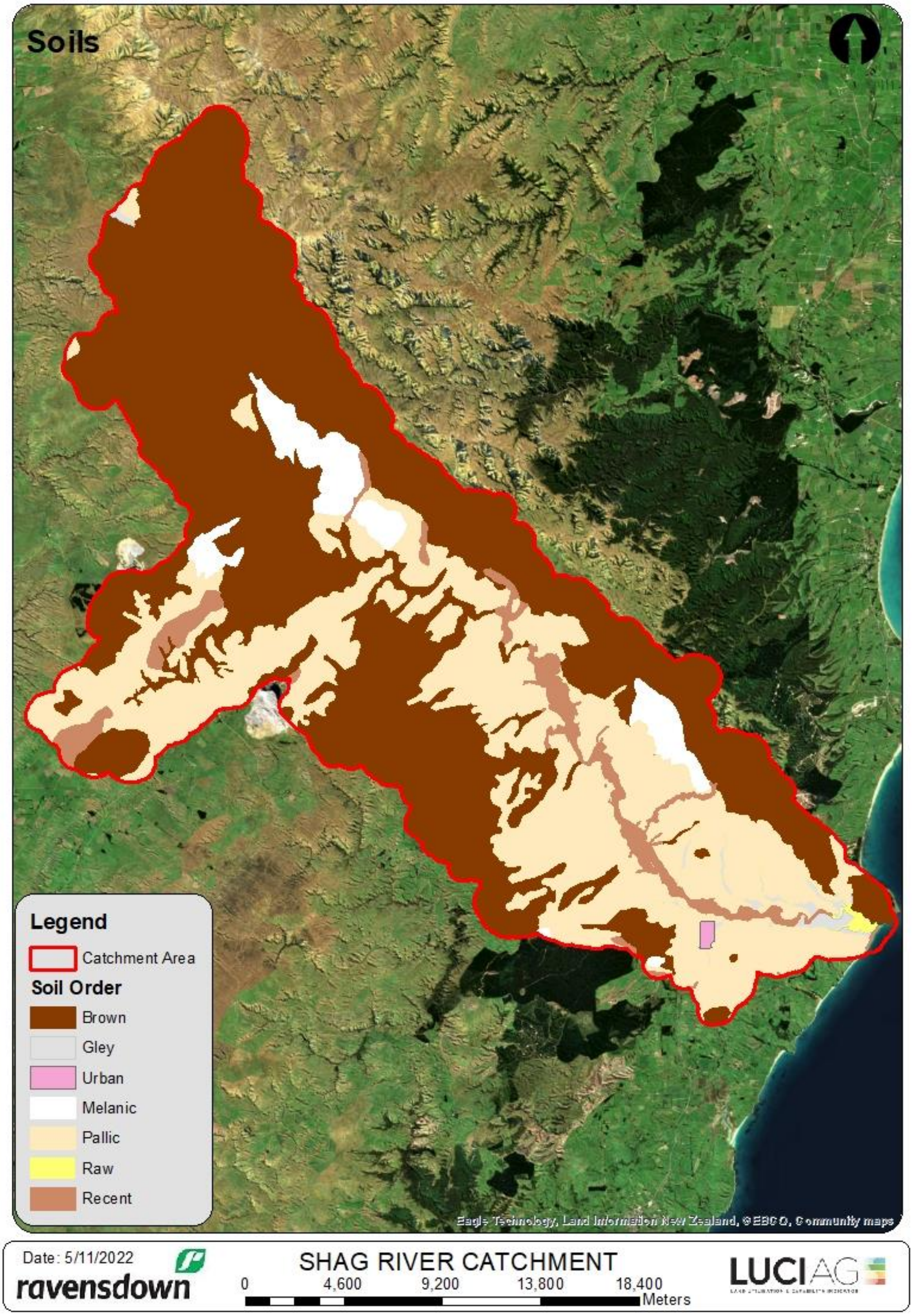

Figure 3. Soil orders (NZSC) present in the catchment.

