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# A review of land-based phosphorus loss and mitigation strategies for the Lake Rotorua catchment

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Prepared for:

**Bay of Plenty Regional Council**

# A review of land-based phosphorus loss and mitigation strategies for the Lake Rotorua catchment

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# A review of land-based phosphorus loss and mitigation strategies for the Lake Rotorua catchment

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## Executive Summary

Bay of Plenty Regional Council is in the process of approving Plan Change 10 (PC10) to the Regional Water and Land Plan. Plan Change 10 sets rules for nutrient management in the Lake Rotorua catchment. Included are specific provisions to review the supporting science (LR M2 of the proposed plan change). This report has been prepared as part of the Science Review associated with Plan Change 10 of the Bay of Plenty Regional Council (BOPRC) Regional Water and Land Plan (RWLP).

The report contributes to the Science Review by summarising available information on pasture, planted forest and indigenous vegetation land-based P losses and mitigation strategies for Lake Rotorua catchment. The focus is on anthropogenic P losses.

Anthropogenic P losses are influenced both spatially and temporally by biophysical factors such as soil, rainfall and topography. Land use and its management influence P loss, either exacerbating or mitigating losses.

Optimising soil Olsen P, farm dairy effluent management, use of low-soluble P fertilisers are amongst the most cost-effective P mitigation strategies with minimal or positive impact on farm profit. Other P mitigation strategies are worth future consideration, including detainment bunds, and a greater focus on critical source areas (CSAs).

The effectiveness of different P mitigation strategy combinations was explored, based on existing publications and OVERSEER® scenarios. A combination of P mitigation strategies can potentially achieve a 40% reduction in P with minimal impact on profit. However, there remains uncertainty around the effectiveness of individual mitigations and implementation costs, largely driven by variable farm system and catchment conditions.

Of the land use P loss coefficients used, the forestry coefficients were the most variable across the literature and had the most associated uncertainty. Given the suggested changes from pasture to forestry in the future scenarios, the impact of the forestry values used will impact on the results and follow through to any subsequent decisions based on the results.

Adequate P reductions to achieve a P load target are not achievable through targeting N load alone (i.e. there is a reduced P load associated with N mitigation - termed P “by-catch”) and targeted P mitigation strategies area required.

Achieving a P load of between 30 and 35 t P/yr seems possible through P specific land-based P mitigation strategies, even if a future N based reduction scenario is implemented. However, caution is still required around the estimates, especially around the assumptions associated with the land use P loss coefficients and mitigation % effectiveness estimates used.

Key to the ongoing assessment of PC10 implementation effectiveness for P loss reductions (but also N loss reductions) is the capture of finer (farm scale data) that can be used to refine catchment scale modelling of N and P load to Lake Rotorua.

Recommendations for improving data and information on P loss and P mitigation strategies specific to the Lake Rotorua catchment include:

- Improved monitoring data for Olsen P (via soil tests and preferably in a maintained database) for all farms (potentially at block level for use in OVERSEER®).

- Maintain the current soil testing frequency as suggested in the NMP template, with the expectation that soil Olsen P will decrease by 1-2 units/year once the mitigations are implemented.
- Ensure good capture (preferably in a maintained database) of and monitoring of the state of Farm Dairy Effluent (FDE) storage and land application data.
- Continue to maintain connections with P mitigation research and promote and support mitigation research within the Lake Rotorua catchment to assess the local applicability of P mitigations (for example, detainment bunds).
- Support the development of multiscale spatial approaches to prioritising P (and N) mitigation placement to better target P sources, P form and P loss pathways.
- Support research to better understand the changes in P loss associated with the different stages of forestry, from harvest to forest maturity. Research across the range of forest soils in the Lake Rotorua catchment is likely requirement as well.
- Support the investigation of the increasing trend in particulate P identified in Dare (2018) with a focus on long term drivers (e.g. climate change), and P generation sources and transfer pathways.
- Target P reductions alongside N reductions (i.e. a dual nutrient reduction approach) given that the P load target is not achievable through P “by-catch” associated with N focussed mitigation alone.
- Explore the opportunity to improve data on P mitigation associated with forestry management (possibly via the NPS-PF).
- Build on the existing Nutrient Management Plan template to increase the quantitative and measurable capture of P nutrient inputs, mitigations and outputs, similar to N capture.
- Improve and support soil map information, regionally and where possible, at farm scale to improve nutrient budget estimates as well as NMP implementation.
- Monitor and report P mitigation implementation and loss data (initially via nutrient budgets in the NMP) for all farms in the Lake Rotorua catchment and refine the criteria around the collection, recording, storage of data, as well as NMP implementation monitoring and auditing.
- Develop the geospatial database to include implemented P mitigation actions and P losses through time.

# 1 Introduction

## 1.1 Background

### 1.1.1 Plan Change 10 Science Review

Bay of Plenty Regional Council is in the process of approving Plan Change 10 (PC10) to the Regional Water and Land Plan. Plan Change 10 sets rules for nutrient management in the Lake Rotorua catchment. Included are specific provisions to review the supporting science (LR M2 of the proposed plan change).

The Science Review terms of reference (TOR) includes tasks to:

- Identify the key places where phosphorus mitigation should be focussed in general terms and whether this is measurable, and
- Identify priority catchments for application of focussed phosphorus (P) control. This will include a high-level estimate of potential achievements with respect to reducing P inputs to the lake.

This report contributes to the science review by summarising available information on pasture, planted forest and indigenous vegetation land-based P losses and mitigations for the Lake Rotorua catchment.

### 1.1.2 Land-based Phosphorus

McDowell (2012) states that the difference between current P losses and those produced naturally (termed reference conditions) represents the anthropogenic loss, a portion of which will be manageable. The proportion of natural losses vary geographically (spatially) but not usually over time (temporally).

Anthropogenic P losses are influenced both spatially and temporally by biophysical factors such as soil, rainfall and topography. Land use and its management influence P loss, either exacerbating or mitigating losses.

Abell (2013) concluded in a study of 101 lakes that human-related sources of P were to be the dominant influence on TP concentrations in New Zealand lakes, with the extent of intensive pastoral agriculture the best land use predictor of TP concentrations (accounting for 41.0% of variation in TP concentrations) and exotic forestry a further 18.8% of the variation. For P loss in the Rotorua catchment, both the natural P losses and anthropogenic P losses to Lake Rotorua have been described and estimated by Tempero et al. (2015).

Tempero et al. (2015) estimated a total annual P load of 48.7 t P/yr to Lake Rotorua from the catchment. Of this, the natural conditions (baseline) load was estimated at 25.3 t P/yr and the anthropogenic load 23.4 t P/yr. This differs from many situations nationally where the natural conditions component of P loss (relative to anthropogenic losses) is generally low (McDowell 2012). The need to reduce anthropogenic P losses remains an important requirement to achieve improved water quality for Lake Rotorua; a P reduction amount of 8-13 t P/yr has been estimated by Tempero et al. (2015).

Particulate P (P-P) accounted for 74% of the anthropogenic load, suggesting P loss mitigation strategies should focus on reducing the P-P fraction, over the DRP fraction.

Nitrogen (N) remains the regulatory focus as set within the Operative RPS. An assumption that nitrogen reduction initiatives through PC10 will also achieve adequate phosphorus reductions (termed “by-catch”) does not necessarily hold true, primarily because of the differences in N and P sources and pathways of nutrient loss. Park (2017) notes that the P reductions can be managed under the Council's wider Rotorua Lakes Programme through non-regulatory activities at a programme level as a part of rule implementation, the Lake Rotorua Incentives Scheme, sector best practice and engineering solutions.

Lake Rotorua is co-limited by N and P, requiring both nutrients to be managed to achieve a target trophic level index (TLI). Loading model calculations suggests 435 t/N and between 33.7 to 38.7 t/P are the annual sustainable loads required to achieve and maintain a target TLI of 4.2.

Current Alum dosing and other engineering methods provide partial, possibly temporary solutions to reducing P in the lake, meaning land-based P mitigation strategies will have to contribute to ongoing P reductions.

## 1.2 Scope of this report

The aims of this report are to:

1. Describe the management of P losses, with a focus on the Rotorua catchment.
2. Estimate P losses (kg P per ha/yr and tonnes P/yr) from major current rural land uses; pastoral uses, forestry and native bush.
3. Identify the suite of P mitigation strategies relevant to Lake Rotorua's catchment, and the range of achievable reductions in P losses from both land use change and land management change.
4. Provide an aggregate assessment of land-based P load to Lake Rotorua for:
    a. the current landuse
    b. a credible future landuse scenario
5. Address the questions of how to monitor, assess and report on the level of on-farm phosphorus good management practice (GMP) adoption and efficacy across the Lake Rotorua.
6. Recommend future P mitigation investigations relevant to the Lake Rotorua catchment.

# 2 Management of P losses

## 2.1 Land-based P sources and loss

The variability of P loss differs across land uses and is influenced by soil, climate and topography and management (Menneer et al., 2004; McDowell,2010; McDowell et al., 2013). All factors are important for the Rotorua catchment which has pastoral (dairy and drystock cattle, sheep and deer) and plantation forest land uses over a range of dominant Soil Orders (Podzols, Pumice, Allophanic, Recent and Organic Soils), a strong rainfall gradient (increasing with altitude to around 2400 mm/year), and a predominantly rolling to steep topography.

Rural land-based sources of P have been grouped simply into soil P (40%) and animal dung (30%), Plants (20%) and fertiliser additions (10%) McDowell et al., 2013; McDowell et al., 2016). Relative to the Rotorua catchment are sources from soil status (soil P level management), stock access (direct deposition of dung to waterways), effluent (management of the land application) and fertiliser (timing and form of P fertiliser).

The form of P (the P fraction) is an additional consideration as the loss pathways differ for the fractions, as do their mitigation requirements. Phosphorus fractions can be divided into soluble P (P that passes through a 0.45 µm filter) and particulate P (P-P; i.e. > 0.45 µm). A review of water quality trends for the Rotorua Lake catchment (Dare, 2018) indicated an 88% increase in particulate P from 2009-2017. The specific sources of the increased particulate P require confirmation (Dare, 2018).

The pathways of P loss to water are by surface (particulate > dissolved P) and subsurface flow (dissolved P) and depend on the combination of land use and biophysical factors (Figure 1). Mitigation combinations are an effective approach to achieving P loss reduction targets. For example, a combination of improved effluent management, optimum soil Olsen P and use of low soluble P fertiliser could be used to reduce P losses by more than 50% (to below a reduction target) with no net impact on profit (presentation to the Land TAG - McDowell et al., 2016 and McDowell et al. ,2017). Internationally, Murphy et. al. (2015) showed P reductions were achievable with minimal impact on pastoral farm profitability in Ireland, and cost-effective approaches towards P mitigation have been analysed for other farmland-lake environments, for example at Lake Erie (Pyo et al., 2017).

A range of mitigations are available, and the optimal combination will vary depending on the specific characteristics of an individual property. However, for efficient reduction of P losses, the main P sources and loss pathways should be the focus.

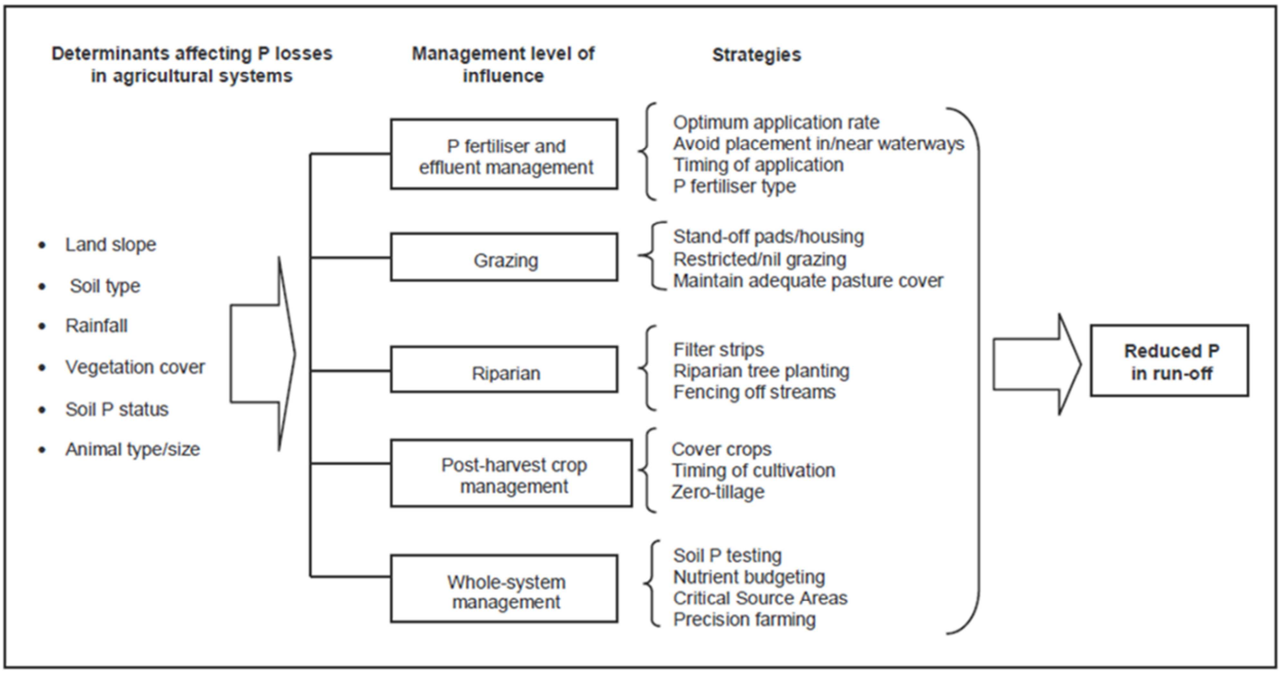


**Figure 1. Main determinants affecting P losses in agricultural systems and key management strategies for mitigating losses (from Menneer et al., 2004).**

# 3 P mitigation strategies

## 3.1 P mitigation strategies for Lake Rotorua catchment

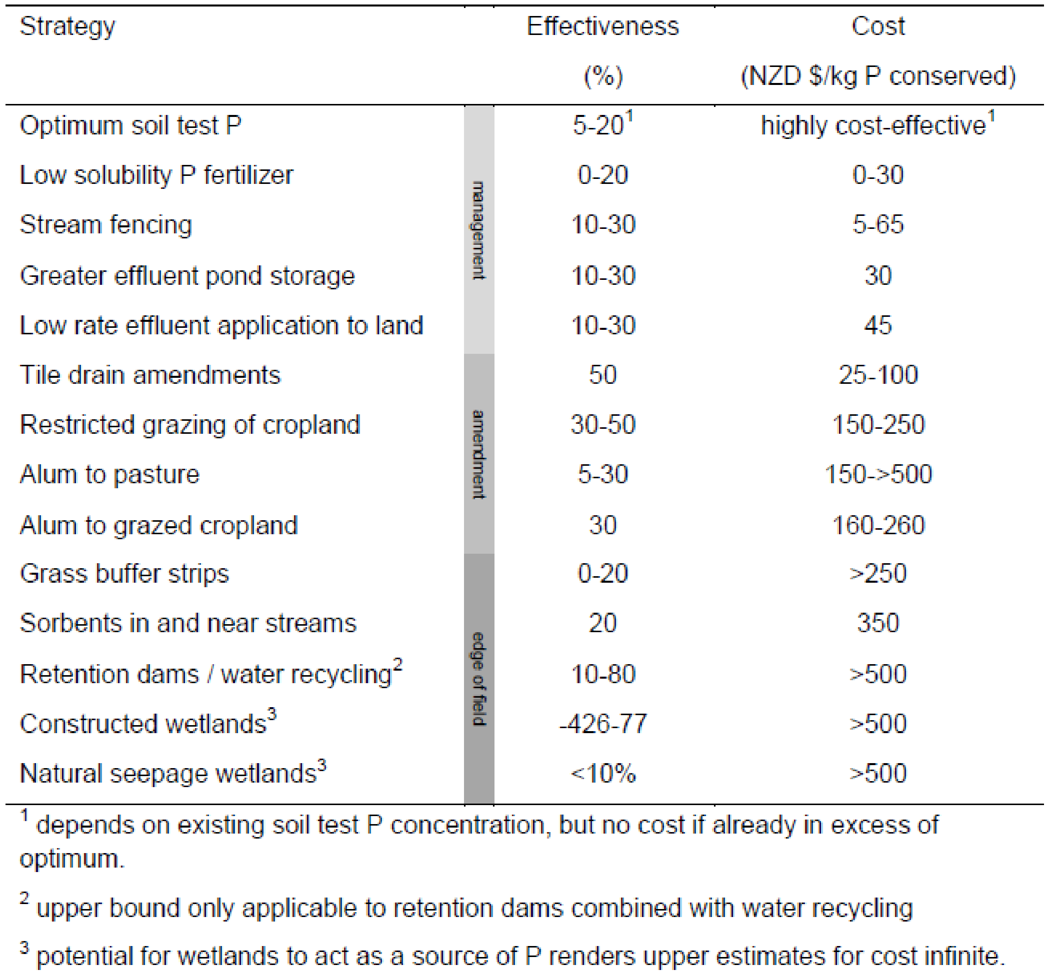
McDowell (2010) provides a report summarising the range of current or near future mitigation options to lessen P loss from grazed grassland farms in the Lake Rotorua catchment. The summary includes mitigation efficacy and cost.