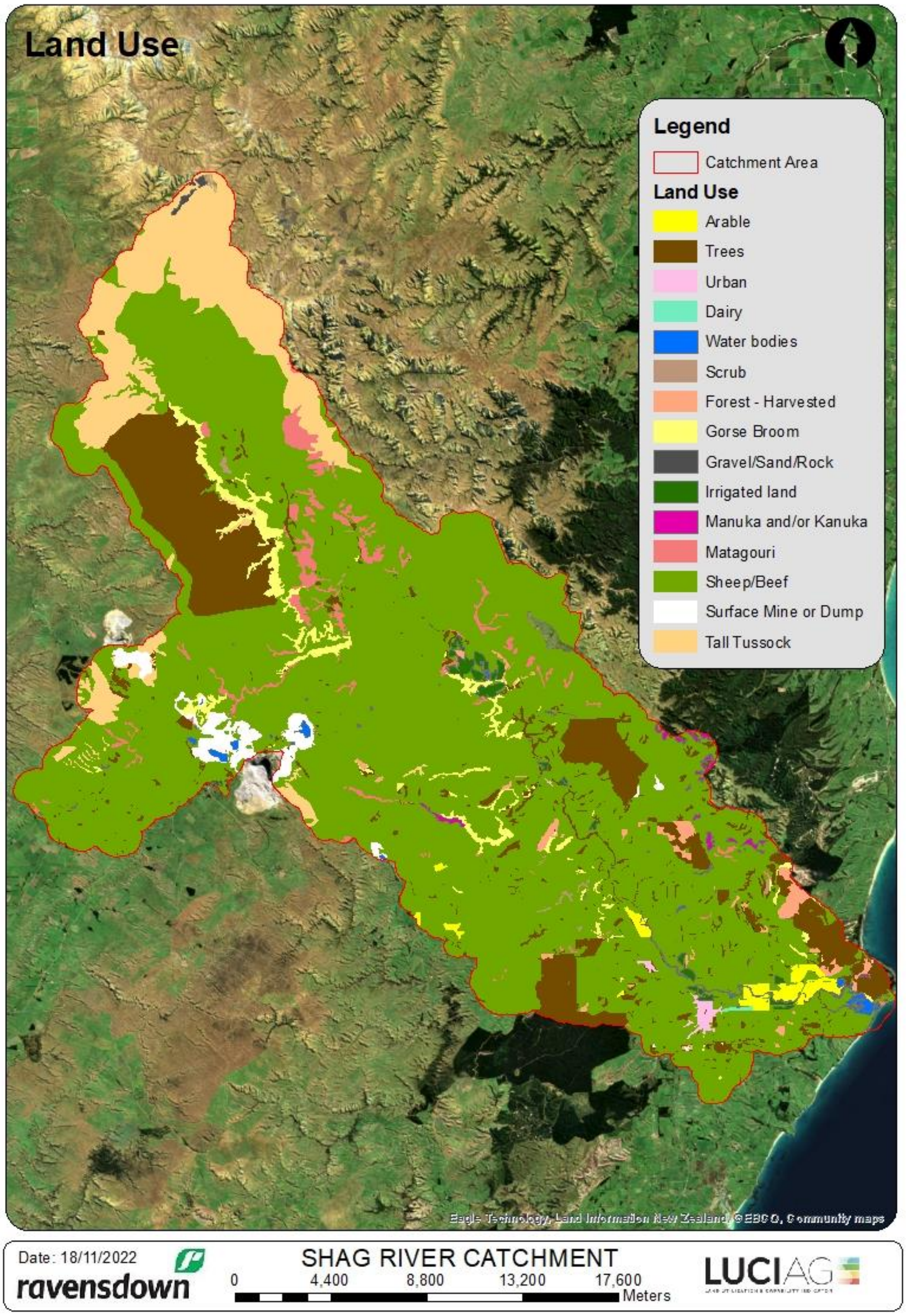

Figure 4. Predicted land management and landcover within the Shag River catchment. Predictions are based off farm reports, aerial photos and the following databases: Land Information New Zealand – NZ Property titles, Manaaki Whenua – Land Cover DataBase.

Water quality within the catchment

Two permanent and five single year water quality monitoring sites are located within the catchment. Of the two permanent sites, one is a mid-catchment site at Craig Road and the other is near the lower end of the catchment at Goodwood Pump. Based on the monitoring results at these sites the Shag river has very good water quality (LAWA, 29 Nov 2022). These sites are compared against the predicted annual average N & P concentrations from LUCI-Ag. These values are calculated using modelled annual N & P loads at that point, divided by annual stream volume at that same point.

Table 1 – Instream 5 year median for total nitrogen and total phosphorus concentrations at water quality monitoring sites within the Shag River Catchment (LAWA, 29 Nov 2022).

Monitoring Site	Total nitrogen (mg TN/L)	LUCI-Ag predicted (mg TN/L)	Total phosphorus (mg TP/L)	LUCI-Ag predicted (mg TP/L)
Craig Road	0.32	0.89	0.00075	0.00294
Goodwood Pump	0.45	0.98	0.009	0.00295

The difference between the predicted P and N concentrations and the measured in-stream concentrations could be due to many factors:
-Complexity of attenuation factors
-Complexity of groundwater/surface water interactions
-Spot sampling not capturing significant variation in stream concentrations (e.g., flooding events).

Baseline Scenario Modelling

Nitrogen

Figure 5 shows the likely pattern of N lost via leaching and overland flow at each point over the catchment as modelled by OverseerFM. The model links N load to:

- Fertiliser N inputs
- Effluent N inputs
- Stocking rates
- Rainfall
- Irrigation
- Soil variables, particularly those related to drainage

Nitrogen load only includes what is generated at that point as a result of these variables, and it does not include N received at that point from up-hill sources. Please also note that N load in Figure 5 is categorised from high to low based on the catchment data only and does not relate to either average or expected regional or national loss values.

The highest N loads in the catchment were found to be in parts of the catchment used for winter grazed crops. This is because winter grazing areas have high stocking intensity (more urine patches), periods when soils are fallow (no plant N uptake) when there is a high risk of N leaching loss due to more drainage than other parts of the year.

Figure 6 shows N load generated at a point in the landscape plus that contributed to that point from up-hill sources. This is called 'accumulated N load'. Areas of very high accumulated N load identify pathways where water and nutrients converge in the landscape on the way to waterways. Pathways of highest accumulation are often associated with channels, gullies and/or wetter areas within paddocks (catchment) and these are good target areas for mitigation. Although the majority of N from productive land is lost via leaching rather than overland flow, in hill country areas, leached N tends to move laterally with shallow soil throughflow into local wet areas, gullies and waterways.

Mitigations to address N loss via LUCI-Ag include:

- Changes in fertiliser N application rates
- Changes to effluent N application rates
- Changes to stocking rates
- Fencing or fencing and planting additional waterways or wetter gully areas connected to waterways
- Fencing or fencing and planting other areas of high N loss risk areas

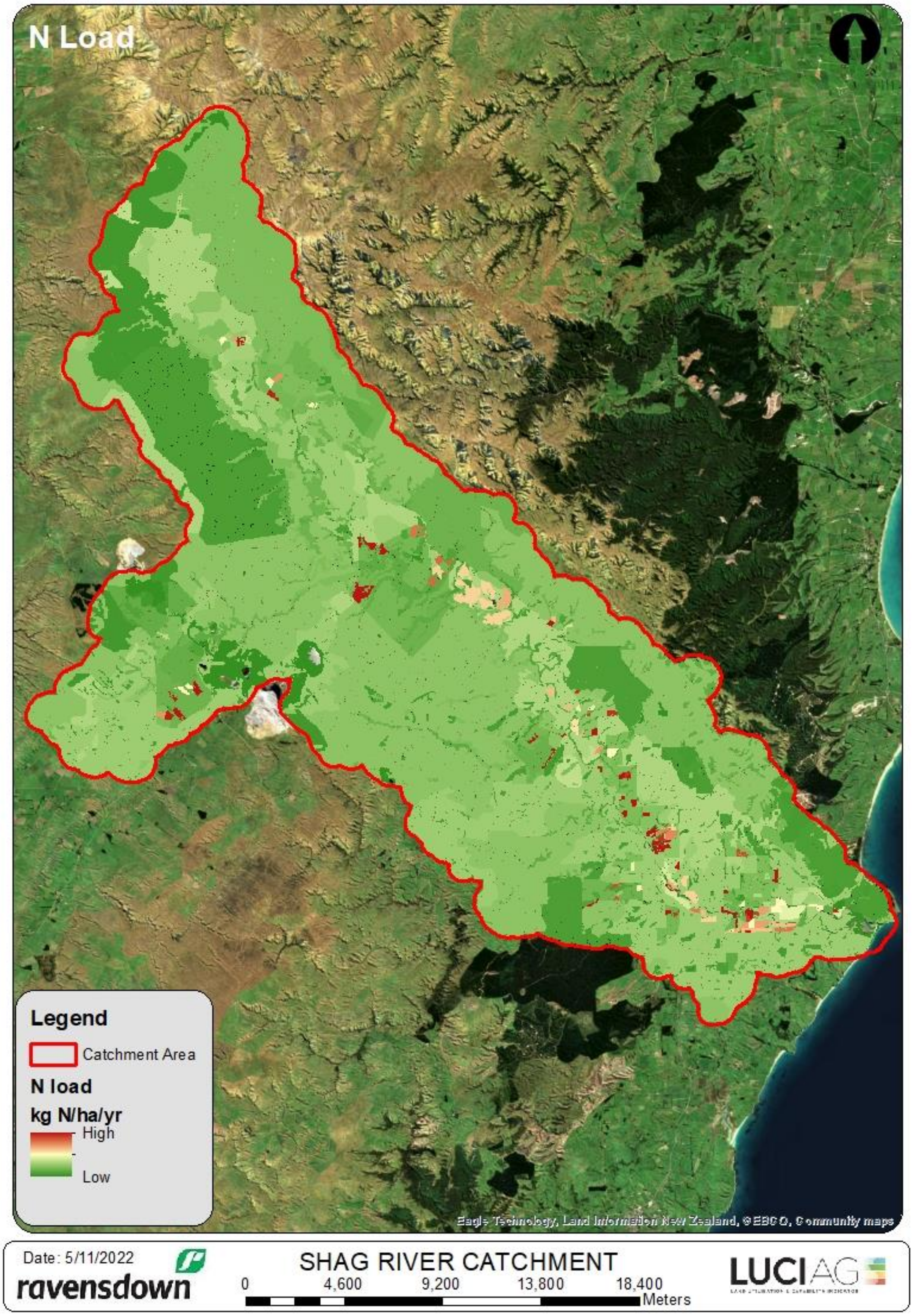

Figure 5. Nitrogen load (kg N/ha/yr) in the Shag River catchment as modelled by LUCI-Ag. NOTE: N load is categorised from high to low based on the catchment data only and is not related to either average or expected regional or national N loss values.

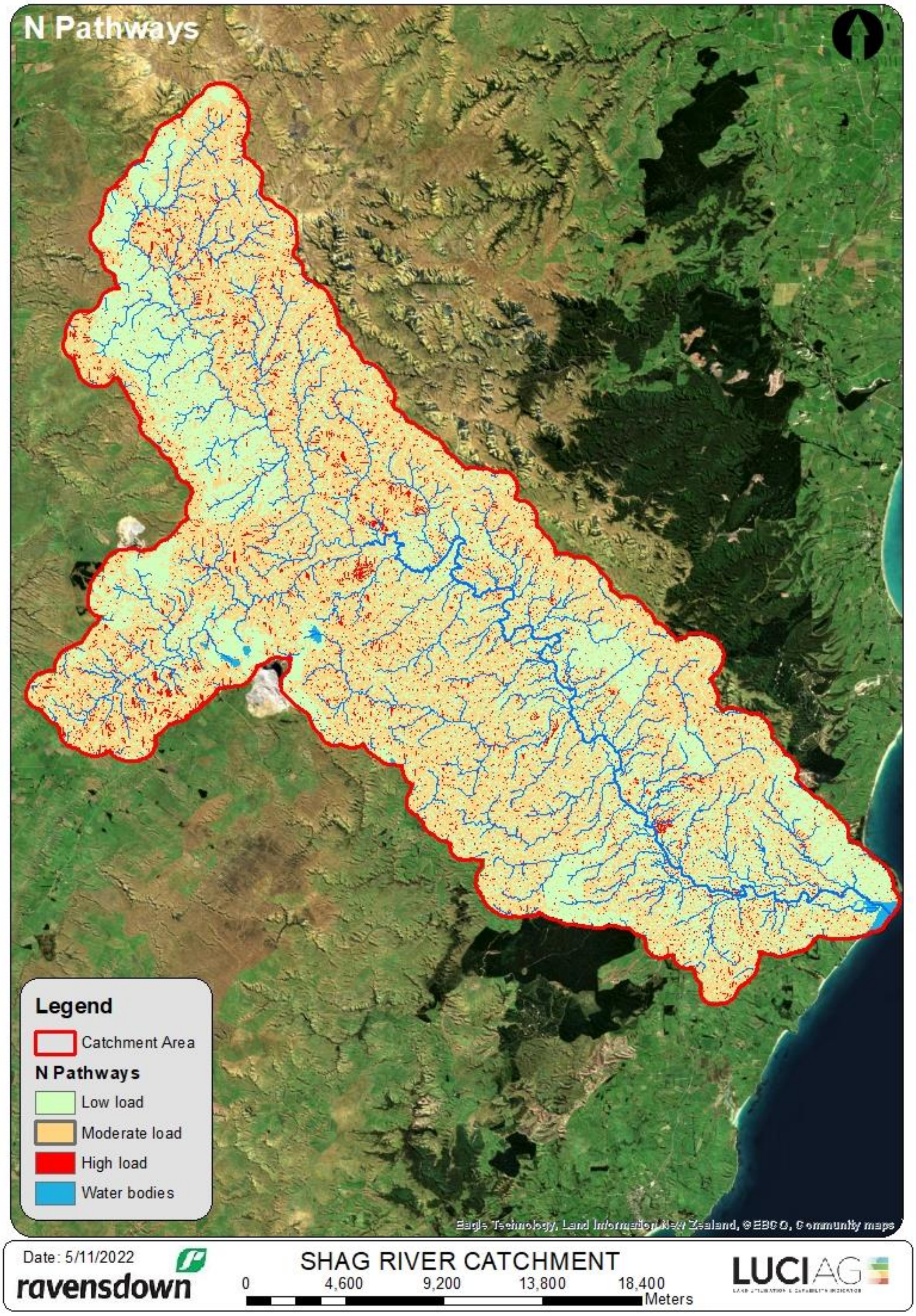

Figure 6. Pathways of accumulated nitrogen load in the Shag River catchment as modelled in LUCI-Ag. NOTE: N pathways is categorised from high to low based on the catchment data only and is not related to either average or expected regional or national N loss values.