Also provided, is a summary of relative total phosphorus, dissolved reactive phosphorus (DRP) and suspended sediment (as an index of particulate P loads) from various Rotorua catchment streams and changes in TP from the 1970s to the 1990s.

The key point illustrated is the variability – spatially across the catchments and temporally, for catchments through time. Both reflect differences in catchment characteristics associated with inherent characteristics (such as geology, soil and topography) and land use changes. Both are important to consider when selecting mitigation strategies, to ensure the different P fractions are targeted.

Key to the ranking mitigations for potential uptake is their classification into three classes of intervention: 1) on-farm management, such as optimum soil test P, low solubility P fertilizer and effluent spreading; 2) amendments, such as alum; and 3) edge-of-field management, such as in-stream sorbents, buffer strips, constructed wetlands and dams for water recycling (Table 1).

**Table 1. P mitigation strategies specific to the Lake Rotorua catchment (Table 2 in McDowell 2010).**



| Strategy | | Effectiveness (%) | Cost (NZD $/kg P conserved) |
|---|---|---|---|
| Optimum soil test P | management | 5-20[1] | highly cost-effective[1] |
| Low solubility P fertilizer | | 0-20 | 0-30 |
| Stream fencing | | 10-30 | 5-65 |
| Greater effluent pond storage | | 10-30 | 30 |
| Low rate effluent application to land | | 10-30 | 45 |
| Tile drain amendments | amendment | 50 | 25-100 |
| Restricted grazing of cropland | | 30-50 | 150-250 |
| Alum to pasture | | 5-30 | 150->500 |
| Alum to grazed cropland | | 30 | 160-260 |
| Grass buffer strips | edge of field | 0-20 | >250 |
| Sorbents in and near streams | | 20 | 350 |
| Retention dams / water recycling[2] | | 10-80 | >500 |
| Constructed wetlands[3] | | -426-77 | >500 |
| Natural seepage wetlands[3] | | <10% | >500 |

[1] depends on existing soil test P concentration, but no cost if already in excess of optimum.

[2] upper bound only applicable to retention dams combined with water recycling

[3] potential for wetlands to act as a source of P renders upper estimates for cost infinite.

The mitigation strategies have been selected based on applicability to the Lake Rotorua catchment, and include the form(s) of P they mitigate (summarised in Table 2).

**Table 2. Potential P mitigation strategies specific to the Lake Rotorua catchment (McDowell 2010) with P forms mitigated added.**

| P mitigation | | Effectiveness % | Cost of P conserved $/kg | P forms targeted |
|---|---|---|---|---|
| Optimum soil test P | management | 5-20 | highly cost effective[1] | dissolved and particulate P |
| Low solubility P fertilizer | | 0-20 | 0-30 | dissolved P (and via soil enrichment - particulate P) |
| Stream fencing | | 10-30 | 5-65 | dissolved and particulate P |
| Greater effluent pond storage | | 10-30 | 30 | dissolved and particulate P |
| Low rate effluent application to land | | 10-30 | 45 | dissolved and particulate P |
| Tile drain amendments | amendment | 50 | 25-100 | particulate and dissolved P (depending on soil P and effluent applications) |
| Restricted grazing of cropland | | 30-50 | 150-250 | mostly particulate P |
| Alum to pasture | | 5-30 | 150->500 | dissolved P |
| Alum to grazed cropland | | 30 | 160-260 | dissolved P |
| Grass buffer strips | edge of field | 0-20 | >250 | particulate-P |
| Sorbents in and near streams | | 20 | 350 | particulate-P and dissolved-P |
| Retention dams / water recycling[2] | | 10-80 | >500 | particulate-P and some dissolved-P |
| Constructed wetlands[3] | | -426-77 | >500 | particulate-P |
| Natural seepage wetlands[3] | | <10% | >500 | particulate-P |

[1] Depends on existing soil test P concentration, but no cost if already more than optimum.

[2] Upper bound only applicable to retention dams combined with water recycling.

[3] Potential for wetlands to act as a source of P renders upper estimates for cost infinite.

Although several subsequent publications by McDowell and others (McDowell and Nash, 2012; McDowell et al., 2013 and McDowell et al., 2017) provide additional detail regarding P mitigation strategies, McDowell (2010) does provide a sufficiently comprehensive and relevant set of P mitigation strategies, including many that are relevant to Lake Rotorua catchment.

## 3.2 Additional P mitigation strategy considerations

Additional mitigations have been mentioned in the various literature, including McDowell (2010), McDowell et al. (2013) and McDowell et al. (2017) and some looked at in the Lake Rotorua catchment, such as wetlands (Hamill et al. 2010 and Özkundakci et al., 2010) and shallow weirs and vegetation filter strips (Ledgard et al., 2007). However, there seems either to be insufficient current data to support their current use, or the cost benefit for P recovery is less favourable. For example, cultivating P-enriched soils near streams to reduce soil P concentrations and P loss is identified as a P mitigation but has a large associated cost (McDowell et al., 2017). Several P mitigations are discussed in more detail below because they have (or are being) considered for Lake Rotorua catchment or could be considered in the future, especially as more data to support their efficacy becomes available and technological advances reduce the cost of implementation.

### 3.2.1 Track and lane management with berms or sorbents

Track and lane management either by engineering methods (runoff diversion berms) or by sorbents (McDowell, 2007) can be applied to either pastoral or forestry tracks. Generally during forest harvesting management of roading as part of consent conditions for harvesting will include requirements for road maintenance and surface runoff diversion at set spacings. McDowell et al. (2007) who traced 90% of the P loss back to runoff from a crossing where daily traffic resulted in regular dung deposition i.e. a critical source area. Installing a P-sorbent on the side of the lane has been shown to decreased catchment P losses by up to 80% (McDowell et al., 2013).

### 3.2.2 In-paddock critical source areas (CSAs)

The areas around gateways, lanes and around barns and troughs are important sources of P loss (McDowell et al., 2013), especially when they are in ephemeral pathways, near-stream areas and areas connected to the stream. Work by Hively et al. (2005) and Lucci et al. (2010) found that the potential for P loss from areas such as gateways, lanes and around barns and trees (camp sites) and troughs was much greater than from the rest of a grazed paddock. McDowell and Srinivasan (2009) also confirmed that when connected to a stream these areas are important sources of P all year round. P loss to most waterways which can be decreased by the addition of P-sorbents in these areas, including around gateways, lanes, and around barns and troughs.

While P losses from critical source areas (CSAs) can be responsible for the majority of total farm P losses - up to 80% from 20% of the farm area (McDowell, 2010), there is currently no fully available tool available to model losses or show how losses may be reduced by focusing P mitigation efforts on CSAs. Recent developments of farm scale spatial tools such as MitAgator (https://ballance.co.nz/mitagator) could provide a useful tool to achieve improved inclusion of CSA management. MitAgator provides a spatial view of where losses are occurring, identifies CSAs, and using combinations of 24 mitigations, compares the effectiveness and cost of different mitigation scenarios. The main limitation of the tool (and other spatial farm scale mapping tools) is currently their accessibility to all farmers in the catchment.

### 3.2.3 Strategic grazing

Strategic grazing was highlighted by McDowell et al. 2016 in the Land TAG presentation (McDowell et al., 2016) and McDowell et al. (2017). The mitigation relates to the strategic grazing of forage cropped paddock with stream, so that grazing is last in areas close to the stream and ephemeral pathways. Given the decreasing use of fodder cropping predicted under PC10, this P mitigation strategy has limited application for cropping scenarios, but the principle is equally relevant for intensive strip grazing of pasture, particularly during winter months.

### 3.2.4 Grass buffer strips

Grass buffer strips specifically target particulate-P in surface (overland) flows and have been trialled in the Rotorua Lakes catchment. McKergow et al. (2007) installed fenced off grass buffer strips within paddocks and based on two events, achieved a 40% decrease in P losses from the buffer strip area compared to a grazed control. Other trials have been less successful in reducing P losses (e.g. Longhurst, 2009), and in general grass buffer strips have limitations that limit their widespread use. These including reduced effectiveness if overland flows become chanellised or the strips become clogged with sediment, and the loss of land from production (McDowell, 2010).

### 3.2.5 Detainment bunds and ponds

Detainment bunds and ponds are a mitigation that pond surface runoff within farms, to remove P before being discharged to natural waterways. They are considered a new type of mitigation strategy designed to target ephemeral waterways during intense rainfall and runoff events, removing sediment and associated P from water leaving pastoral farmland (Clarke et al., 2013). There is minimal published data on their design requirements, effectiveness and cost. Brown et al. (1981) provides data showing that ponds retained 65% and 76% of sediments from surface runoff leading to P retention efficiencies of 25% and 33%. A subsequent MSc. Study (Clarke 2013) indicated the potential for P mitigation using detainments bunds but was inconclusive in providing sufficient robust quantitative data on the efficacy and costs of the mitigation strategy (Levine et al. 2017).

The Phosphorus Mitigation Project (PMP) is a farmer initiated collaborative effort between national and regional government entities, local farmers, private industries and universities, with the objective to identify cost-effective strategies to reduce the amount of P entering Lake Rotorua by surface runoff. Their research efforts have focussed on detainment bunds and ponds. Based on current prototypes the mitigation could be effective over 25-55% of a suitable farm in the Rotorua Lakes catchment, with the upper end of the percentage range looking more likely (Pers. Comm. J. Paterson). A high-resolution analysis (GIS) project is looking at identifying potential catchment areas where detainment bunds may be appropriate. At this point in time no additional data on the efficacy or cost are available. Detainment bunds could be an effective strategy at managing P loss from farm catchments and could provide a cost-effective P mitigation strategy in the near future.

### 3.2.6 Wetlands

The use of wetlands (constructed, natural and seepages) for P mitigation has been a focus in the Lake Rotorua catchment (Hamill et al., 2010 and Özkundakci et al., 2010). McDowell et al. (2017) stated that P removal from constructed wetlands was minimal because P removed via sedimentation was subsequently released as dissolved P. Similar findings were reported by Özkundakci et al. (2010) for a 2.3 hectare (ha) constructed wetland in the Lake Okaro catchment. Initial P retention of 42% occurred for the 2 years following wetland construction but then decreased as P enrichment of sediment lead to P release. However, they concluded that the combined effect of all restoration procedures (on-farm nutrient management and riparian planting) resulted in a relatively rapid decrease in TP concentrations, which may be prolonged by continued external load reduction.

Hamill identified restoring seepage wetlands and natural wetlands was the most cost effective for P mitigation; a $1 million wetland package consisting of these mitigations could reduce catchment P by 0.033 t P/yr.

The cost of P recovered for constructed wetlands is comparatively high and variable depending on site characteristics. In the lake Rotorua catchment constructed wetlands are most likely in the lower catchment around the lake margins. For this reason, P mitigations that reduce P upstream are a preferred option as ongoing input of P into constructed wetlands is likely to impact on mitigation efficacy.

## 3.3 P mitigation strategy efficacy and cost

Several relevant publications (from New Zealand and internationally) state the importance of cost-benefit for farmer uptake, and the importance of farmer uptake for effective P loss mitigation (McDowell, 2010; McDowell and Nash, 2012; McDowell et al., 2015; Murphy et al., 2015).

Adoption of mitigation strategies favours those with a low cost for retrieving P ($/kg P) and highest TP effect (% effectiveness). Other mitigation strategies may not primarily target P or may be costly. In general, mitigations are more efficient and cost less the closer they are to the source (farm management > amendment > edge of field).

The cost-effectiveness of P mitigation measures varies greatly, from profit-enhancing (e.g. reducing soil Olsen P levels to optimum production levels) to relatively expensive constructed wetlands and detention dam structures.

McDowell (2010), McDowell et al. (2013) and McDowell et al. (2017) use a common metric to describe a strategy in terms of the cost per kg of P mitigated on a per ha basis. In general, mitigations are more efficient in terms of cost per kg P conserved the closer they are to source (farm management > amendment > edge of field). The concept is shown in Figure 2.

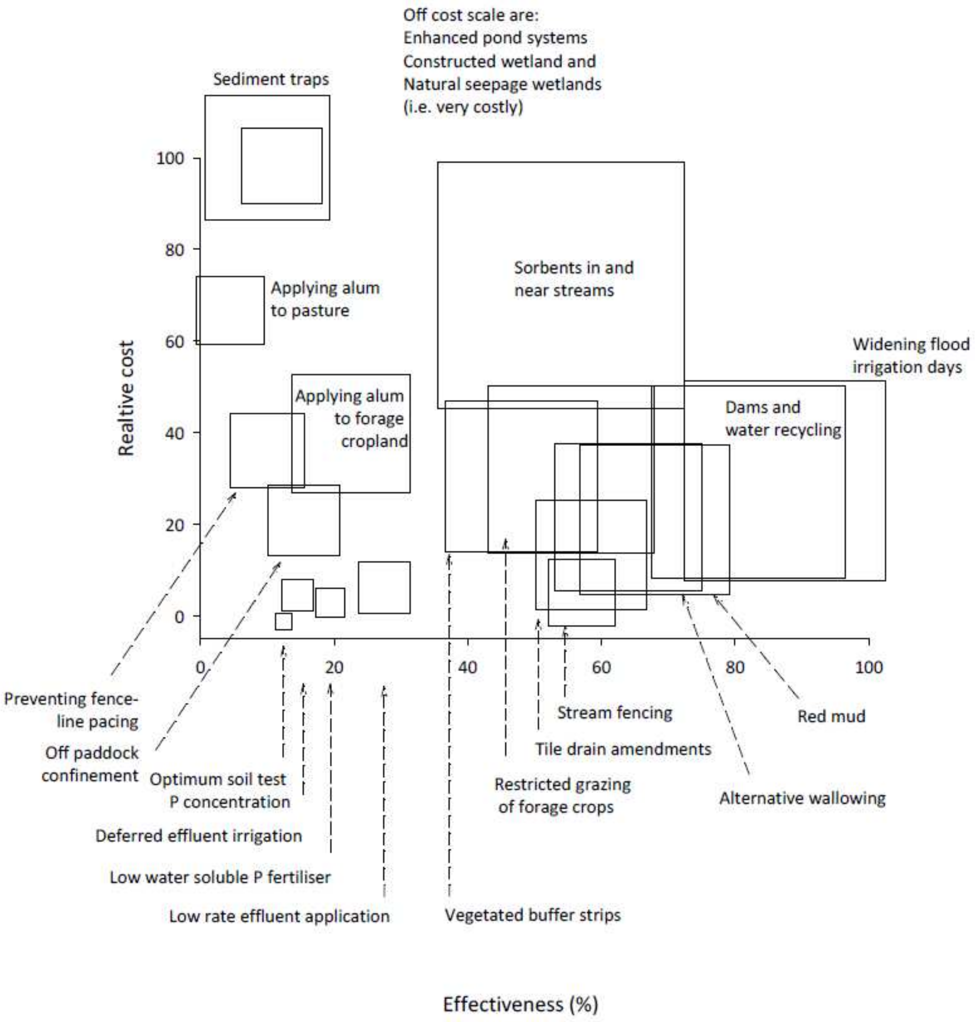


**Figure 2. The cost and effectiveness of farm scale P mitigation strategies for reducing losses to water (McDowell et al., 2013).**

Mitigation strategies are more likely to be adopted by the farmer if they are part of farm management. For this reason, emphasis is placed on using those associated with farm management as opposed to those mitigations considered edge of field because in theory they can be adjusted with existing farm management or built into farm management with negligible impact on the farm system.

## 3.4 P mitigation strategy adoption

Another consideration is the current likelihood of adoption in the Lake Rotorua catchment. For the Lake Rotorua catchment several of the mitigations provided in McDowell (2010) may not currently or likely to be used by farmers. Mitigations have been grouped (Table 3) based on an assessment of their current and likely future uptake (this is a subjective ranking based on feedback from farm advisors). Factors that are likely to change adoption are improvements to the mitigation cost effectiveness (*viz*. technology advances), inclusion in farm/nutrient management plans or nutrient management rules, and improved robust science supporting the effectiveness of the mitigation.

**Table 3. Ranking of P mitigations based on an assessment of their current and likely future uptake in the Rotorua lakes catchment.**

| P mitigation | | Likely adoption (High, Possible, Low) | |
|---|---|---|---|
| | | Current | Future |
| Optimum soil test P | management | Possible | High |
| Low solubility P fertiliser | | Low | Possible |
| Stream fencing | | High | High |
| Greater effluent pond storage | | Possible | High |
| Low rate effluent application to land | | High | High |
| Paddock CSAs (troughs, gateways and camp areas) | | Possible | High |
| Tile drain amendments | amendment | Low | Possible |
| Strategic grazing | | Low | Possible |
| Track and lane management | | Possible | Possible |
| Restricted grazing of cropland | | Possible | Possible |
| Alum to pasture | | Low | Low |
| Alum to grazed cropland | | Low | Low |
| Grass buffer strips | edge of field | Low | Possible |
| Sorbents in and near streams | | Low | Low |
| Retention dams / bunds / water recycling | | Low | Possible |
| Constructed wetlands | | Low | Possible |
| Natural seepage wetlands | | Possible | Possible |

With the exception of the use of low solubility P fertiliser (e.g. RPR) the table provides a sound basis for ranking mitigations in terms of effectiveness and cost benefit. For the P mitigation combination assessment (later in the report) some mitigations may be excluded based on the likelihood of low uptake.

## 3.5 P mitigation strategy combinations

There are more than 22 mitigation strategies focussed on P reduction (McDowell et al. 2013). To maximise P mitigation on any individual farm, the methods would need to be tailored to the relevant farm system, topography, soil type and nutrient status etc. Some mitigations, notably optimum Olsen P levels using RPR, will apply to the whole farm. Most other mitigations will realistically apply to a proportion of the farm.

McDowell et al. (2012) found that applying mitigation strategies to target CSAs (small specific P loss areas) was 6-7 times more cost-effective than applying the strategies across entire paddocks of the farm.

A combination of known or "standard" on-farm phosphorus management practices could potentially reduce P losses per hectare by up to 50%, although this can be achieved more easily on dairy farms than on drystock farms. The main methods are:

- reducing soil Olsen P levels to the lower end of the productive optimum range
- using low solubility fertiliser i.e. RPR (reactive phosphate rock) instead of super-phosphate
- low-rate effluent irrigation, possibly in combination with greater effluent storage

Similar P mitigation strategies are found in guidance based on the fertiliser industry's "Nutrient Management Code of Practice" (Fert Research, 2007) and other sector best management templates and guidance publications (e.g. McDowell et al., 2013; Mackay and Power, 2012). McDowell et al. (2017) concluded that combinations of P mitigation strategies could decrease P (or N) loss by more than 50% with minimal impact on farm profit.

The reduction gains were greater for those mitigations termed "management", with lesser reductions associated with mitigations further from source (Figure 3).

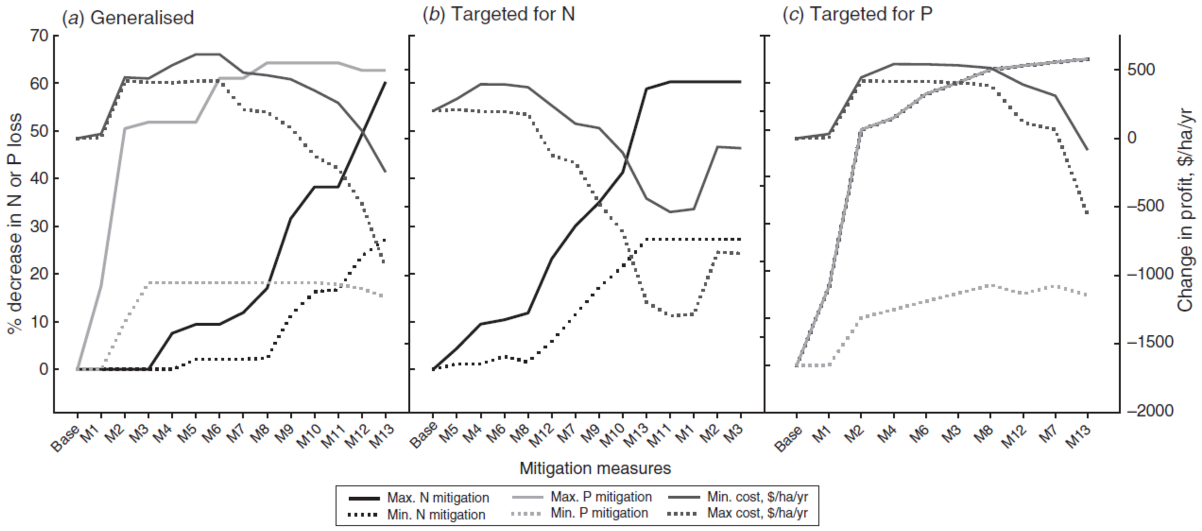


**Figure 3. Decrease in N or P loss from consecutively implemented mitigation measures (McDowell et al., 2017).**

The other important point to note is to be fully effective (including cost), mitigations had to be selected to target the specific nutrient issue; P reduction required P mitigation strategies as opposed to relying on P "by-catch" via N mitigation strategies.

While P losses from CSAs can be responsible for the majority of total farm P losses - up to 80% from 20% of the farm area (McDowell, 2010), there is currently no fully available tool available to model losses or show how losses may be reduced by focusing P mitigation efforts on CSAs.

Due to the current high amount of stream fencing and planting completed in the Lake Rotorua catchment, it is likely that there is less scope to achieve very high CSA-based reductions locally, other than within the paddock and on tracks. Despite this limitation, there are still likely to be combinations of standard P mitigations (e.g. Olsen P and effluent management) and CSA initiatives that make an overall farm P loss reduction of 50% achievable and credible.

## 3.6 P mitigation efficacy potential

Two approaches have been used to check the P mitigation potential of combined P mitigation strategies, specifically would they achieve (or approach) an overall 50% reduction in P loss, and the likely achievable P reduction range. One approach applies a combination of P mitigation strategies based on McDowell (2010) and other sources, and a second approach uses a combination of P mitigations available in OVERSEER® analysis.

Park (2012) combined P mitigations to estimate the cumulative reduction. The approach seems logical and because the mitigations are ranked (based on McDowell, 2010), a greater weighting is placed on the mitigations at the top of the ranking.

For each P mitigation strategy, the net P reduction effectiveness (%) is a product of effectiveness - representing the percentage reduction that can be attributed to the individual strategy, and the relevant farm area which is the area of the farm the individual strategy can be placed. Some P mitigation methods can apply to 100% of a farm or too much smaller areas, the latter have been estimated by expert knowledge. The effectiveness rates were simply based on the mid-point of the range given by McDowell. The average net effectiveness is calculated from the mid-point effectiveness multiplied by the relevant farm area that it can be applied to (e.g. 20% of 30% = 6% for row three). The approach conservatively assumes that there are no synergies between mitigations and, as percentages, they cannot be simply summed. Rather, each successive mitigation applies to the balance of the “yet to be mitigated P loss”. The selected combination for a hypothetical dairy farm is shown in Table 4. For example (using content from Table 4), the value of the cumulative reduction in row three (stream fencing), final column, is derived from subtracting the previous value in that column from 100% (100 - 21.3 = 78.7% P left to mitigate after previous types of mitigation are implemented), multiplying that by the average net effectiveness (6% of 78.7% = 4.7%), and adding that to the previous value (21.3% + 4.7% = 26%).

**Table 4. A P mitigation combination for a hypothetical dairy farm (from Park, 2012).**

| P Mitigation Strategy | Effectiveness % | Mid-point effectiveness | Relevant farm area | Effectiveness (net) | Cumulative reduction |
|---|---|---|---|---|---|
| Optimum soil test P | 5-20 | 12.5% | 100% | 12.5% | 12.5% |
| Low solubility P fertilizer | 0-20 | 10% | 100% | 10.0% | 21.3% |
| Stream fencing | 10-30 | 20% | 30% | 6.0% | 26.0% |
| Greater effluent pond storage | 10-30 | 20% | 15% | 3.0% | 28.2% |
| Low rate effluent application | 10-30 | 20% | 15% | 3.0% | 30.3% |
| Restricted grazing of cropland | 30-50 | 40% | 5% | 2.0% | 31.7% |
| Alum to pasture | 5-30 | 0% | 0% | 0.0% | 31.7% |
| Alum to grazed cropland | 30 | 0% | 0% | 0.0% | 31.7% |
| Grass buffer strips | 0-20 | 10% | 10% | 1.0% | 32.4% |
| Sorbents in and near streams | 20 | 10% | 0% | 0.0% | 32.4% |
| Retention dams / water recycling | 10-80 | 45% | 25% | 11.3% | 40.0% |
| Constructed wetlands | -426-77 | 0% | 0% | 0.0% | 40.0% |
| Natural seepage wetlands | <10% | 5% | 5% | 0.3% | 40.3% |

The cumulative reduction was 40.3%, short of the 50% reduction "target" indicated as achievable by McDowell (2010). However, it should be noted here (and in Tables 5 and 6) that the total cumulative reduction (40.3%) has large confidence limits extending way beyond the 50% value. This is the result of the wide range of values for effectiveness (column 2 in Table 4), and the resultant propagation of errors for the net combined effect that is calculated for the cumulative reduction (bottom of column 6 in Table 4).

Park (2012) revised several mitigations, the revisions deemed "optimistic";

- Optimum Olsen P efficacy increased from 12.5% to 20%.
- Effluent pond storage and low rate irrigation efficacies increased from 20% to 25%, but still applied to 15% of farm area (typical effluent block proportion).
- Fodder crop grazing restriction efficacy increased from 40% to 50%.
- Area treated by grass buffers raised from 10% to 30% of farm, and area treated by retention dams raised from 25% to 35%.

The net effect of the revised combination of P mitigations achieved the 50% target (just over 50%). Although the revised combination of mitigations did address some CSAs there was scope to include a more comprehensive array of CSA related mitigations. Also, Park acknowledged that the combination and efficacy of mitigations would vary with land use, soil, slope, rainfall and the farm system.

Overall the approach has many uncertainties associated with it, including the broad range of effectiveness for individual mitigations strategies, the estimates of the relevant farm area and calculating the net effectiveness and cumulative reductions. Although some of this uncertainty could be reduced with additional science and research, much of it is an inherent feature of the multiple combinations of farm systems and catchment conditions.

### 3.6.1 Revised P mitigation strategy combinations

A revision of P mitigation strategy combinations from Park (2012) included:

1. Reassessment of the combinations by Park (2012)
2. Modification of combinations to cover drystock and lifestyle land uses, and
3. New combinations of potential mitigations

In total, six P mitigation combinations for dairy were developed (including revisions of Park's). These were modified to provide drystock and lifestyle versions of each. The P mitigation combinations provide the basis for the P load scenarios later in this report. One point to note is that for the retention dam (detention bunds) mitigation the estimates for percentage effective area were not revised from those used by Park (2012). Although, the emerging research suggests higher percentage effective areas are very likely (refer section 3.2.5), a decision was made to wait until the research project results are finalised.

The recalculated Park (2012) combination in Table 4 above was 40.2% and the "optimistic" version provided a cumulative reduction of 49.7%. This slightly lower figure than the 50% achieved by Park is due to a reduction in the area assigned to "natural seepage wetlands (from 5% to 3% of farm area) and a minor calculating difference. The net reduction effectively achieves 50%.

For drystock, using the same available suite of mitigations achieves lower cumulative reductions of 36.4% and 41.1% respectively (Tables 5 and 6). These lower values are to be expected using the same available combination of mitigations because the effluent related mitigations are additionally not applicable (the number of effective mitigations in the combination is less).

**Table 5. Combined P mitigations for drystock based on the Park (2012) "original" combination for dairy (decreases highlighted in red).**

| Mitigation | Effectiveness % | Mid-point effectiveness | Relevant farm area | Effectiveness net | Cumulative reduction |
|---|---|---|---|---|---|
| Optimum soil test P | 5-20 | 12.5% | 100% | 12.5% | 12.5% |
| Low solubility P fertilizer | 0-20 | 10.0% | 100% | 10.0% | 21.3% |
| Stream fencing | 10-30 | 20.0% | 30% | 6.0% | 26.0% |
| Greater effluent pond storage | 10-30 | 20.0% | 0% | 0.0% | 26.0% |
| Low rate effluent application | 10-30 | 20.0% | 0% | 0.0% | 26.0% |
| Restricted grazing of cropland | 30-50 | 40.0% | 5% | 2.0% | 27.5% |
| Alum to pasture | 5-30 | 0.0% | 0% | 0.0% | 27.5% |
| Alum to grazed cropland | 30 | 0.0% | 0% | 0.0% | 27.5% |
| Grass buffer strips | 0-20 | 10.0% | 10% | 1.0% | 28.2% |
| Sorbents in and near streams | 20 | 10.0% | 0% | 0.0% | 28.2% |
| Retention dams / water recycling | 10-80 | 45.0% | 25% | 11.3% | 36.3% |
| Constructed wetlands | -426-77 | 0.0% | 0% | 0.0% | 36.3% |
| Natural seepage wetlands | 0-10% | 5.0% | 5% | 0.3% | 36.4% |

**Table 6. Combined P mitigations for drystock based on the Park (2012) "optimistic" combination for dairy (increases highlighted in green, decreases in red).**

| Mitigation | Effectiveness % | Mid-point effectiveness | Relevant farm area | Effectiveness net | cumulative reduction |
|---|---|---|---|---|---|
| Optimum soil test P | 5-20 | **12.5%** | 100% | 12.50% | 12.50% |
| Low solubility P fertilizer | 0-20 | 10% | 100% | 10.00% | 21.3% |
| Stream fencing | 10-30 | 20% | 30% | 6.00% | 26.0% |
| Greater effluent pond storage | 10-30 | 20% | 0% | 0.00% | 26.0% |
| Low rate effluent application | 10-30 | **25%** | 0% | 0.00% | 26.0% |
| Restricted grazing of cropland | 30-50 | **50%** | 5% | 2.50% | 27.8% |
| Alum to pasture | 5-30 | 0% | 0% | 0.00% | 27.8% |
| Alum to grazed cropland | 30 | 0% | 0% | 0.00% | 27.8% |
| Grass buffer strips | 0-20 | 10% | **30%** | 3.00% | 30.0% |
| Sorbents in and near streams | 20 | 10% | 0% | 0.00% | 30.0% |
| Retention dams / water recycling (2) | 10-80 | 45% | **35%** | 15.75% | 41.0% |
| Constructed wetlands (3) | -426-77 | 0% | 0% | 0.00% | 41.0% |
| Natural seepage wetlands (3) | <10% | 5% | **3%** | 0.15% | 41.1% |

The combined P mitigations applied to lifestyle land use produced even lower cumulative reductions; 28.4% and 30.1% respectively. Again, the number of applicable mitigations from the suite available was reduced (effective retention dams).