Phosphorus

Figure 7 shows the likely pattern of P lost via overland flow and leaching at each point over the catchment as modelled by LUCI-Ag. The model links P load to:

- Fertiliser P inputs
- Effluent P inputs
- Rainfall
- Irrigation
- Slope
- Soil variables, P retention and Olsen P

Phosphorus load only includes what is generated at that point as a result of these variables and it does not include P received at that point from up-hill sources. Higher P loads can be expected on steeper slopes and cultivated areas because P tends to move in runoff attached to sediment in the form of particulate P. Please also note that P load in Figure 7 is categorised from high to low based on the farm data only and does not relate to either average or expected regional or national loss values.

The high P load areas within the catchment were highlighted to be on steeper productive land, underlain by Pallic soils.

There is a clear artifact (steep gradient in P losses at the top of the catchment) in the modelling due to the annual rainfall layer which should be acknowledged. The phosphorus loss model has an inflexion point with the impact of annual rainfall on P loss increasing markedly above 750mm. In the Shag catchment there is a rainfall gradient from 560 to 1200 mm. Hence predicted P losses increase north of the 750mm isohyet near Pigroot Hill (45.35° S). In reality there will be much more spatial and temporal variability in P runoff in relation to the intensity of individual storms.

The highest P losses were on steeper productive land, underlain by Pallic soils. This is due to the steeper land and the slow draining Pallic soils, increasing the chance of overland flow and associated loss of particulate P. The productive land has higher levels of P in the soil to maintain production, thus more P can therefore be lost when overland flow/soil loss occurs. Winter grazing and bare ground will also increase the risk of P loss.

Figure 8 shows P load generated at a point in the landscape plus that contributed to that point from up-hill sources. This is called the 'accumulated P load'. Areas of very high accumulated P load identify pathways where water and nutrients converge in the landscape on the way to waterways. Pathways of highest accumulation are often associated with channels, gullies and/or wetter areas within paddocks and these are good targets for mitigation.

Mitigations to address P loss via LUCI-Ag include:

- Changes in fertiliser P application rates and/or form
- Changes to effluent P application rates
- Changes to soil Olsen P concentrations

- Fencing or fencing and planting additional waterways or wetter gully areas connected to waterways.
- Fencing or fencing and planting other areas of high P loss risk.
- Wetlands/buffer zones

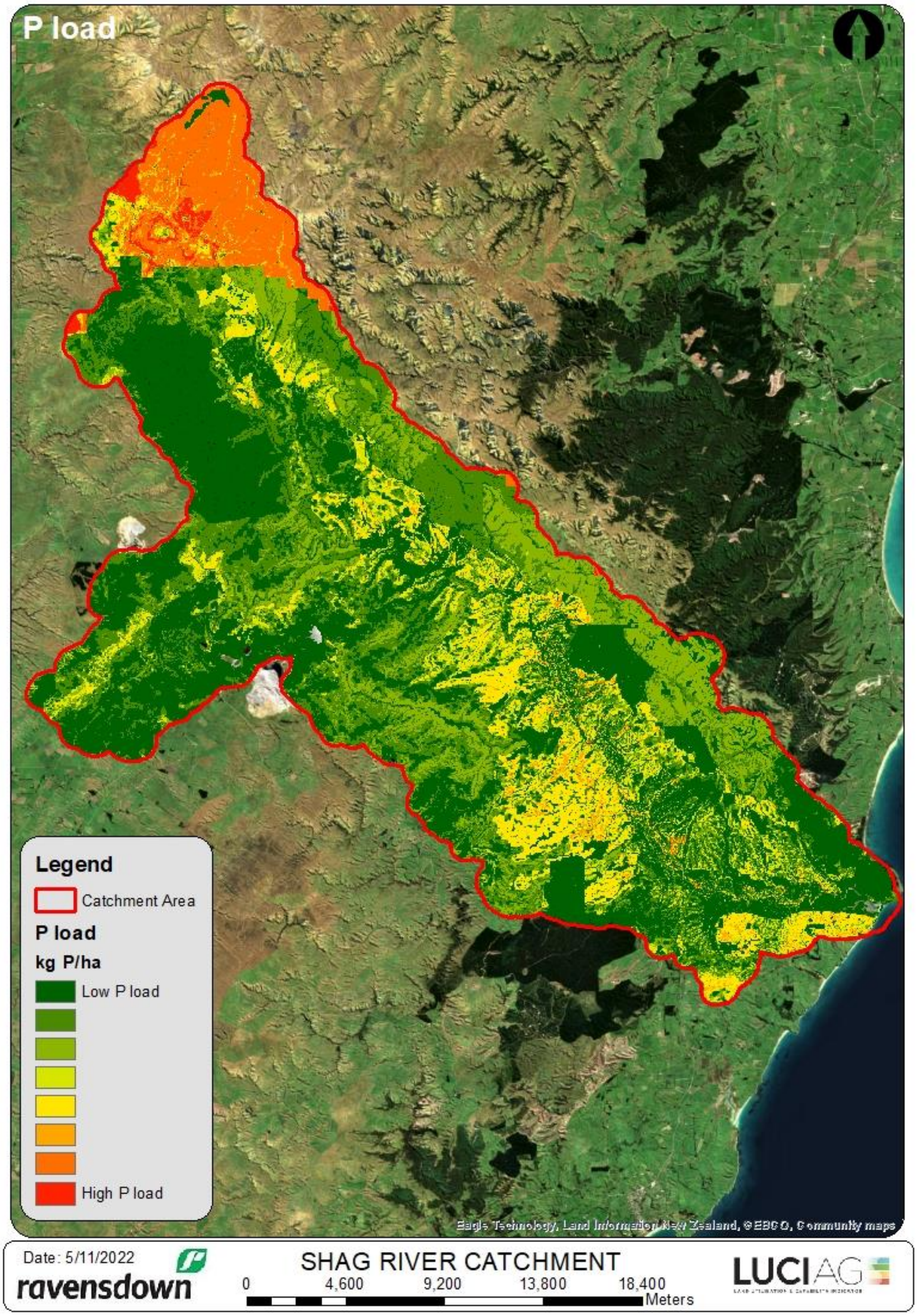

Figure 7. Phosphorus load (kg P ha/yr) in the Shag River catchment as modelled in LUCI-Ag. NOTE: P load is categorised from high to low based on the catchment data only and is not related to either average or expected regional or national P loss values.