## 3.7 P mitigation effectiveness

To assess the potential range of effectiveness for the P mitigation combination, the high and low effectiveness points were used for individual mitigations. The range of cumulative reductions for dairy, drystock and lifestyle are presented in Table 7.

**Table 7. The high and low effectiveness point cumulative P reductions for dairy, drystock and lifestyle land use mitigation combinations.**

| Land use | Cumulative reduction (%) | |
|---|---|---|
| | High-point | Low-point |
| Dairy | 65.1 | 15.0 |
| Drystock | 61.7 | 12.4 |
| Lifestyle | 46.8 | 9.2 |

The cumulative reduction values for dairy and drystock are relatively close, with lifestyle lower. This is mainly due to the influence of the detention dam/bund mitigation (the absence of it for the lifestyle mitigation combination). At the high-point all land uses exceed or are at least are very nearly at the target 50% reduction. Although it is near certain that all mitigations will not achieve either high or low-point effectiveness.

Two new P mitigation combinations were compiled using refined effectiveness estimates from OVERSEER® and potential mitigations (Table 8). For the Original + OVERSEER® combination different estimates of effectiveness were provided for dairy and drystock – based on each farm's reference file. The purpose of providing a combination with additional "potential" mitigations was to estimate what could be achieved in the future and potentially use the cumulative reduction as an estimate in future scenarios of P loss reduction.

**Table 8. Description of two P mitigation combinations using refined effectiveness estimates from OVERSEER® and potential mitigations.**

| | Main features | | |
|---|---|---|---|
| P mitigation combination | Mitigations | Effectiveness | Relevant farm area |
| Original + OVERSEER® (adjusted effectiveness) | No additional mitigations | Reference files for dairy and drystock were modified in OVERSEER® - the difference provided the effectiveness percentage. | Either based on commonly used areas (e.g. fertiliser and effluent mitigations) or estimated (e.g. CSA management) |
| | | **Olsen P** mitigation from high level to optimum production Olsen P level. | Applicable to whole farm |
| | | **Low solubility P fertiliser** used (RPR replaced phosphate). | Applicable to whole farm |
| | | **Low effluent application** effectiveness from Park (2012) OVERSEER® assessment. | 15% of farm area |
| Original + additional mitigations | **In-paddock CSAs**: Includes minimizing bare ground (usually by re-grassing or revising paddock management) around gateways, troughs and animal camp areas (McDowell, 2010). | (40%)[1]<br>Estimated at between 30 and 50% (midpoint 40%). Similar range to "restricting grazing of cropland" | Estimated combination of gateway, trough and camp areas at 3% of farm area. |
| | **Strategic grazing**: Directional grazing to maximise the buffering effect of ungrazed grass closer to waterways and water flow paths (McDowell et al., 2016). | (10-80%)<br>McDowell et al., 2016 indicated up to 80% effective. No low point effectiveness provided but have assumed at least 10% | Estimated that applicable to 1 in 4 paddocks on average (25% farm area); depends on topography. |
| | **Tracks and lane management**: Includes adding berms to tracks to divert runoff to grassed areas, good track surface maintenance, and use of side of track sorbents to intercept P in runoff (McDowell, 2010). | (40%)[1]<br>Estimated conservatively; similar to stream fencing, lower than in-paddock CSAs because tracks still retain erosion risk with of bare ground (track surface) and batters. | Estimates of the area of tracks on dairy and drystock farms was from a 2012 Waikato Regional Council assessment of soil stability (Taylor, 2016); 8% for dairy and 5% for drystock farms. |

[1] 2016 Land TAG P mitigation workshop

The cumulative reductions for each P mitigation combination for each land use is shown below in Table 9.

**Table 9. OVERSEER® derived cumulative reductions for each P mitigation combination by land use.**

| Land use | Cumulative reduction (%) | |
|---|---|---|
| | Original + Overseer® | Original + additional mitigations |
| Dairy | 50.7 | 57.6 |
| Drystock | 42.8 | 50.0 |
| Lifestyle | 32.1 | 40.7 |

The values for the Original + OVERSEER® combination are at the 50% target for dairy only, with drystock and lifestyle dropping by about 10% and 20% respectively. It is worth noting that the reduction for dairy could be higher. The dairy “low effluent rate” effectiveness value looks quite low compared with the value used in the “optimistic” combination.

Higher overall cumulative reductions were reached for the Original + additional mitigations combination with dairy and drystock very near or above the 50% target; lifestyle was about 10% below. The addition of CSA focussed P mitigations is worthwhile and likely to be adopted as part of farm management more so than more costly mitigations or mitigations at edge of field.

## 3.8 P loss and OVERSEER®

### 3.8.1 OVERSEER®P sub-model

Gray et al. (2016 and 2016a) provide a comprehensive overview of the P loss capability of the OVERSEER® model. In their review Gray et al. (2016) state that the P loss sub-model in OVERSEER® was developed over a decade ago. There have been intermittent updates to the sub-model. However, in general, OVERSEER® predicts P loss reasonably well ($R^2$>0.80; P<0.001). Several updates were suggested; arable cropping, cut and carry, and fodder (forage) crops. Limitations in these areas are unlikely to impact on OVERSEER® P loss estimates for farms in the Lake Rotorua catchment because of the small areas in these land uses. However, additional enhancements relevant to P loss in the Lake Rotorua catchment were suggested:

1. That P losses via subsurface flow and surface runoff are reported separately and the subsurface flow component is integrated with aquifer characteristics to indicate a risk of connectivity to groundwater and influencing stream baseflow. The rationale is that these pathways have potentially different mitigation strategies and more specific mitigation decisions could be modelled.
2. A review of structures (laneways, feed pads, silage stacks) to identify whether additional P loss should be included in the model, in particular P loss from lanes to determine whether the current loss factor is reasonable - currently all structures are reported cumulatively as “other sources”.
3. Improving the sediment model (and in turn improving estimates of P loss) to include sediment loss from mass movement. The incorporation of a process based model (e.g. SedNetNZ) could improve this but would require OVERSEER® to be spatially explicit.
4. Increasing the spatial and temporal capabilities of OVERSEER® could enhance the capture and P loss estimates from CSAs. This is a key point that McDowell (2010) also noted given the high relative contribution of in-paddock CSAs to farm P loss.

### 3.8.2 Overseer estimation of P mitigation effectiveness

Park (2017) used a hypothetical and simplified dairy farm created in OVERSEER® using the current version (5.4.10) to estimate p mitigation effectiveness. The main farm parameters reflect the author’s knowledge of Rotorua dairy farm systems, and include: 200 ha effective area, rolling topography, Oturoa sandy loam soil, Olsen P = 60, 2.7 cows/ha, maintenance super-phosphate, 180 kg N/ha/yr as urea, 30 ha (15%) effluent block with nil fertiliser and 1800 mm mean annual rainfall. The OVERSEER® prediction of N and P loss was 10,007 kg N/yr and 595 kg P/yr, corresponding to rates of 50 kg N/ha/yr and 3.0 kg P/ha/yr respectively. The important point to note is the proportional reduction that can be achieved by applying credible mitigation strategies within OVERSEER®. The three changes made were:

- Reduce Olsen P from 60 to 40 (mg P/kg soil). Note that the optimum range for pumice soils at average production levels is 35-45. While some Rotorua dairy farms are high producing, most are below national and regional averages due to climate limitations. Further, an Olsen P of 60 is fairly typical (see Redding et al., 2006).
- Use a low rate effluent irrigation system
- Use RPR instead of super phosphate

The OVERSEER® file was run for each mitigation as the sole change from the status quo, then again with all three together. The results are summarised in Table 10.

**Table 10. OVERSEER® derived percentage P reductions from combined P mitigation strategies using a hypothetical Rotorua dairy farm in Overseer.**

| Mitigation | Farm P loss (kg P/yr) | kg P/ha/yr | % change |
|---|---|---|---|
| Olsen P = 40 | 461 | 2.305 | -22.5% |
| Low rate effluent | 554 | 2.77 | -6.9% |
| Use RPR | 532 | 2.66 | -10.6% |
| All 3 above | 366 | 1.83 | -38.5% |

OVERSEER® allows the user to apply grass filter strips in addition to the more typical mitigations used in Table 2. An ambitious set of filter strip parameters can reduce P loss by a further 10%. However, it is more realistic to expect a range of CSA-focused mitigations would be necessary to lift mitigation from about 38% to about 50% overall.

### 3.8.3 Revised OVERSEER® dairy and drystock mitigation scenarios

A range of P mitigations available in OVERSEER® were explored to estimate the changes in P loss to water. Rotorua lake reference files for dairy and drystock were used as a starting point (equivalent of current average farms). The reference files are OVERSEER® files that have been built to represent the average benchmarked farm. Each reference file represents the average benchmark management practices (e.g. stock type, stocking rate, fodder cropping, etc.) together with the biophysical characteristics (e.g. soil, slope, rainfall) of the benchmarked areas to form an average sector file. (http://www.rotorualakes.co.nz/reference-files). These files were further refined by applying a slope class differential for each soil (each Soil Sibling block area) was disaggregated into two slope classes using a 16-degree slope break – similar to the slope break used to define the twelve soil/rainfall/slope zones used for determining base data nitrogen discharge allowance files. A summary of the mitigations explored, and the resulting P loss estimates are presented in Table 11.

**Table 11. OVERSEER® derived P loss estimates using selected P mitigations for farm reference files.**

| | OVERSEER® P loss estimate (kg P/ha/yr) | | | |
|---|---|---|---|---|
| | Dairy | | Drystock | |
| P mitigation(s) | Reference file | Reference file with slope differential | Reference file | Reference file with slope differential |
| Base reference files | | | | |
| Base (no mitigations added) | 2.7 | 3.1 | 1.8 | 1.9 |
| Olsen P | | | | |
| Olsen P 40 | 3.0 | 3.5 | 3.2 | 3.4 |
| Olsen P 60 | 3.8 | 4.4 | NA | NA |
| Effluent management | | | | |
| Effluent irrigation low rate | 2.7 | 3.1 | NA | NA |
| Effluent irrigation area 15% farm | 2.7 | 3.1 | NA | NA |
| Effluent irrigation area 25% farm | 2.7 | 3.1 | NA | NA |
| Fertiliser | | | | |
| Fertiliser – RPR[1] | 2.1 | 2.4 | 1.6 | 1.7 |
| Combined mitigations | | | | |
| Combined RPR + Olsen P 40[1] | NA | NA | 3.0 | 3.1 |
| Combined RPR + Effluent area 25%+ low effluent irrigation rate + Olsen P 40 | 2.4 | 2.7 | NA | NA |
| Combined RPR + Effluent area 25%+ low effluent irrigation rate + Olsen P typical soil level | 2.1 | 2.4 | NA | NA |

[1] For drystock Olsen P was reduced to typical soil levels provided in Overseer®

The use of more detailed slope data to delineate soil blocks (a slope differential) provided the greatest change for dairy (from 2.7 to 3.1 kg P/ha/yr, a +15% change). The change for drystock was less (from 1.8 to 1.9 kg P/ha/yr, a +6% change).

- The **inclusion of a slope differential** increased the P loss estimate, though there is no evidence to support the absolute values are more accurate than values when slope is not included.

The P loss estimates for the mitigation were estimated as follows:

- **Reducing Olsen P soil levels** from likely current levels to lower levels closer to optimum dairy from 60 to 40 and drystock from 40 to more typical based on soil type). For dairy the change was a reduction of 20-22%. For drystock the change was a reduction of 13-15%.
- For dairy, altering the **rate of application** of farm dairy effluent and **increasing the land application area** did not show a change in the whole farm P loss.
- The **use of RPR** (instead of soluble P fertiliser reduced whole farm P loss for both dairy and drystock. For dairy the change was a reduction of 22-23%. For drystock the change was a reduction of 11%.
- **Combining the above mitigations** provided a 37-39% reduction in farm P loss for dairy and a 50% reduction in farm P loss for drystock. These findings agree with Park's 2012 estimates for dairy above and the estimates presented in the McDowell et al. (2016) Land TAG P mitigation presentation.

A comparison with the data from Park (2012) is provided in Table 12.

**Table 12. A comparison of the OVERSEER® P mitigation outputs from this assessment against the OVERSEER® P mitigation outputs from Park (2012).**

| Mitigation | Park (2012)[1] | This report[1] | |
|---|---|---|---|
| | Dairy, % change | Dairy, % change | Drystock, % change |
| Olsen P = 40[2] | -23% | -21% | -6% |
| Low rate effluent | -7% | No data | No data |
| Use RPR | -11% | -23% | -11% |
| Combined | -39% | -38% | -15% |

[1] Values rounded to nearest whole number.

[2] For drystock Olsen P was reduced to optimum soil levels for soil group. For dairy Olsen P was reduced from 60 to 40.

For drystock, the reduction for all (combined) mitigations is 15%. This is because there is no effluent related reduction and the reduction in Olsen P is less because drystock Olsen P values are estimated at 40 – the reduction will only be for Allophanic and Recent Soils at 40 reducing to 25 (the standard production optimum for these soils). For the two dairy examples the reductions for Olsen P and All mitigations are similar -despite the absence of a reduction for the low rate effluent mitigation.

### 3.8.4 Analysis of P data from Parsons et al. (2015)

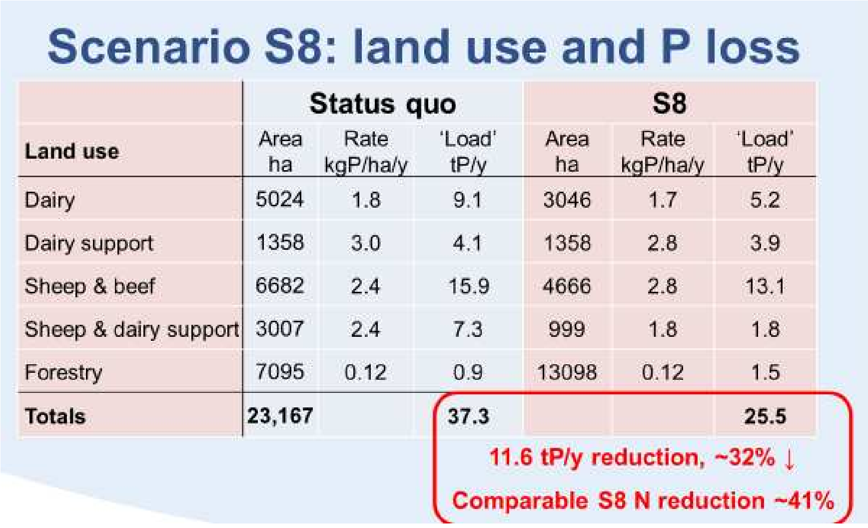
Park (2017) use the raw model economic model Excel outputs to estimate the likely P loss reductions from land use changes associated with Scenario 'S8' of Parsons et al. (2015). Scenario outputs were sorted to focus on P losses under the main land uses. The main comparison was between the status quo land use and Scenario 'S8'. The latter is similar to the PC10 allocation regime in combination with the Incentives Scheme. Key points about this analysis are:

- Multiple realistic farm 'typologies' were modelled in OVERSEER® v6.1.3 and FARMAX, with N mitigation cost curves determined via a hierarchy of system and land use changes.
- The focus was 'commercial' land including forestry, with ~5000 ha small blocks ignored
- All N allocation scenarios were forced to reduce aggregate N loss from 633 to 372 t N/yr, (a decrease of 41%), with a range of constraints around cost-effectiveness and landowner willingness to trade N

Park noted some caution is warranted in interpreting the Parsons et al. P data because:

- The area modelled is less than the actual area due to the 'commercial' assumption
- The OVERSEER® P loss boundary is the '2nd order stream' and further attenuation is not modelled
- P was not the focus and there may be unforeseen methodology anomalies.

The P reduction results are summarised in Figure 4 below.



Scenario S8: land use and P loss

| Land use | Status quo<br>Area ha | <br>Rate kgP/ha/y | <br>'Load' tP/y | S8<br>Area ha | <br>Rate kgP/ha/y | <br>'Load' tP/y |
|---|---|---|---|---|---|---|
| Dairy | 5024 | 1.8 | 9.1 | 3046 | 1.7 | 5.2 |
| Dairy support | 1358 | 3.0 | 4.1 | 1358 | 2.8 | 3.9 |
| Sheep & beef | 6682 | 2.4 | 15.9 | 4666 | 2.8 | 13.1 |
| Sheep & dairy support | 3007 | 2.4 | 7.3 | 999 | 1.8 | 1.8 |
| Forestry | 7095 | 0.12 | 0.9 | 13098 | 0.12 | 1.5 |
| **Totals** | **23,167** | | **37.3** | | | **25.5** |

11.6 tP/y reduction, ~32% ↓

Comparable S8 N reduction ~41%

**Figure 4. Estimated P reduction from land use changes from status quo to scenario S8 of Parsons et al. (2015).**

- Scenario S8 gave a 11.6 t P/y or 32% reduction in P loss 'without trying' i.e. P by-catch. This was mainly driven by ~6000 ha pasture converting to pine forestry
- The P reduction is very sensitive to the OVERSEER® forestry P loss @ 0.12 kg P/ha/yr. **IF** forest P loss rate is assumed = 1.0 kg P/ha/yr, total P reduction is only 5.4 t P/yr or 12% (relative to status quo).
- Additional P loss reductions (beyond S8) would be possible via (i) improved P farm practices and (ii) GMPs on ~5000 ha non-commercial pasture, mainly small blocks <40 ha.

A revision of this analysis was undertaken, based on the same outputs but incorporating P loss rates for each Soil Order. The resulting estimated reduction increased from Park's estimated change from 37.2 (status quo) to 25.5 (S8) to 22.3 for S8. This equates to a percentage P loss reduction of 40% (*viz*. 32%).

### 3.8.5 Assessing likely PC10 P 'by-catch' by reviewing OVERSEER files

Park (2017) compared three pairs of OVERSEER files to check what level of P 'by-catch' may occur when the focus is on N. The comparisons were:

- One dairy and one drystock example, both comparing 'benchmark' vs '2032 NDA' files
- The PC10 drystock reference files, comparing:
    - the 'as notified' file that targeted the average drystock NDA with ~27 kg N/ha/yr in OVERSEER v6.2.3
    - the revised file that aims to be representative of all benchmarked drystock

Park stated that little could be concluded from the analysis due to the randomness of the single case studies and the apparent disconnect within the files on what is driving the respective N and P reductions.

The two drystock OVERSEER® reference files were examined for Soil Order and slope influence on N and P loss. The results showed contrasting P loss rates across different Soil Orders, it is not clear if and how this can be targeted given there are fundamental soil properties underpinning this variation, notably Anion Storage Capacity (ASC or 'Phosphate Retention').

## 3.9 Sector promoted good practice

Park (2017) provides a brief summary of “sector promoted good practice”, presenting a sample of industry initiatives (Table 13).

The dairy and drystock sectors encourage their farmers to adopt industry-defined best practice, notably through their respective farm plan templates. Similarly, the forestry sector has well established Environmental Management Systems. Dairy effluent and forestry harvesting have long been managed through resource consents with conditions requiring practices to reduce nutrient loss, including P loss (Park 2017).

Recently, the National Environmental Standards for Plantation Forestry (NES-PF) has been implemented. The NES-PF has the objectives of maintaining or improving the environmental outcomes associated with plantation forestry activities and increasing the efficiency and certainty of managing plantation forestry activities. The NES-PF arguably could result in a net reduction of P loss from plantation forestry in the Lake Rotorua catchment. However, there is no evidence to support this given the very recent implementation and lack of associated formal monitoring requirements.

It will be difficult to determine what difference sector promoted good practice makes because:

- If good practices are already routinely followed, then there is little room for improvement (*viz*. near 100% reported stock exclusion of streams)
- Comparing pastoral sector ‘best practice’ with OVERSEER® derived P loss rates is problematic due to OVERSEER®’s general presumption that ‘good management practices’ are followed. OVERSEER can model some poor practice and therefore estimate what improvement is possible by adopting good practice. A pertinent example is ensuring soil Olsen P levels do not exceed the production optimum.
- The forestry sector’s highly episodic harvesting cycle (and the associated high-risk period for sediment and P loss) makes it inherently difficult to measure or model good or poor practice.

Many of the P mitigation strategies in McDowell (2010) and McDowell et al. (2013) are incorporated[1] into ‘sector promoted best practice’ systems illustrated in Table 13 (Park 2017).

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[1] Commonality between pastoral sector guides partly reflects science relevant to these sectors and some common authorship, notably by AgResearch (NZ’s pastoral science CRI).

**Table 13: Sample of industry good phosphorus practices (from Park, 2017).**

| Sector | P good practice | Comment |
|---|---|---|
| **Sheep and beef (also deer)** | P good practice is captured within B&LNZ's Land and Environment Plans, including its Menu of practices to improve water quality which includes advice on a wide range of practices targeting N, P, sediment and micro-organisms, with estimates of reduction (low, medium & high), relative cost and relative benefit (latter refers to farm profitability). 'Menu' examples for P include:<br>• Keep Olsen P at agronomic optimum (using soil testing) – this has a 'high' rating for P reduction with low cost and high benefit<br>• Stock management to reduce erosion, pugging<br>• Managing critical source areas – hotspots e.g. Direct stockyard run off to paddock | The 'Menu' good practice document was developed in association with the Upper Waikato Primary Sector Partnership but appears relevant to Lake Rotorua catchment |
| **Dairy** | DairyNZ has developed a comprehensive range of (N & P) nutrient good practice guides, tools and extension capability. Key resources include:<br>• Nutrient management on your dairy farm which covers many N and P good practices as well as the fundamentals of N and P sources, cycles, loss pathways and waterway impacts | Good effluent practice has historically been noted as a significant means of reducing P loss from dairy farms, especially shifting from ponds (discharging to water) to land irrigation. However, land irrigation has been the norm for all BOP dairy farms for many years. |
| **Deer** | The NZDFA Landcare Manual Deer provides specific practice guidance for deer farms while building on many practices identified for sheep and beef farms. There is a particular focus on:<br>• soil protection e.g. minimising fence-line pacing<br>• water protection e.g. managing wallowing | NZDFA has a relationship with B&LNZ to enable use of the LEP toolkit on deer farms. |
| **Forestry** | The NZ Forest Owner's Association (NZFOA) has promoted good nutrient management as part of a formal Codes of Practice since 1990. The 2015 Environmental Code of Practice (E-CoP) was developed by a team including several BOP contributors. The E-CoP targets operational practitioners and forest planners within an EMS framework. Numerous listed practices seek to minimise soil disturbance and sediment loss with consequent P benefits, including:<br>• Earthworks controls and revegetation<br>• Engineered stream crossings<br>• Avoiding earthworks within 5m of waterways | In addition to E-CoP, most commercial NZ foresters participate in the internationally recognised Forest Stewardship Council (FSC) EMS (2013 version). Scion continues to develop the NuBalM model which will ultimately be able to predict N & P loss rates, with scope to link to OVERSEER. |
| **Small blocks** | The Small Block guide (prepared by Landconnect Ltd, awaiting publication) | |

Many Rotorua farmers will have voluntary industry farm plans (SMPs and LEPs) that both assist with the regulatory Nutrient Management Plan (NMP) and which encourage P good management practices.

It is plausible that a high adoption level of P (and sediment) good practices would result in a meaningful reduction in current P losses from each of the major land use sectors, as illustrated in reports by McDowell (2010) and a related extrapolation by Park (2012). However, it is difficult to reliably quantify the potential reduction in P loss if landowners followed sector good practice without further analysis.

McDowell (2017) noted in his commentary on Park (2017) that many of the B&LNZ practices referred to in Table 13 above were stated as providing "high water quality benefit" for P. McDowell cautions that this may not be so and disputed the categorical effectiveness for P mitigation listed. This does signify the importance of having scientifically robust mitigations and the ongoing requirement to refine the knowledge around P mitigation strategies, especially efficacy and costs.

## 3.10 Good practice P 'by-catch' when focusing on N

N mitigation does not always mean there will be accompanying P mitigation. However, Park (2017) suggests that P mitigation (P "by-catch") can be indicated by considering recommended practices with both N and P mitigation benefits. For example, the B&LNZ Menu of practices to improve water quality rates each practice as low, medium or high for N and/or P reduction efficacy, in terms of likely water quality benefits. In broad terms, the ratings correspond to these estimated % reductions (at whole farm scale):

- Low = <10% for N, <20% for P; Medium = 10-25% for N, 20-50% for P; High = >25% for N, >50% for P

## 3.11 Overview of PC10 provisions on phosphorus

Park (2017) stated that the main thrust of PC 10 to reduce nitrogen losses from land to help meet the sustainable annual lake load of 435 t N but acknowledged that P provisions were in PC 10:

- **Policy P2:** To manage phosphorus loss through the implementation of management practices that will be detailed in Nitrogen Management Plans prepared for individual properties/farming enterprises.
- **Method M2:** The five yearly science reviews will include '...an assessment of the efficacy and risks of alum dosing and an assessment of land-based phosphorus loss mitigation.'
- **Method M5:** Council will….

  (d) provide land advisory services and incentives to support land use management change and land use change that reduces nitrogen **and phosphorus** loss in the catchment; and

  (e) encourage industry good practices to be implemented on rural properties/farming enterprises to reduce nitrogen **and phosphorus** loss in the catchment. [**emphasis** added]
- **Schedule Six – Nitrogen Management Plans** [includes]

  5(b) *Phosphorus management:* To identify the environmental risks associated with phosphorus and sediment loss from the subject property, the significance of those risks and implementation of industry best practice management to avoid or reduce the risks.

Additional NMP requirements relate to effluent management (5(d) and fertiliser management (5(f)), both of which address P losses and good practice.

In response to PC10 submissions, staff propose that NMPs are now Nutrient Management Plans (i.e. more explicitly N and P) and that Schedule Six 5(b) is expanded by adding [after 'good practice management measures…]:

> This shall include the identification of appropriate mitigation actions within critical source areas, with these areas including:
>
> (i) overland flow paths and areas prone to flooding and ponding

(ii) erosion prone areas
(iii) farm tracks and races and livestock crossing structures
(iv) areas where effluent accumulates including yards, races and underpasses
(v) fertiliser, silage, compost, or effluent storage facilities and feeding or stock holding areas

These amended provisions strengthen PC10's focus on P (i.e. PC10 is not solely about N). The new recommended critical source area provisions in PC10 are particularly important given CSAs can contribute ~80% of total farm P loss from ~20% of the area (Land TAG presentation McDowell et al., 2016).

## 3.12 Monitoring of GMP and P mitigation

Assuming a dual nutrient (N and P) approach with associated nutrient loss targets, quantitative data to assess progress towards targets is equally essential for both nutrients. Sound baseline capture of the level of mitigation implementation is also required to assess the potential contribution of individual mitigations. For example, if riparian areas are near to completely fenced then there is limited opportunity for that mitigation to contribute as a mitigation. Similarly, if soil Olsen P levels are on average higher than estimated there is greater opportunity for that mitigation to contribute to reducing P loads in the catchment. A combination of field assessment and capture of data through NMPs can inform this.

Consistent capture and recording of data are essential. An NMP approach, including the use of a standardised nutrient budget template (e.g. OVERSEER®) provides a good mechanism for this but requires a (preferably spatial) supporting database. This becomes increasingly important for future assessment of progress as well as compliance auditing.

### 3.12.1 P loss within current provisional NMPs

The indirect approach of PC10 means that with sector promoted good practice, it is difficult to assess the degree of P reduction that will occur. Park (2017) undertook a brief review of two completed (but provisional) NMPs:

- The NMP include a 'phosphorus loss' subheading followed by a current state OVERSEER® block loss table, total P loss and average kg P/ha loss, followed by comments -noting where block losses appear high and stating the possible reasons for that (high Olsen P, low soil ASC).
- No actions explicitly targeted P mitigation although one nominated NPKS fertiliser regime may have achieved this in part. As noted above, some N mitigation actions will have some P 'by-catch'.
- Adding to this, is the logistical requirement to complete NMPs for the whole catchment – leading to multiple advisors and multiple data collection approaches. This is an issue facing other regions (e.g. Hawke's Bay and Canterbury) and likely to face other regions.

Park (2017) suggested it would be possible to review additional completed provisional NMPs. The suggestion raises the question of being able to quantify the reduction of P as part of PC10 NMPs (essentially policy effectiveness around P loss reductions associated with PC10).

As part of this review an example nutrient management plan (provided by a farm advisor in the Lake Rotorua catchment) identified that N remained the focus of the plan. P management is included in the plan, but actions are qualitative rather than quantitative and although guidance and recording of the CSAs are based on potential CSA risk area maps provided by BOPRC (and in this example, locations are recorded), the quantification of the P loss associated with the CSAs on a farm basis will be difficult to quantify. A notable feature was the absence of a requirement to record and report OVERSEER® P mitigations and provide P loss outputs as part of the nutrient budget outputs.

Key to the ongoing assessment of PC10 implementation effectiveness for P loss reductions (but also N loss reductions) is the capture of finer (farm scale data) that can be used to refine catchment scale modelling of N and P load to Lake Rotorua.

McDowell (2017) also raised the point of the lack of (or opportunity) to capture P mitigation actions spatially at farm scale. This georeferenced data could form the basis for quantitatively assessing policy effectiveness once NMPs have been put in place, and actions are implemented.

Recent and near future developments may assist with this; spatially supported farm planning platforms such as AgFirst's Landbase, Ravensdown's "My Farm" the MitAgator tool (AgResearch/Ballance) and spatial OVERSEER® (AgResearch/MPI/FANZ).

One of the limiting factors for this to progress could be the proprietary ownership of various tools restricting full catchment uptake and data sharing.

### 3.12.2 Progress towards the P target

A key feature of this review is the uncertainties associated with land-based P mitigations. That said the review does suggest that land-based P mitigations do have the potential to contribute to the reduction in P load in the catchment. Several points are worth noting when considering an approach towards future policy targets.

Selection and placement of P mitigation strategies can be improved with farm scale soil and land feature mapping. This has in part been provided (e.g. slope and ephemeral pathways GIS layers provided by BOPRC). Farm scale soil map information poses more of a challenge due to the resource requirements to complete finer scale mapping.

At catchment scale, prioritising where to place the most effective mitigation strategies to achieve the greatest P reduction could be of value. There are several examples of different approaches that could be useful to explore. Examples include the Land Use Suitability tool being developed by the Our Land and Water Programme (Our Land and Water, 2018) the biophysical prioritisation work used in the Waikato River and Waipā River Restoration Strategy (Waikato Regional Council, 2018) or the Kaipara Harbour Sediment Mitigation Study (Green and Daigneault, 2018) could provide guidance for sub-catchment scale mitigation placement.

# 4 Aggregate assessment of catchment land-based P load and mitigation

## 4.1 Background

In 2012 a spreadsheet-based model to estimate the reductions in P load to Lake Rotorua was developed (Park, 2012). The purpose of the model was to provide a basis for reductions in P load from the Lake Rotorua catchment for use in Lake DC modelling based on:

- Combinations of on-farm P mitigation strategies designed to achieve a high but credible overall reduction in P loss from pastoral land across dairy, drystock and "lifestyle" land uses
- Separate and additional P load reductions from proposed sewage reticulation, septic tank upgrades and urban storm water improvements
- Catchment P load estimates based on land use areas and P loss coefficients for status quo and mitigated scenarios consistent with the R-0, R-250, R-300 and R-350 ROTAN scenarios.