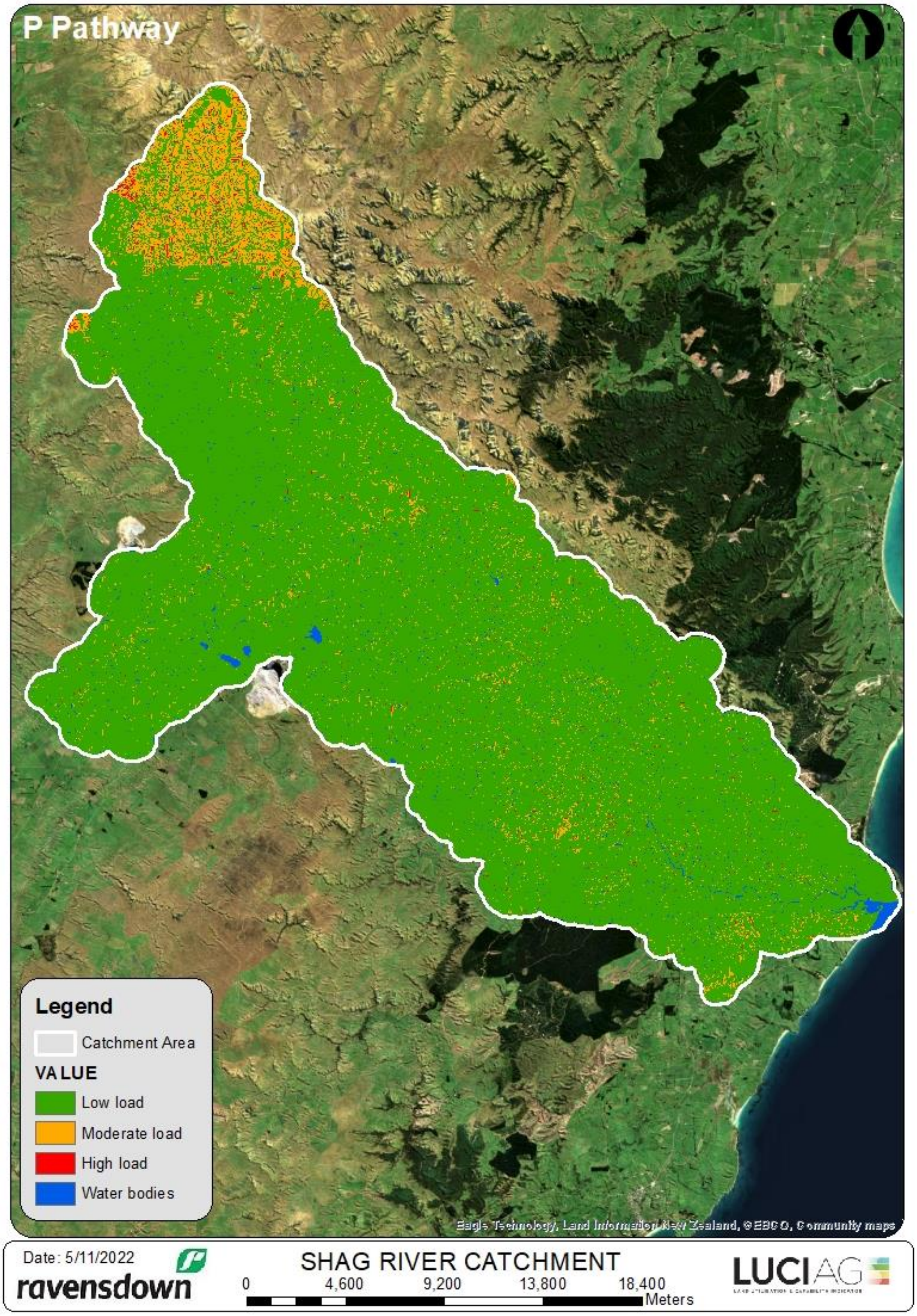

Figure 8. Pathways of accumulated phosphorus load in the Shag River catchment as modelled in LUCI-Ag. NOTE: P load is categorised from high to low based on the catchment data only and is not related to either average or expected regional or national loss values.

Potential mitigations options for hot spot areas

Phosphorus loss hot spot: *Steeper productive land underlain by Pallic soils.*

What farms can do to reduce P loss:
-Soil Olsen P maintained at optimum range through regular soil test monitoring
-Avoiding/minimising bare soil (e.g. winter grazing), particularly on steeper slopes
-Apply P fertilisers at the right place, right time, right rate and right product
-Manage soils to maintain good soil structure, improving soil drainage and infiltration rate
-Avoiding/minimising soil damage/pugging/compaction
-Improved winter forage grazing management (discussed below)

Once the P has been lost from the paddock, there are potential 'edge of field' methods of trapping the lost P such as:
-Fencing/riparian planting off waterways
-Constructed wetlands (discussed below)
-Installation of sediment traps

Nitrogen loss hot spot: *Winter grazed crops*

Nitrogen losses from farm are predominately via nitrate leaching. The hot spot areas within paddocks are urine patches, where urine is deposited at high rates (e.g. 700 kg N/ha).

What farms can do to reduce N loss:
-More cool season active cultivars/species (e.g. Italian ryegrass) can significantly reduce N losses (Talbot *et al,*, 2021), as the plants are up taking N that may otherwise be leached. Avoid autumn/winter inactive cultivars/species.
-Feeding lower N concentration supplements such as fodder beet and whole crop cereal silage, can significantly reduce stock urine-N concentration, compared with higher N supplements e.g. pasture silage (Talbot *et al.,* 2020)
-Efficient use of supplements/feed/N fertiliser through feed budgeting
-Apply N fertilisers at the right place, right time, right rate and right product
-Avoiding/minimising soil damage/pugging/compaction during cool/wet periods of the year
-Minimising cultivation (e.g. minimum till or direct drill) and bare soil, where possible
-Improved winter forage grazing management (discussed below)

Once the N has been lost from the paddock there are potential methods of trapping the lost N, such as:
- Constructed wetlands (discussed below)

To reduce environmental losses from Intensive Winter Grazing (IWG), the following mitigations are available:

-Avoid sloped land as steeper slopes increase run off risk
-Replanting the paddock as soon as practically possible, catch crops (e.g. Oats or Italian ryegrass) have been shown to reduce losses from winter grazing (Malcolm *et al*, 2018; Malcolm *et al.,* 2021). Having ground cover increases plant N and P uptake and physically holds the soil together, reducing N, P and sediment losses
-Avoid planting (leave in pasture) and grazing of critical source areas (e.g., swales and gullies where runoff accumulates).
-Avoid grazing close to waterways/drainage
-Graze paddocks strategically e.g. graze slope downwards, allowing the rest of the crop to acts as a buffer zone for longer
-Place supplementary feed and troughs in areas away from critical source areas, waterways, ponding areas
-Back fencing can reduce stock movement and soil damage
-Reducing mob size
-Selecting appropriate paddocks to winter graze and having a winter grazing plan
-Minimising cultivation (minimum tillage and direct drill) when establishing the crop, where possible

Additional Information on wetlands, riparian fencing and forestry

Constructed wetlands
There are several types of constructed wetlands, although surface-flow wetlands are considered the most appropriate type for mitigating contaminant loss (i.e., nitrogen, phosphorus, sediment) in agricultural runoff. Typically, they comprise channels or a series of vegetated shallow impoundments, with water flowing across the surface of the wetland soil, through beds of aquatic plants such as sedges and bulrushes. They can treat flows entering it from a range of sources including storm-generated overland flow (surface runoff), sub-surface (tile) drains, open drainage channels, and small streams or creeks. Detailed technical information for the design of constructed wetlands for the treatment of pastoral farm run-off is given in Tanner et al. (2021).

Wetlands reduce sediment and nutrient loads in farm run-off by a range of physical, chemical and biological processes. Nitrogen is removed mainly by microbial processes that convert dissolved inorganic nitrogen (nitrate-N and ammoniacal-N) into nitrogenous gases (*viz* denitrification), undertaken by bacteria and fungi naturally present in wetlands. By comparison, uptake of dissolved inorganic nitrogen by plants and algae is a relatively small sink in most wetlands.

Suspended sediment and particulate-associated phosphorus are predominantly removed by settling and deposition. Larger or denser particles (e.g. sands and soil aggregates) are deposited in the inlet zone of a wetland, with finer particles (silt and clay) dispersed through the wetland where they may be removed by adhesion to biofilms (microbial slimes) that grow on the surfaces of plants and detritus in the wetland, and by flocculation processes. The phosphorus-containing sediments that accumulate in the wetland need to be regularly removed to maintain trapping efficacy and reduce the risk of remobilisation during high flows or through decomposition and release of soluble phosphorus. Very fine unaggregated clay particles are extremely slow to settle, requiring long residence times, so their reduction in wetlands is limited.

Dissolved forms of phosphorus can be removed by sorption to sediment and organic matter and taken up by plants and algae, although when the algae die or plant leaves fall and degrade in the wetland, much of this phosphorus can be released back into the wetland. In addition, once the wetland becomes anaerobic, while it can remove nitrogen via denitrification, reducing conditions lead to the dissolution of phosphorus associated with iron and manganese, causing the wetland to become a source, not sink of dissolved phosphorus.

The performance of constructed wetlands depends largely on the retention time of water within the wetland, which is affected by the size of the wetland relative to its inflow, and how uniform the flow is as it passes through the wetland. The performance of different sized wetlands relative to the size of their contributing catchments has been assessed by Woodward et al. (2020). They show:

- Wetlands occupying 1% and 5% of their catchment area should, on average, in warm regions remove 24% and 52% respectively and in cool regions 18% and 38% respectively of their long-term average total N inputs.
- Wetlands occupying 1% and 5% of their catchment area should, on average, remove 26% and 48% respectively of the long-term average total P input.
- Wetlands occupying 1% and 5% of their catchment area should, on average, remove 50% and 90% respectively of the long-term average sediment input.

Riparian buffer strips

A riparian buffer is a strip of land which separates agricultural activity from a waterway. Buffers are usually fenced to exclude livestock and ideally established with a permanent vegetation ground cover. They have a wide range of roles including erosion control stabilising stream banks, native biodiversity, provision of food and habitat for freshwater life and importantly can be used to remove contaminants (N, P, E. coli and sediment) from both surface runoff and subsurface flow.

A multi-function riparian buffer may be used to remove contaminants from both surface runoff (via a filter strip) and subsurface flow (via the planted riparian buffer). Filter strips are managed bands of dense vegetation (grass) which run parallel to the stream. They act as a physical barrier, slowing shallow surface runoff, allowing particles to settle in the backwater created at the filter face. They also increase soil permeability, allowing surface runoff to infiltrate into the riparian soil, increasing contact between soil and contaminants.

Planted riparian buffers are created by establishing a band of vegetation in the riparian zone (along a drain, stream or river), to promote N and P uptake and processing. Plants selected usually include grasses, sedges, flax, shrubs, and trees. They can remove nutrients and sediment by i) acting as a filter strip if the vegetation is dense at ground surface, ii) using nutrients in shallow subsurface water for plant growth, iii) improving soil structure and increasing the ability of water to infiltrate into the soil, iv) providing a source of organic matter which creates conditions that enhance water retention, allowing nutrients to attach to soil (fine sediment and phosphorus), and support microbially-driven processes such as denitrification.