McDowell (2017) provided some comments on the approach of the model, stating that the mitigation potential estimated was in line with recent findings that showed 20-80% of the anthropogenic load was mitigated (McDowell et al., 2015).

A revision of this model has been undertaken, incorporating updated P loss coefficients for land uses, revised P mitigation efficacies and new future scenarios based on the N allocations scenarios of Parsons et al. (2015). The revised model provides estimates of catchment P loads, relative P losses from rural land uses, P mitigation contribution from rural land and estimates of P "by-catch" associated with future N mitigation related land use changes.

The method for this revision is closely based on that used by Park (2012) with the addition of revised P loss coefficients for rural land uses and the application of realistic mitigations.

## 4.2 P loss coefficients for rural land use (dairy, drystock, planted and native forest)

The P loss coefficients applied to different land uses form the basis of catchment load predictions. There are numerous sources of coefficients usually relating to individual catchment studies or sometimes derived individually from a range of publications. Also, refinements are sometimes made (e.g. averaging) to land use P coefficients, as in Park (2012). Table 7 of the Proposed Rotorua-Rotoiti Action Plan (EBOP, 2007), the Rerewhakaaitu Nutrient Budget and the Lake Tarawera Nutrient Budget and Restoration Plans provide most of data for deriving the P loss coefficients for the land uses classes (Table 14).

Table 14. Sources of land use P coefficients used in this assessment**Error! Not a valid link.** Generally, in this assessment and in Park (2012), a group of P loss coefficients from the same or similar catchment studies have been used for a scenario. This increases the relativity of coefficients across the land uses; keeping in mind that catchment features such as topography vary from catchment to catchment. In this assessment one "hybrid" assortment of land use P loss coefficients was created based on three main sources; the proposed Rotorua-Rotoiti Action Plan, Rerewhakaaitu Nutrient budget and the Tarawera nutrient budget and restoration plan (PRRAP-R/T).

The coefficients selected for this scenario were considered the most recent and realistic of the available coefficients. Additionally, an averaged forestry scenario was compiled using a mix of values from several sources. McDowell (2017) questioned the 0.12 kg P/ha/yr listed by Park (2017), suggesting that this figure could be low and that the estimated decrease in P losses associated with a landuse change from pasture to forestry would result in a lower long term P decrease estimated.

The P loss coefficients for forestry provided in Table 14 above, range between 0.1 to 0.4. Hamilton et al. (2006) consider 0.4 kg P/ha/yr to be at the high end, representing where forest harvest is implicated in enhanced nutrient loss. Studies suggest that P loss from forest are in the order of 24-57% of losses from pasture. Comparisons of pine forest versus grazing systems show that in all situations the total P losses from pine plantations are in the order of 24-57% of that from pasture catchments (Menneer et al. 2004). In a review of water quality of New Zealand forested streams, Baillie and Neary (2015) suggested sediment yields (and therefore approximating particulate P) were a magnitude greater than pre-harvest, returning to about three time greater than pre-harvest after at six years. Their review also estimated that total P concentrations for pasture were about twice that of plantation forest streams, which in turn were about twice that of indigenous streams. They note stream P concentrations were variable for forest streams, attributed to different lithologies, soil type and land management history.

A median value of 0.27 t P/yr has been calculated from the range of values for forestry. This sits at the lower end of the P loss comparison with pasture and is very similar to the indigenous forest P loss coefficient used for the Tarawera Nutrient Budget (McIntosh, 2012a).

## 4.3 Catchment P load scenarios

Three main components make up each scenario; P loss co-efficients, P mitigations by land use and Land use area (current and future). Each scenario may use different combination and data sources of the three components. Future land use scenarios were based on two existing N models; the ROTAN model (Rutherford et al. 2011) and a N allocation model (Parsons et al., 2015). An additional "hybrid" scenario was derived using a combination of land use changes from both models. The main challenge was to apportion the scenario land use changes from each model, to derive a set of land use changes for each scenario in this assessment.

### 4.3.1 Use of ROTAN model for scenarios

Any P mitigation scenario will necessarily be relative to the status quo P load. For modelling purposes, the current or status quo load is equivalent to the R-0 scenario whereby land use, nutrient loss rates and all other inputs are held constant at 2010 levels.

The land use areas (adjusted from ROTAN scenarios) have been combined with status quo and mitigated P loss coefficients to give a range of P mitigation reductions for the catchment overall.

Each overall load is a combination of on-farm mitigation and land use change. All the ROTAN-based mitigation scenarios (R-0, R-250, R-300 and R-350) are subject to P mitigation adjustments and are compared to “R-0 with no P mitigation” i.e. the status quo. To avoid confusion, the R-0 mitigated scenario is called R-P. In addition to the 50% reduction in pastoral P loss and all relevant land use changes (mainly to forestry, as per ROTAN), the following changes are applied:

- Urban P loss is reduced by 0.5 t P/yr, applied as a 20% reduction from 0.70 kg P/ha/yr to 0.56 kg P/ha/yr, which corresponds to Action Plan assumptions+
- The combined septic tank reticulation and WWTP upgrades reduce P load by 1.0 t P/yr, in line with Action Plan assumptions

No changes are applied to springs and rainfall and the P-locking plants are ignored i.e. it is assumed that the range of land-based P mitigations are potentially a substitute for stream alum dosing, at least in this desktop study.

### 4.3.2 Use of N allocation model for scenarios

The N allocation model of Parsons et al. (2015) is an economic analysis of N allocation scenarios. Unlike ROTAN, the model does not use the scenarios to derive an N budget related to land change, instead the model uses different allocation scenarios within the N cap (determined by Bay of Plenty Regional Water and Land Plan Rule 11).

The evaluation of allocation mechanisms involves the application of a catchment-level optimisation model. The model only includes commercial land. The model method involved (from Parsons et al., 2015):

- Division of the catchment into biophysical zones (based on soil, slope and rainfall).
- Establishing representative farm systems (dairy, sheep and beef, sheep and dairy support, and specialist dairy support) for each biophysical zone.
- Developing agreed and consistent modelling protocols to reflect realistic farmer N mitigations.
- Applying the modelling protocols to farm systems using FARMAX and OVERSEER (version 6.1.2) to establish relationships between profit and nitrogen leaching.
- Obtaining annualised forestry-profit information from SCION (including carbon).
- Obtaining land-use change cost benefit data from Regional Council.

Integrating this information on profit and nitrogen leaching for individual farm types into an economic model describing the whole catchment. This model incorporates trading of N leaching rights both among farmers, and with an incentives fund that buys out nitrogen. Supply and demand is driven by nitrogen prices generated by the catchment model based on mitigation costs.

## 4.4 Future scenarios

The revision of the P loss spreadsheet included credible future scenarios, using the same P coefficients for land use, an expanded P mitigation strategy combination and likely land use changes based on N mitigation scenarios of Rutherford et al. (2011) and Parsons et al. (2015), (table 15).

**Table 15. Catchment P load scenarios.**

| Scenario | Data source (model) | Description | Resulting land use changes |
|---|---|---|---|
| R-0 | ROTAN[1] | Land use and nitrogen exports remain at their current levels from 2015-2100. This provides the baseline for | No Change |

| | | | |
|---|---|---|---|
| | | the assessment. | |
| R-P | | Uses R-0 but with P mitigation adjustments | No Change |
| R-350 | | Total nitrogen export reduced by 350 tN/yr through a combination of land use change and a reduction in nitrogen export. 100% of the dairy area becomes either Lifestyle or drystock. In addition, 85% of drystock becomes either lifestyle or forest. Overall forest increases by 55% and lifestyle by 145% compared with R-0. | No dairy; large decrease drystock; large increase lifestyle; large increase exotic trees; small increase forest. |
| S8 | N allocation[2] | Range – each sector has an allocation range; drystock has a range of 15.5–31.5 kg N/ha/yr; dairy has a range of 40–53 kg N/ha/yr; dairy and drystock experience a uniform proportional reduction. | Large decrease dairy; large decrease drystock; no change to lifestyle; large increase exotic trees; small increase forest. |
| H1 | N allocation and ROTAN | As for S8 but with ROTAN R-350 lifestyle increase, and an associated reduction in exotic trees to balance (i.e. a portion of dairy and drystock pasture change to lifestyle instead of exotic forest) | Large decrease dairy; large decrease drystock; large increase lifestyle; large increase exotic trees; small increase forest. |

[1] Rutherford et al. (2011)

[2] Parsons et al. (2015)

### 4.4.1 Land use areas

Land use areas were based primarily on aggregated ROTAN land use class areas derived for the model developed by Park (2012) with the addition of disaggregation of the "Forest" land use into Exotic forest "Trees" and indigenous vegetation "Forest". The disaggregation used land cover data provided by BOPRC GIS staff. The resulting land use classes and areas are shown in Table 16.

**Table 16. Land use areas and percentage changes for all scenarios.**

| **Land use areas for all scenarios (ha)** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **R-0** | **R-P** | **R-250** | **R-300** | **R-350** | **S1-S2** | **S8** | **H1** |
| Dairy | 4499 | 4499 | 2250 | 0 | 0 | 2597 | 2726 | 2726 |
| Drystock | 14861 | 14861 | 8890 | 12491 | 8910 | 10784 | 9452 | 9452 |
| Lifestyle | 1053 | 1053 | 2577 | 2577 | 2577 | 1053 | 1053 | 2577 |
| Exotic trees | 7521 | 7521 | 13614 | 12385 | 15644 | 12986 | 13883 | 12359 |
| Forest | 9192 | 9192 | 9795 | 9673 | 9995 | 9706 | 10012 | 10012 |
| Urban | 3353 | 3353 | 3353 | 3353 | 3353 | 3353 | 3353 | 3353 |
| lake | 8077 | 8077 | 8077 | 8077 | 8077 | 8077 | 8077 | 8077 |
| totals | 48556 | 48556 | 48556 | 48556 | 48556 | 48556 | 48556 | 48556 |
| **Land use areas for all scenarios (%)** | | | | | | | | |
| | **R-0** | **R-P** | **R-250** | **R-300** | **R-350** | **S1-S2** | **S8** | **H1** |
| Dairy | 100% | 100% | 50% | 0% | 0% | 58% | 61% | 61% |
| Drystock | 100% | 100% | 60% | 84% | 60% | 73% | 64% | 64% |
| Lifestyle | 100% | 100% | 245% | 245% | 245% | 100% | 100% | 245% |
| Exotic trees | 100% | 100% | 181% | 165% | 208% | 173% | 185% | 164% |
| Forest | 100% | 100% | 107% | 105% | 109% | 106% | 109% | 109% |
| Urban | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| lake | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| totals | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

## 4.5 Results and discussion

### 4.5.1 Total load estimates

A comparison of the Park (2012) P load estimates with the revised estimates is shown in Table 17. The table provides a relative comparison of status quo, impact of mitigations and impact of expanded future mitigations combined with N reduction related land use changes.

The estimates of P load exports to the lake (t P/yr) and the mitigated scenario change relative to the R-0 P load using different percentage mitigation efficiencies are presented in Tables 17 and 18.

**Table 17. P load estimates for mitigation scenarios using pasture 50% P mitigation (Rere, Tara NBs = Rerewhakaaitu, Tarawera nutrient balances; Tara L. Rest.Plan = Tarawera Lake Restoration Plan; RRAP = Rerewhakaaitu Restoration Action Plan).**

| Original ROTAN scenario (Park, 2012) (RRAP) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **P loss coeft export to lake (RRAP) kgP/ha/yr** | | | | **P loads export to lake tP/yr** | | | | | |
| | R-0 | mitigate | R-P and scenarios | | **R-0** | **R-P** | **R-350** | **S8** | **H1** |
| Dairy | 0.9 | 50% | 0.45 | Dairy | 4.0 | 2.0 | 0.0 | 1.2 | 1.2 |
| Drystock | 0.9 | 50% | 0.45 | Drystock | 13.4 | 6.7 | 4.0 | 4.3 | 4.3 |
| Lifestyle | 0.8 | 50% | 0.40 | Lifestyle | 0.8 | 0.4 | 1.0 | 0.4 | 1.0 |
| Exotic trees | 0.11 | 0% | 0.11 | Exotic trees | 0.8 | 0.8 | 1.7 | 1.5 | 1.4 |
| Forest | 0.11 | 0% | 0.11 | Forest | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 |
| Urban | 0.70 | 20% | 0.56 | Urban | 2.3 | 1.9 | 1.9 | 1.9 | 1.9 |
| rainfall | 0.15 | 0% | 0.15 | rainfall | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Septic tanks | | 50% | | Septic tanks | 1.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| WWTP | | 25% | | WWTP | 1.6 | 1.2 | 1.2 | 1.2 | 1.2 |
| springs | | 0% | | springs | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| | | | | **totals** | **39.5** | **28.9** | **25.7** | **26.4** | **26.9** |
| | | | | reduction Vs R-0 | | 10.6 | 13.7 | 13.0 | 12.6 |

| Original ROTAN scenario (Park, 2012) (Rere/Tarawera draft APs) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **P loss coeft (Rere/Tarawera draft APs) kgP/ha/yr** | | | | **P loads export to lake tP/yr** | | | | | |
| | R-0 | mitigate | R-P and scenarios | | **R-0** | **R-P** | **R-350** | **S8** | **H1** |
| Dairy | 1.1 | 50% | 0.55 | Dairy | 4.9 | 2.5 | 0.0 | 1.5 | 1.5 |
| Drystock | 1.2 | 50% | 0.60 | Drystock | 17.8 | 8.9 | 5.3 | 5.7 | 5.7 |
| Lifestyle | 0.8 | 50% | 0.40 | Lifestyle | 0.8 | 0.4 | 1.0 | 0.4 | 1.0 |
| Exotic trees | 0.40 | 0% | 0.40 | Exotic trees | 3.0 | 3.0 | 6.3 | 5.6 | 4.9 |
| Forest | 0.40 | 0% | 0.40 | Forest | 3.7 | 3.7 | 4.0 | 4.0 | 4.0 |
| Urban | 0.70 | 20% | 0.56 | Urban | 2.3 | 1.9 | 1.9 | 1.9 | 1.9 |
| rainfall | 0.15 | 0% | 0.15 | rainfall | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Septic tanks | | 50% | | Septic tanks | 1.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| WWTP | | 25% | | WWTP | 1.6 | 1.2 | 1.2 | 1.2 | 1.2 |
| springs | | 0% | | springs | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| | | | | **totals** | **49.7** | **36.4** | **34.5** | **35.0** | **35.0** |
| | | | | reduction Vs R-0 | | 13.3 | 15.1 | 14.6 | 14.6 |

| Revised Coeffs - Table 7 (PLRRAP) (D/S adjusted) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **P loss coef. export to lake (RRAP) kgP/ha/yr** | | | | **P loads export to lake tP/yr** | | | | | |
| | R-0 | mitigate | R-P and scenarios | | **R-0** | **R-P** | **R-350** | **S8** | **H1** |
| Dairy | 0.7 | 50% | 0.35 | Dairy | 3.1 | 1.6 | 0.0 | 1.0 | 1.0 |
| Drystock | 0.9 | 50% | 0.45 | Drystock | 13.4 | 6.7 | 4.0 | 4.3 | 4.3 |
| Lifestyle | 0.9 | 50% | 0.45 | Lifestyle | 0.9 | 0.5 | 1.2 | 0.5 | 1.2 |
| Exotic trees | 0.10 | 0% | 0.10 | Exotic trees | 0.8 | 0.8 | 1.6 | 1.4 | 1.2 |
| Forest | 0.12 | 0% | 0.12 | Forest | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 |
| Urban | 0.70 | 20% | 0.56 | Urban | 2.3 | 1.9 | 1.9 | 1.9 | 1.9 |
| rainfall | 0.15 | 0% | 0.15 | rainfall | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Septic tanks | | 50% | | Septic tanks | 1.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| WWTP | | 25% | | WWTP | 1.6 | 1.2 | 1.2 | 1.2 | 1.2 |
| springs | | 0% | | springs | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| | | | | **totals** | **38.7** | **28.5** | **25.8** | **26.2** | **26.7** |
| | | | | reduction Vs R-0 | | 10.2 | 12.9 | 12.5 | 12.0 |