The effectiveness of riparian buffer strips for reducing contaminant loss will vary greatly depending on specific site conditions such as by the slope length, slope angle, clay type and drainage (how the water moves across the landscape). There is detailed technical information for the design of constructed riparian buffer strips for the treatment of pastoral farm run-off is given in McKergow et al. (2022) and DOC (1995) that can assist with the determining the effective buffer strip design for your site.

Afforestation

Changing the vegetation cover in a catchment is known to affect both the catchment hydrology and water quality. A change from pasture to a forest reduces the amount of precipitation reaching the forest floor due to interception and evapotranspiration processes in forests. The physical, biological and chemical characteristic of forest soils effect water infiltration, contaminant removal and nutrient cycling. Subsurface flow provides an important pathway for transport of water to streams, subsequently reducing overland flow and associated erosion and soil loss. In an addition, forest moderates climate extremes, influencing the quantity, timing, thermal regime and water quality characterises of stream water.

A recent review of water quality in New Zealand planted forests showed improving water quality in a change from pasture to planted forest for a large proportion of the forestry-growing cycle (Baillie and Neary 2015). Afforestation of pasture often results in significant improvement in water quality quite rapidly (within 4-6 years) for a wide range of water quality attributes e.g. stream temperature, nutrient and sediment concentrations and microbial contamination. However, the inherent cyclical nature of planted forests can result in negative changes in water quality at points during a rotation e.g. particularly when clear-cut harvesting up to stream edges.

Changing the vegetation cover in a catchment has been shown to cause changes in the hydrological response of catchments. This includes effects on total water yields, low flow, on flood peaks and groundwater recharge. There are a series of paired catchment studies, established over 40 years ago in different parts of New Zealand that have allowed insights into how converting from grassland and tussock to mostly exotic forest influences the hydrological response of catchments. These studies have found that afforestation of pasture or tussock land reduces annual water yields between 20% to 50%. Low flows are reduced following afforestation, but it appears that in some cases these are affected to a lesser extent than the annual water yield. The effect of afforestation on annual peak flood flows has also been shown to be large, particularly on small floods, with reductions in peak flows of up to 50% reported.

Table 2. Selection of national studies and their conclusion regarding the effect of afforestation on Streamflow.

Location	Study Description	Main Conclusions	Reference
Hunua Ranges (Auckland)	Scrubland to pine forest	Stream flow increased 19% after clearing of vegetation to prepare for planting. Stream flow **decreased 70%** (68 mm/yr) after seven years of afforestation. Summer stream flow decreased by 50%.	Herald (1979)
Mamaku Plateau region	Paired catchment study with afforestation	Geology (ignimbrite jointing controls the drainage). Flows are extremely variable. Could not be related to vegetation types.	Dell (1982)
Tarawera catchment	Native forest to pine forest (large-scale study)	Summer and winter Tarawera River flow reductions of 9.6–1.4 m^3/s (1964–1981). c. 4.5 m^3/s of these reductions (i.e. 13% of the mean flow over the calibration period) could be attributed to afforestation (the remainder is linked to decreased rainfall).	Dons (1986)
Eastern Raukumara Range (Gisborne)	Reforestation with *P. radiata*	Stream flow **reduced by 30%** (170 mm).	Pearce et al. (1987)
Glendhu, Berwick (Otago); Moutere, Big Bush (Nelson); Maimai (Reefton); Purukohukohu (Rotorua); Mangatu (Gisborne)	Pasture to pine forest; Native forest to pine forest; Shrub to pine forest	Stream flow **reduced by 30–50%** (5–10 years after planting). Similar reductions expected in low flows. Storm quickflows and flood peaks can fall by over 50%. Sylvicultural practices and forest harvesting in moderate-to-high areas can increase flows.	Fahey (1994)
Moutere catchment (Nelson)	Paired catchment study: hill country pasture and tall dense gorse to pine forest	Declining surface water yield following 2–3 years with canopy closure (167 mm/yr less after seven years in comparison to pasture). Longer periods of dry streams (+3 months).	Duncan (1995)
Maimai (Reefton), Big Bush (Nelson), Glendhu (Otago)	Paired catchment study: afforestation on pasture or tussock land	Annual steam flow **reduced by 20–50%**.	Davie and Fahey (2005)
Purukohukohu (Rotorua)	Paired catchment study: pasture, *P. radiata*, native forest	Annual stream flow reduced by 400 mm after canopy closure. Stream flow from pine forest c. 100 mm/year less than from native forest.	Beets and Oliver (2007)
Motueka catchment (Tasman)	Predictive model (SWAT): maximum pine potential plantations compared to current land use	Evapotranspiration increased by 6%. Annual surface water yield decreased by **4.5%**. Quickflow decreased by 13%.	Cao et al. (2009)
Glendhu (Otago)	Paired catchment study: tussock to *P. radiata*	Average annual flow **reduced by 33%** (273 mm/yr) and low flows reduced by 26% after canopy closure. Average peak flows reduced by 78% and 37% for small and large events, respectively.	Fahey and Payne (2017)

Mitigation scenarios modelled

Mitigation Scenarios:

In summarising the farmer's wishes around future mitigations and aligning these with the mitigation actions the ORC has used for their recent community consultations (stage 2), Ravensdown has arrived at the most likely potential future mitigation scenarios which would affect stream water quality within the Shag River catchment. Many options are not applicable and unlikely, due to the farm systems (largely sheep and beef) in the catchment.

Scenario 1 – Case study farms

Based on discussion with each farm entity a mitigation and in some cases intensification plan was developed. For each farm the areas with a land use change were mapped and where relevant an updated OverseerFM nutrient budget completed. A GIS layer with the updated LUCI-Ag input data for the modified land uses for all case study farms was created and overlaid on the Shag River Catchment LUCI-Ag base layer. LUCI-Ag outputs for each farm were clipped from the catchment output and displayed.