| Revised scenario with P coeffs from Rere and Tara NB, and Rest. Plan | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **P loss coef. (Rere,Tara NBs/Tara L. Rest. Plan) kgP/ha/yr** | | | | **P loads export to lake tP/yr** | | | | | |
| | R-0 | mitigate | R-P and scenarios | | **R-0** | **R-P** | **R-350** | **S8** | **H1** |
| Dairy | 1.1 | 50% | 0.55 | Dairy | 4.9 | 2.5 | 0.0 | 1.5 | 1.5 |
| Drystock | 1.2 | 50% | 0.60 | Drystock | 17.8 | 8.9 | 5.3 | 5.7 | 5.7 |
| Lifestyle | 0.8 | 50% | 0.40 | Lifestyle | 0.8 | 0.4 | 1.0 | 0.4 | 1.0 |
| Exotic trees | 0.18 | 0% | 0.18 | Exotic trees | 1.4 | 1.4 | 2.8 | 2.5 | 2.2 |
| Forest | 0.12 | 0% | 0.12 | Forest | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 |
| Urban | 0.70 | 20% | 0.56 | Urban | 2.3 | 1.9 | 1.9 | 1.9 | 1.9 |
| rainfall | 0.15 | 0% | 0.15 | rainfall | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Septic tanks | | 50% | | Septic tanks | 1.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| WWTP | | 25% | | WWTP | 1.6 | 1.2 | 1.2 | 1.2 | 1.2 |
| springs | | 0% | | springs | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| | | | | **totals** | **45.4** | **32.2** | **28.3** | **29.2** | **29.5** |
| | | | | reduction Vs R-0 | | 13.3 | 17.2 | 16.3 | 15.9 |

| Hybrid scenario with P coeffs based on Rere and Tara NB, and pRRAP | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **P loss coef. (Rere,Tara NBs/Tara L. Rest. Plan) kgP/ha/yr** | | | | **P loads export to lake tP/yr** | | | | | |
| | R-0 | mitigate | R-P and scenarios | | **R-0** | **R-P** | **R-350** | **S8** | **H1** |
| Dairy | 1.00 | 50% | 0.50 | Dairy | 4.5 | 2.2 | 0.0 | 1.4 | 1.4 |
| Drystock | 1.10 | 50% | 0.55 | Drystock | 16.3 | 8.2 | 4.9 | 5.2 | 5.2 |
| Lifestyle | 0.80 | 50% | 0.40 | Lifestyle | 0.8 | 0.4 | 1.0 | 0.4 | 1.0 |
| Exotic trees | 0.27 | 0% | 0.27 | Exotic trees | 2.0 | 2.0 | 4.2 | 3.7 | 3.3 |
| Forest | 0.12 | 0% | 0.12 | Forest | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 |
| Urban | 0.70 | 20% | 0.56 | Urban | 2.3 | 1.9 | 1.9 | 1.9 | 1.9 |
| rainfall | 0.15 | 0% | 0.15 | rainfall | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Septic tanks | | 50% | | Septic tanks | 1.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| WWTP | | 25% | | WWTP | 1.6 | 1.2 | 1.2 | 1.2 | 1.2 |
| springs | | 0% | | springs | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| | | | | **totals** | **44.2** | **31.9** | **29.2** | **29.8** | **30.0** |
| | | | | reduction Vs R-0 | | 12.3 | 14.9 | 14.4 | 14.2 |

**Table 18. P load estimates for mitigation scenarios using dairy 50%, drystock 41%, lifestyle 30% P mitigation.**

**Original ROTAN scenario (Park, 2012) (RRAP)**

| P loss coeft export to lake (RRAP) kgP/ha/yr | | | | P loads export to lake tP/yr | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | R-0 | mitigate | R-P and scenarios | | R-0 | R-P | R-350 | S8 | H1 |
| Dairy | 0.9 | 50% | 0.45 | Dairy | 4.0 | 2.0 | 0.0 | 1.2 | 1.2 |
| Drystock | 0.9 | 41% | 0.53 | Drystock | 13.4 | 7.9 | 4.7 | 5.0 | 5.0 |
| Lifestyle | 0.8 | 30% | 0.56 | Lifestyle | 0.8 | 0.6 | 1.4 | 0.6 | 1.4 |
| Exotic trees | 0.11 | 0% | 0.11 | Exotic trees | 0.8 | 0.8 | 1.7 | 1.5 | 1.4 |
| Forest | 0.11 | 0% | 0.11 | Forest | 1.0 | 1.0 | 1.1 | 1.1 | 1.1 |
| Urban | 0.70 | 20% | 0.56 | Urban | 2.3 | 1.9 | 1.9 | 1.9 | 1.9 |
| rainfall | 0.15 | 0% | 0.15 | rainfall | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Septic tanks | | 50% | | Septic tanks | 1.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| WWTP | | 25% | | WWTP | 1.6 | 1.2 | 1.2 | 1.2 | 1.2 |
| springs | | 0% | | springs | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| | | | | **totals** | **39.5** | **30.2** | **26.9** | **27.4** | **28.0** |
| | | | | reduction Vs R-0 | | 9.2 | 12.6 | 12.1 | 11.4 |

**Original ROTAN scenario (Park, 2012) (Rere/Tarawera draft APs)**

| P loss coeft (Rere/Tarawera draft APs) kgP/ha/yr | | | | P loads export to lake tP/yr | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | R-0 | mitigate | R-P and scenarios | | R-0 | R-P | R-350 | S8 | H1 |
| Dairy | 1.1 | 50% | 0.55 | Dairy | 4.9 | 2.5 | 0.0 | 1.5 | 1.5 |
| Drystock | 1.2 | 41% | 0.71 | Drystock | 17.8 | 10.5 | 6.3 | 6.7 | 6.7 |
| Lifestyle | 0.8 | 30% | 0.56 | Lifestyle | 0.8 | 0.6 | 1.4 | 0.6 | 1.4 |
| Exotic trees | 0.40 | 0% | 0.40 | Exotic trees | 3.0 | 3.0 | 6.3 | 5.6 | 4.9 |
| Forest | 0.40 | 0% | 0.40 | Forest | 3.7 | 3.7 | 4.0 | 4.0 | 4.0 |
| Urban | 0.70 | 20% | 0.56 | Urban | 2.3 | 1.9 | 1.9 | 1.9 | 1.9 |
| rainfall | 0.15 | 0% | 0.15 | rainfall | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Septic tanks | | 50% | | Septic tanks | 1.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| WWTP | | 25% | | WWTP | 1.6 | 1.2 | 1.2 | 1.2 | 1.2 |
| springs | | 0% | | springs | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| | | | | **totals** | **49.7** | **38.2** | **35.9** | **36.2** | **36.5** |
| | | | | reduction Vs R-0 | | 11.5 | 13.8 | 13.4 | 13.2 |

**Revised Coeffs - Table 7 (PLRRAP) (D/S adjusted)**

| P loss coef. export to lake (RRAP) kgP/ha/yr | | | | P loads export to lake tP/yr | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | R-0 | mitigate | R-P and scenarios | | R-0 | R-P | R-350 | S8 | H1 |
| Dairy | 0.7 | 50% | 0.35 | Dairy | 3.1 | 1.6 | 0.0 | 1.0 | 1.0 |
| Drystock | 0.9 | 41% | 0.53 | Drystock | 13.4 | 7.9 | 4.7 | 5.0 | 5.0 |
| Lifestyle | 0.9 | 30% | 0.63 | Lifestyle | 0.9 | 0.7 | 1.6 | 0.7 | 1.6 |
| Exotic trees | 0.10 | 0% | 0.10 | Exotic trees | 0.8 | 0.8 | 1.6 | 1.4 | 1.2 |
| Forest | 0.12 | 0% | 0.12 | Forest | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 |
| Urban | 0.70 | 20% | 0.56 | Urban | 2.3 | 1.9 | 1.9 | 1.9 | 1.9 |
| rainfall | 0.15 | 0% | 0.15 | rainfall | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Septic tanks | | 50% | | Septic tanks | 1.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| WWTP | | 25% | | WWTP | 1.6 | 1.2 | 1.2 | 1.2 | 1.2 |
| springs | | 0% | | springs | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| | | | | **totals** | **38.7** | **29.9** | **27.0** | **27.1** | **27.9** |
| | | | | reduction Vs R-0 | | 8.8 | 11.7 | 11.6 | 10.8 |

**Revised scenario with P coeffs from Rere and Tara NB, and Rest. Plan**

| P loss coef. (Rere,Tara NBs/Tara L. Rest. Plan) kgP/ha/yr | | | | P loads export to lake tP/yr | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | R-0 | mitigate | R-P and scenarios | | R-0 | R-P | R-350 | S8 | H1 |
| Dairy | 1.1 | 50% | 0.55 | Dairy | 4.9 | 2.5 | 0.0 | 1.5 | 1.5 |
| Drystock | 1.2 | 41% | 0.71 | Drystock | 17.8 | 10.5 | 6.3 | 6.7 | 6.7 |
| Lifestyle | 0.8 | 30% | 0.56 | Lifestyle | 0.8 | 0.6 | 1.4 | 0.6 | 1.4 |
| Exotic trees | 0.18 | 0% | 0.18 | Exotic trees | 1.4 | 1.4 | 2.8 | 2.5 | 2.2 |
| Forest | 0.12 | 0% | 0.12 | Forest | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 |
| Urban | 0.70 | 20% | 0.56 | Urban | 2.3 | 1.9 | 1.9 | 1.9 | 1.9 |
| rainfall | 0.17 | 0% | 0.17 | rainfall | 1.4 | 1.4 | 1.4 | 1.4 | 1.4 |
| Septic tanks | | 50% | | Septic tanks | 1.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| WWTP | | 25% | | WWTP | 1.6 | 1.2 | 1.2 | 1.2 | 1.2 |
| springs | | 0% | | springs | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| | | | | **totals** | **45.6** | **34.1** | **29.8** | **30.5** | **31.1** |
| | | | | reduction Vs R-0 | | 11.5 | 15.8 | 15.1 | 14.5 |

**Hybrid scenario with P coeffs based on Rere and Tara NB, and pRRAP**

| P loss coef. (Rere,Tara NBs/Tara L. Rest. Plan) kgP/ha/yr | | | | P loads export to lake tP/yr | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | R-0 | mitigate | R-P and scenarios | | R-0 | R-P | R-350 | S8 | H1 |
| Dairy | 1.00 | 50% | 0.50 | Dairy | 4.5 | 2.3 | 0.0 | 1.4 | 1.4 |
| Drystock | 1.10 | 41% | 0.65 | Drystock | 16.3 | 9.6 | 5.8 | 6.1 | 6.1 |
| Lifestyle | 0.80 | 30% | 0.56 | Lifestyle | 0.8 | 0.6 | 1.4 | 0.6 | 1.4 |
| Exotic trees | 0.27 | 0% | 0.27 | Exotic trees | 2.0 | 2.0 | 4.2 | 3.7 | 3.3 |
| Forest | 0.12 | 0% | 0.12 | Forest | 1.1 | 1.1 | 1.2 | 1.2 | 1.2 |
| Urban | 0.70 | 20% | 0.56 | Urban | 2.3 | 1.9 | 1.9 | 1.9 | 1.9 |
| rainfall | 0.15 | 0% | 0.15 | rainfall | 1.2 | 1.2 | 1.2 | 1.2 | 1.2 |
| Septic tanks | | 50% | | Septic tanks | 1.2 | 0.6 | 0.6 | 0.6 | 0.6 |
| WWTP | | 25% | | WWTP | 1.6 | 1.2 | 1.2 | 1.2 | 1.2 |
| springs | | 0% | | springs | 13.0 | 13.0 | 13.0 | 13.0 | 13.0 |
| | | | | **totals** | **44.2** | **33.5** | **30.5** | **30.9** | **31.4** |
| | | | | reduction Vs R-0 | | 10.7 | 13.7 | 13.3 | 12.8 |

The revised P loads to the lake provided in Park (2012) compare well to the PPRAP and Rere/Tara P coefficient-based estimates; the Revised PRRAP = 40.3 t P/yr vs Original PRRAP = 39.5 t P/yr and the Revised Rere/Tara = 45.6 t P/yr vs Original Rere/Tara = 50.0 t/y. The hybrid scenario using P coefficient values from both the PRRAP and Rere/Tara sources is similar to the Revised Rere/Tara scenario.

The Revised Rere/Tara scenario is 4.4 t P/yr lower that the original, due mainly to the lower P coefficients for forestry. These estimates are more in alignment with the Hamilton et al. (2012) and Tempero et al. (2015) P load estimates (51.2 t P/yr and 48.7 t P/yr respectively), than previous lower estimates. This suggests the P coefficients are likely to be accounting for (at least in part) for the additional particulate P component from high flow events discussed by Tempero et al. (2015).

### 4.5.2 Comparison of scenarios

Catchment P load estimates were compared across the range of base, mitigation and land use change scenarios (Figure 5).

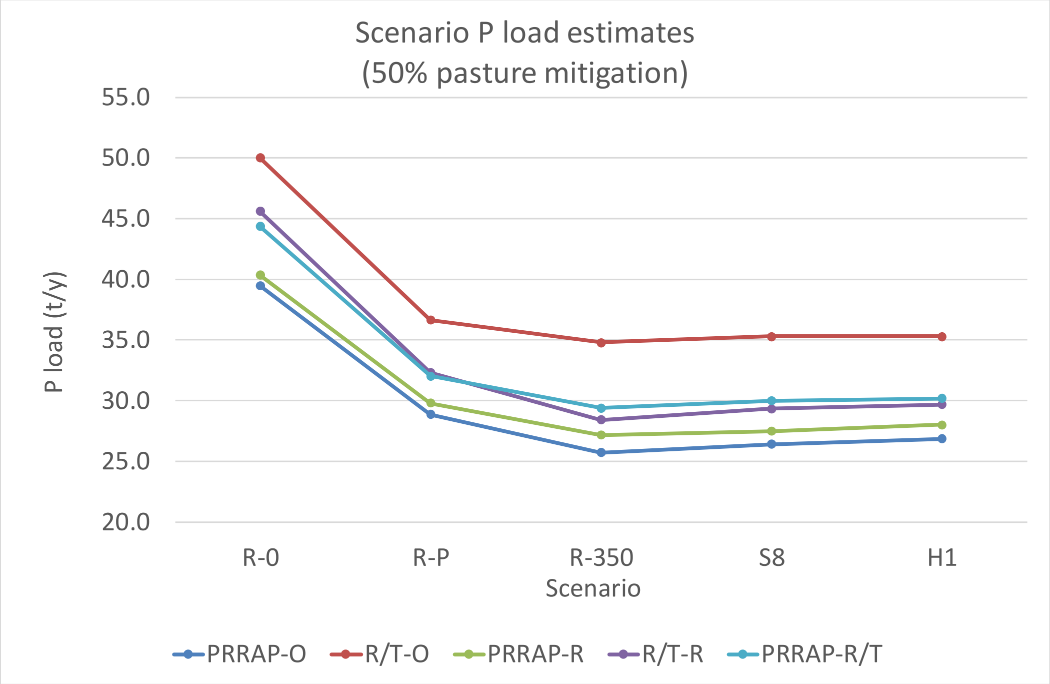

**Figure 5. Catchment P load estimates across the range of base, mitigation and land use change scenarios**

The greatest effect was with the addition of mitigations to the base scenario (from R-0 to R-P). The variability between the scenarios with difference P coefficient source data showed the next greatest effect. The most common were the mid-range (~30 t/y) PRRAP-R/T and R/T-R scenarios. There was minimal collective difference between the ROTAN derived scenario R-350, the N allocation derived scenario (S8) and the hybrid scenario (H1). This partly to be expected as all scenarios involve similar amounts of land use change from pasture (especially dairy) to forest. It also highlights the lower benefit associated with “by-catch” (land use changes are primarily focussed on N reductions). In the same way it is promising, as it may provide flexibility in selecting a future land use change scenario that can align with the best economic outcome for the catchment (the goal of scenario S8 derived from Parsons et al., 2015), as well as achieving a required P reduction target. Overall, implementing land-based P mitigations and achieving high effectiveness (through the correct selection and placement of mitigations for individual farm systems) is likely to provide a credible contribution to catchment P reductions.

As with the original P mitigation model developed by Park (2012) this revision of the model relies on multiple assumptions. Where possible assumptions have been based on published data as opposed to expert knowledge. The model is largely based around the findings of McDowell and others (noted in McDowell, 2010) that P mitigation levels up to 50% on pasture land are credible. The model developed by Park also supports this.

This revised spreadsheet-based P mitigation model provides a broader range of scenarios; evaluating different combinations of P coefficients, mitigation effectiveness and land use change scenarios. A major development is the inclusion of land use change scenarios that are based on economic scenarios of Parsons et al. (2015) – one of which (S8) has been developed by a catchment stakeholders group.

From the assessment in this revised model, there are scenarios that look to provide more credible options for achieving a P reduction target through land-based P mitigation (Table 19).

**Table 19. Preferred scenario components.**

| Scenario component | Preferred scenarios: Rationale |
|---|---|
| P coefficients | **R/T-R**: Includes (most) recent P coefficient estimates (2012). Use of the mid-range co efficients for forestry seems more reasonable than the 0.4 values – which is more representative of P loss during forest the harvesting cycle.<br>**PRRAP-R/T**: Combines the most commonly used coefficients for each land use and for forestry averaged coefficient based on range of values as well as aligning with the pine pasture ratio of 0.25. |
| | The P load estimates for these base scenarios were 45.6 t P/yr (R/T-R) and 44.3 t P/yr (PRRAR-R/T). These P loads lie mid-point between the current range of estimates from the literature. |
| Mitigations | The **Base** (50%, 50% 50%) and **MID** (50%, 41%, 30%) combined P mitigation scenarios provide mitigation effectiveness that achieves the P reduction target and is likely credible. An average P mitigation combination of 40% and greater should be sought. |
| Land use | All of the land use scenarios include reduced pasture area and increased forest area. The range of P reductions was shown to be less variable than the effect of different land use coefficients and mitigation combinations. The preferred scenarios are **S8** and **H1**. Their alignment with the economic N allocation scenarios of Parsons et al. (2015) is likely to be favourable for future land use change to achieve N reduction targets as well as P reduction target. |

The combination of the preferred scenarios provides the P load reductions presented in Table 20. All P load reductions fall within the estimated anthropogenic P reduction target range of 10-15 t P/yr in Tempero et al. (2015) or would be sufficient to achieve a TLI target of 4.2 - previously estimated to require a reduction to a TP load of 34.5 t P/yr from the catchment (allowing 3 t P/yr from sewage).

**Table 20. P load reductions for selected scenario combinations.**

| Scenarios and estimated P load (change attributed to rural land use) (t P/yr) | | | | | | |
|---|---|---|---|---|---|---|
| | | Base mitigation (dairy = 50%, drystock = 50%, lifestyle = 50%) | | | MID mitigation (dairy = 50%, drystock = 41%, lifestyle = 30%) | |
| P Coeffs. | R-0 | R-P[1] | S8 | H1 | S8 | H1 |
| R/T-R | 45.6 | 32.3 (13.3) | 29.3 (16.3) | 29.7 (15.9) | 31.2 (14.4) | 30.5 (15.1) |
| PRRAP-R/T | 44.3 | 32.0 (12.3) | 30.8 (13.8) | 30.2 (14.1) | 31.6 (12.7) | 31.1 (13.2) |

[1] Includes a 1 t/yr reduction from non-rural land use sources

The percentage reductions for the S8 scenario range between 29.8% and 35.7%. This range is slightly lower the estimates of Park (2017) and the revised analysis in this report (32% and 40%

respectively) and could represent the importance of targeting P mitigation s to specific soil /land use change combinations.

Previous estimates of catchment phosphorus load to Lake Rotorua are summarised in Table 21.

**Table 21. Previous estimates of catchment phosphorus load to Lake Rotorua (adapted from Hamill 2018 -modified from Rutherford 2008). DRP = dissolved reactive P, TP = total P.**

| Source | Year (data) | DRP (t/yr) | TP (t/yr) | Note |
|---|---|---|---|---|
| Hoare 1980a | 1976-1977 | | 35.6 - 37.4 | Excluding sewage and flood flows, but include septic tanks |
| Hoare 1980a | 1976-1978 | | 42.6 - 44.9 | Excluding sewage but incl. septic tanks, including flood flow PP |
| Rutherford et al, 2011 | 1967-77 | | 33-44 | Excluding sewage and flood flow PP |
| Rutherford et al. 1989 | 1976-77 | | 34 | Excluding sewage and flood flow PP |
| Morgenstern | 2005 | | 39.1 | Including sewage |
| Park 2012 | 2005 | | 39.8 | Co-efficients from Table 7 PRRAP |
| Hamilton et al. 2012 | (2001-2012) | | 51.2 | CLUES |
| Tempero et al. 2015 | (2007-2014) | 27.7 | 48.7 | Includes sewage and flood flow PP |
| Hamill 2018 | (2007-2014) | 24.7 | 46.0 (42.2)[1] | Includes sewage and flood flow PP |
| This report | 2018 | | 44.3-45.6 | Revised Park (2012) |

[1] Long term adjusted

Tempero et al. (2015) and other comments relating to storm events suggest that the estimates overall are likely underestimating the particulate P contribution to the P load. The load estimates using the Catchment Land Use for Environmental Sustainability (CLUES) model (Hamilton et al., 2012) may be accounting for this in their higher load estimate (51.2 t/y) – via the combination of the parameters in the empirical sediment sub-model with CLUES.

Hamill (2018) estimated the proportion of anthropogenic P load to Lake Rotorua for the whole catchment as 17.4 to 19.9 t/yr (38%-43% of total P load) and by Lake Rotorua sub-catchment (Figure 6). The catchments with the highest area specific anthropogenic TP loads were Waiohewa (0.59 kg/ha/yr), Puarenga (0.59 kg/ha/yr), Utuhina (0.57 kg/ha/yr) and ungauged (0.5 to 0.56kg/ha/yr). Hamill suggested (with caution for the ungagged catchments) the sub-catchment estimates could contribute to prioritising P mitigation across the Lake Rotorua catchment.

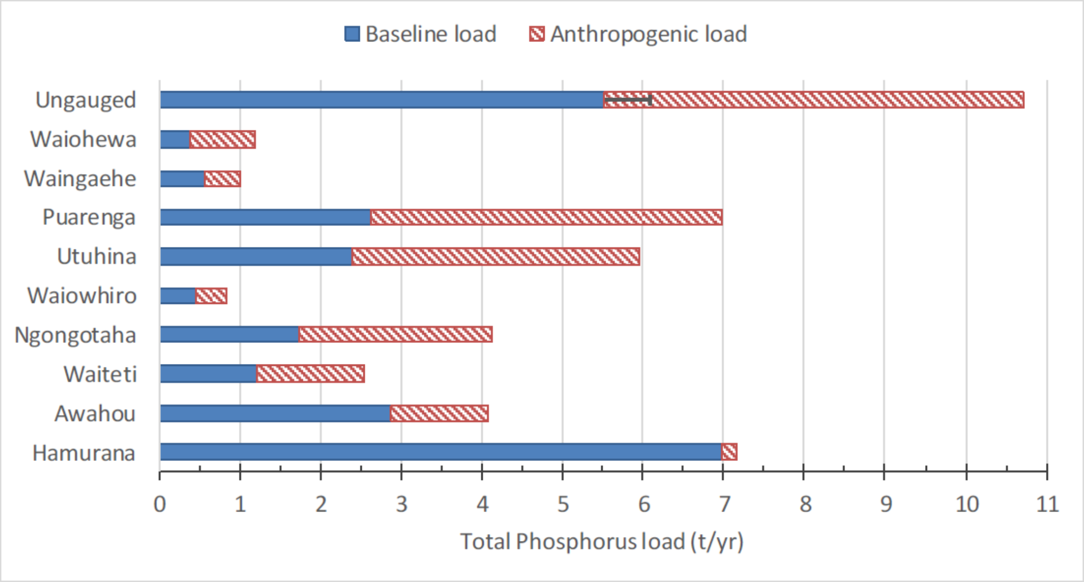

**Figure 6. Proportion of anthropogenic P load for Lake Rotorua sub-catchments (Hamill 2018).**

Overall, the revised model provides catchment P load estimates in line with recent estimates, including the recent estimate of 46.0 t P/yr provided in this science review Hamill (2018). There is support for the potential and credible contribution of land-based P mitigations towards reducing the anthropogenic P load in the catchment, provided that a mitigation effectiveness of greater than 40% for pasture land use is achieved. The P 'by-catch' through N mitigations (mainly associated with land use change) are likely to contribute less to P loss reductions than P mitigation strategies applied to current land use, if a sufficient level of efficacy can be achieved.

# 5 Discussion

The mitigation strategies provided by McDowell (2010) specifically for the Lake Rotorua catchment remain applicable and robust.

Maintaining optimum soil Olsen P levels, managing farm dairy effluent, using low-solubility P fertiliser and managing CSAs, especially in ephemeral watercourses and steep slopes remain the key P mitigation strategies for reducing P loss from rural land. The basis for this is the established use in publications, refined effectiveness estimates and the inclusion in OVERSEER®.

Key to their uptake is the ease of implementation and cost effectiveness (viz. mitigating close to source and having minimal impact on farm profit). These criteria should be considered when adopting future mitigations.

Although the suite of P mitigation strategies is broad, there are new "untested" strategies that could be considered in the near future. Of these, the detainment bunds look to show potential; based on P retention but mainly on the location and area of application in the catchment. Other well documented strategies are mitigations are those reducing sediment on CSAs. However, the lack of current ability to locate and management these at farm scale, remains challenging. The emergence of spatial management tools (e.g. MitAgator should improve this).

P mitigation strategy combinations as presented in McDowell (2010) and McDowell et al. (2017) are a good guide to successive implementation of P strategies to reduce P loss. However, knowing the specific characteristics of individual farms (topography, soil type, soil P levels, soil ASC and the dominant form of P loss) will all improve mitigation targeting and efficacy. In general, soil P levels is of primary importance, both for particulate P loss and DRP P loss.

Mitigation effectiveness and the potential to achieve a net effectiveness level of 50%, was assessed using P mitigation inclusions in OVERSEER® with various P mitigations to compare P loss outputs and using mitigation strategy combinations (with implicit successive implementation). Both approaches included multiple assumptions (especially estimates of individual mitigation effectiveness and % area of application), which detract from the robustness of individual estimates. However, collectively the range of P loss reduction estimates does provide a sufficient guide to determine the likely potential of mitigations to contribute to P loss reduction in the catchment. In general results suggested a P mitigation effectiveness range of between 30% and 50% and a mean effectiveness of 40% was credible. This is lower than the 50% commonly stated in the literature. However, the commonly stated 50% is predominantly based on dairy examples and given the mix of pasture in the Lake Rotorua catchment includes drystock and lifestyle land uses, a lower effectiveness percentage is plausible. P mitigation effectiveness decreases from dairy to drystock to lifestyle, likely reflecting a decreasing range of available mitigation strategies from dairy to drystock to lifestyle land use. In general, successively implementing three to five P mitigation strategies is likely to achieve close to 40% effectiveness.

The revision of the spreadsheet based P load model of Park (2012) P loss provided a catchment P load to Lake Rotorua of between 44.3 and 45.6 t P/yr, depending on the combination of land use P loss coefficients and mitigation efficacies used. This aligns well with the 42.2 t P/yr long term adjusted estimate by Hamill (2018) as part of this science review, and within the range of previous P load estimates by various authors. It is important to note that the Park (2012) model is simplistic in approach and is highly sensitive to land use coefficient and efficacy adjustments. However, it does provide an additional independent estimate of catchment P load. Additionally, the future scenarios (S8 and H1) provided insight into the potential for rural land-based P mitigations contributing to required catchment P loss reductions, as part of N loss based reduction scenarios. The results suggested a ~30% reduction (from status quo; R-0) was plausible, with a range of 12.3-13.3 t P/yr under current land use with P mitigations implemented, and a range of 12.7-16.3 t P/yr under future land use scenarios with P mitigations implemented. These estimates suggest achieving a P load of between 30 and 35 t P/yr is achievable through land based P mitigation strategies, even if a future N based reduction scenario is implemented. However, caution is still required, especially around the assumptions associated with the land use P loss coefficients and mitigation % effectiveness values used.

Of the land use P loss coefficients used, the forestry P coefficients were the most variable across the literature and had the most associated uncertainty. Given the suggested changes from pasture to forestry in the future scenarios, the impact of the forestry values used will impact on the results and follow through to any subsequent decisions based on the results.

The other key point is that adequate P reductions to achieve P load targets are not achievable through targeting N load alone (i.e. there is a reduced P load associated with N mitigation - termed P “by-catch”) and targeted P mitigation strategies area required.

Implementing P specific mitigation strategies is essential to achieving P loss reductions. Although the approach is simplistic, the proportion of the P loss reductions associated with the mitigations is in the range 12.3 to 13.3 t P/yr vs a range of 0.4 to 3.0 t P/yr for the P loss reductions associated with the future land use change (excluding the mitigations).

The expansion of the nutrient management plan to include both N and P is a progressive step towards achieving improved efficacy P loss reduction efficacy. Inclusion of spatially identified risk areas in NMPs enables targeting P loss from CSAs.

The main limitation of the NMP (with regard to P mitigation), is the lack of requirement for quantification of P reductions, either through the inclusion of P loss changes provided in OVERSEER® outputs or documented and mapped on-ground mitigation actions. The lack of spatial data (or at least) progress data through time is a lost opportunity. Capture of farm scale mitigations spatially, could be used to inform policy implementation effectiveness, monitor implementation and NMP compliance and refine nutrient modelling and load estimates.

# 6 Recommendations

The following recommendations for improving data and information on P loss and P mitigation strategies specific to the Lake Rotorua catchment are:

**Research**

- Improved monitoring data for Olsen P (via soil tests and preferably in a maintained database) for all farms (potentially at block level for use in OVERSEER®).
- The current soil testing frequency suggested in the NMP template is sufficient, given reductions in soil Olsen P of 1-2 units/year are likely following mitigation implementation.
- Ensure good capture (preferably in a maintained database) of and monitoring of the state of Farm Dairy Effluent (FDE) storage and land application data.
- Continue to maintain connections with P mitigation research and promote and support mitigation research within the Lake Rotorua catchment to assess the local applicability of P mitigations (for example, detainment bunds).
- Support the development of multi-scale spatial approaches to prioritising P (and N) mitigation placement to better target P sources, P form and P loss pathways.
- Support research to better understand the changes in P loss associated with the different stages of forestry, from harvest to forest maturity. Research across the range of forest soils in the Lake Rotorua catchment is likely requirement as well.
- Support the investigation of the increasing trend in particulate P identified in (Dare, 2018) with a focus on long term drivers (e.g. climate change), and P generation sources and transfer pathways.

**P related GMP and policy**

- Target P reductions alongside N reductions (i.e. a dual nutrient reduction approach) given that the P load target is not achievable through P “by-catch” associated with N focussed mitigation alone.
- Explore the opportunity to improve data on P mitigation associated with forestry management (possibly via the NPS-PF).

- Build on the existing Nutrient Management Plan template to increase the quantitative and measurable capture of P nutrient inputs, mitigations and outputs, similar to N capture.

- Improve and support soil map information, regionally and where possible, at farm scale to improve nutrient budget estimates as well as NMP implementation.

**Monitoring and auditing**

- Monitor and report P mitigation implementation and loss data (initially via nutrient budgets in the NMP) for all farms in the Lake Rotorua catchment and refine the criteria around the collection, recording, storage of data, as well as NMP implementation monitoring and auditing.

- Future opportunities could include developing the geospatial database to include implemented P mitigation actions and P losses through time.

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