Scenario 2 – Riparian access

A catchment wide scenario to implement the government mandated "Resource Management (Stock Exclusion) Regulations 2020" was modelled. Streams generated by LUCI-Ag with Strahler level 2 or greater which intersected the "stock exclusion low slope land map" and pastoral or arable land use were identified. A 5 m riparian buffer was created and given a landcover of shrubs, trees or flax. All farmland covered by the "stock exclusion low slope land map" and any additional land outside this zone, but within 150 m of the identified streams, had the stream access by cattle attribute set to null. Approximately 210 km of streams were identified, although many of these streams would already be fenced and have stock excluded.

Scenario 3 – Irrigate/intensify

A land intensification scenario was created for land which could potentially be irrigated and pastoral land which is most likely to respond to improved management with more productive pasture species, such as lucerne, to give a 10% increase in stocking rate. The location of areas for new irrigation were manually identified using aerial imagery. The selection was guided by slope < 10°, utilising the "stock exclusion medium slope land map", no existing irrigation (ORC irrigation layer) and likely suitability to install a pivot irrigator. As the selection was hypothetical and arbitrary, no account was taken of land ownership. Stocking rate for the new irrigation land was determined by running Ravensdown's proprietary version of the Pasture Growth Forecaster model, followed by use of OverseerFM to determine N loss, assuming centre pivot irrigation based on soil moisture monitoring during the months of November to February. Note that this predicts considerably lower N leaching than the K-line irrigation assumed for existing irrigation. N leaching for the dryland pastoral intensification was determined by increasing N loss per stock unit by 0.3 kg N per stock unit, a factor which was derived from a sensitivity analysis for a generic Shag Catchment sheep and beef farm nutrient budget. A total of 1210 ha (2% of the catchment area) was included in the new irrigation scenario.

Land for pastoral intensification was identified based on the intersection of LCDB classification for high producing grassland and the "stock exclusion medium slope land" map, with Case Study farms excluded. This amounted to 9105 ha (17% of the catchment).

Scenario 4 – Forestry – used to offset intensification

A forestry scenario was created for non-tussock pastoral land where land units have an average slope greater than 25°. A total of 9722 ha (18% of the catchment area) was identified for the new forestry scenario.

Each scenario was applied cumulatively on top of the previous scenario. The riparian/stock access scenario also included the case study farm mitigations and intensification; the intensification and new irrigation scenario incorporated the riparian/stock access scenario and the case study scenario; and the forestry scenario incorporated all of the other scenarios (Table 3).

Table 3. The results of the LUCI-Ag modelling for the Shag River Catchment using the four mitigation scenarios.

	Nitrogen concentration at river exit	Phosphorus concentration at river exit
Scenario 1 – Case study farms	-1%	<-1%
Scenario 2 – Further fencing and planting of riparian zones	<-1%	<-1%
Scenario 3 – Irrigate/intensify	+2%	<+1%
Scenario 4 – Forestry	-9%	-14%

For Scenario 1, the modelled results suggest that the combined effect of all mitigations proposed by the case study farms resulted in small reductions 1% and <1% in N and P concentrations, at the Shag River exit, respectively. This small reduction is due to only 14 farms out of the whole catchment had specific mitigations modelled. These farms make up a small part (~18% of the catchment area) of the combined catchment load. If these reductions are extrapolated out to the rest of the catchment, the modelled reductions are a 7% and 2% reduction in N and P concentrations, at the Shag River exit, respectively. The smaller reduction in P losses may be due to the model predicting high P loads from the top of the catchment (due to the annual rainfall layer) and no farm mitigations were located in that area. The annual rainfall layer effect likely skewed the importance of top of the catchment and diluted the effect of case study farms' effect on P loss.

For Scenario 2, the modelled results suggest that further fencing of low slope land resulted in small reductions (<1%) in N and P concentrations at the Shag River exit. This small reduction is likely due to the small area in the catchment that is low slope land and amount of fencing already completed in that low slope area. It was assumed the high production sheep and beef land (from the Manaaki Whenua – Land Cover DataBase was fenced), while the low production sheep and beef land was not fenced. The main sources of P loss in the catchment are steeper slope land, this is particularly skewed due to the rainfall layer creating high losses in the top of the catchment. There are, however, localised gains in stream quality for smaller streams that are fenced off. Individual farms saw up to 23% and 71% reductions in N and P concentrations, respectively, on stream exits on their farms due to riparian plantings. The average reductions seen on individual farms (with riparian planting as one of the mitigations) saw average reductions of 13% and 50% of N and P concentrations, respectively, in localised streams leaving the farms.

For Scenario 3, the model results suggest that the effect of an addition of ~1200 ha (2% of the catchment area) of highly water efficient centre pivot irrigation and intensification of ~9100 ha (17% of the catchment) of dryland pasture land resulted in an increase of 2% and <1% in N and P concentrations at the Shag River exit, respectively. This is due to increases in production and subsequent small increases in N and P losses.

For Scenario 4, the modelled results suggest that intensification of the flats can be more than offset through planting additional forestry on the steeper land (9722 ha – 18% of the catchment area). The forestry reduced N and P concentrations at the Shag River exit by 9 and 14%, respectively. However, LUCI-Ag does not model the effect forestry has on stream flow, only changes in N and P load going into the river. LUCI-Ag also modelled the forestry without the effect of the harvest. This part of the forestry cycle is the most significant time for losses to occur. This has been seen in previous catchment modelling where recently harvested forest was the sediment loss hotspot. However, this scenario shows that a small area of the catchment going into forestry could offset increased losses due to intensification of the flatter more productive area.

Summary

This project has highlighted N and P hotspots within the catchment as:
Phosphorus loss hot spot: *Steeper productive land underlain by Pallic soils.*
Nitrogen loss hot spot: *Winter grazed crops.*
Focus should be applied to best management practice and suggested mitigations (mentioned above) as methods of reducing N and P losses from these localised hotspots.

The mitigation results show that further intensification of better land can be offset by farmers selecting areas of their less productive land and planting this in forestry. Fencing/riparian planting had a significant effect on localised stream N and P concentrations within farms, however, from a catchment context, more fencing in the low slope land didn't have a large effect on N and P concentrations due to large parts of the catchment not having low slopes and losses having already entered the stream. Due to the challenges of fencing streams off in steeper slope land, constructed wetlands may be a suitable alternative mitigation at a farm scale to reduce N and P losses.

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