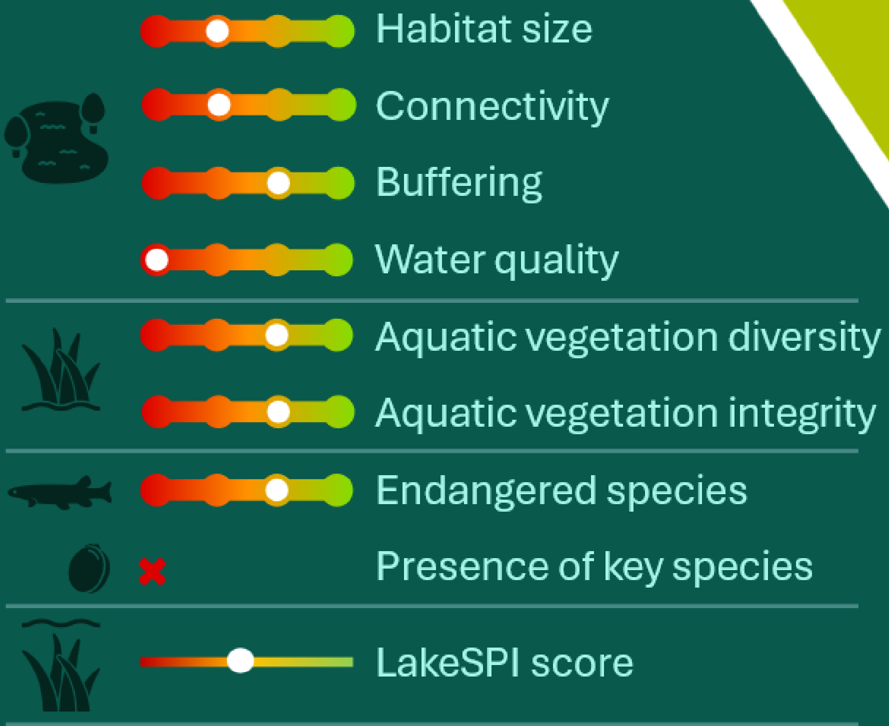
Rotokawau (Sweetwater)

01/05/2024

NRC Lake Number: 116



ECOLOGICAL VALUE SCORE

11 /20

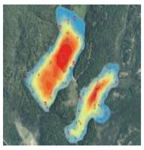
Overall Rank: High

Key impact	Management action
Eutrophication: There are signs of nutrient enrichment from the pasture dominant catchment.	Develop a farm environment plan and use the management tool box for immediate interventions.
Invasive Species: The lake is easy to access so the risk of invasive species introductions is high.	Limit access to the lake and increase biosecurity awareness.
Stock access: Stock have damaged the riparian margin through grazing and pugging.	Exclude stock and allow the riparian vegetation to regenerate.

Did you know:
This lake has a population of the nationally critical *Trithuria inconspicua* in the Te Hiku area.

Northland Regional Council
Te Kaunihera ā rohe o Te Taitokerau

Report card glossary



Habitat size: This score is based on the size and depth of the lake. Large deep lakes are more stable because they have a greater dilution capacity and a larger area to support different habitat types.

Connectivity: This score considers the number of nearby lakes and wetlands. This connectivity is important as several threatened birds travel between waterbodies that form a network of habitats across the landscape.

Buffering: This score is based on the riparian vegetation around the lake and how much native vegetation and wetlands there are in the catchment. This vegetation filters pollutants entering the lake from the surrounding land.

Water quality: This score is based on the nutrient concentrations in the lake. Higher nutrient concentrations typically result in a poor level of ecological health and is often associated with murky water and algal blooms.

Aquatic vegetation diversity: This score is based on how many different species of aquatic plants live in the lake. Lakes with a high diversity of aquatic plants are usually in better ecological condition.

Aquatic vegetation integrity: This score is based on the extent, diversity and condition of native submerged plant. Fully vegetated lakes with a high species diversity are often in the best condition.

Endangered species: This score is based on how many endangered plants and fish live in this lake. Endangered species add value to the ecosystem and are an indicator of good ecological health.

Presence of key species: This score is based on the presence of freshwater mussels (kakahi or torewai). These mussels are important for lake health because they filter the lake and remove algae.

LakeSPI: This score is based on the health, density and extent of native and exotic submerged plants in the lake. This score also integrates the impact of invasive submerged plants.

General description

Rotokawau (Sweetwater) was assessed during the following years: 1985, 1988, 2001, 2004, 2009, 2014, 2019 and 2024.

Rotokawau (Sweetwater) is a moderate-size (14.3 ha), shallow (3.1 m) dune lake adjacent to the southern end of the Rangaunu Harbour (35°01'07"S 173°12'19"E). The lake forms part of a wetland/lake complex that extends west and includes several unnamed waterbodies and the larger Lake Ngatu.

Lake Rotokawau (Sweetwater) - Southern view indicating the extensive emergent vegetation, pasture dominant land use and exotic shelter belt that borders the western end of the lake

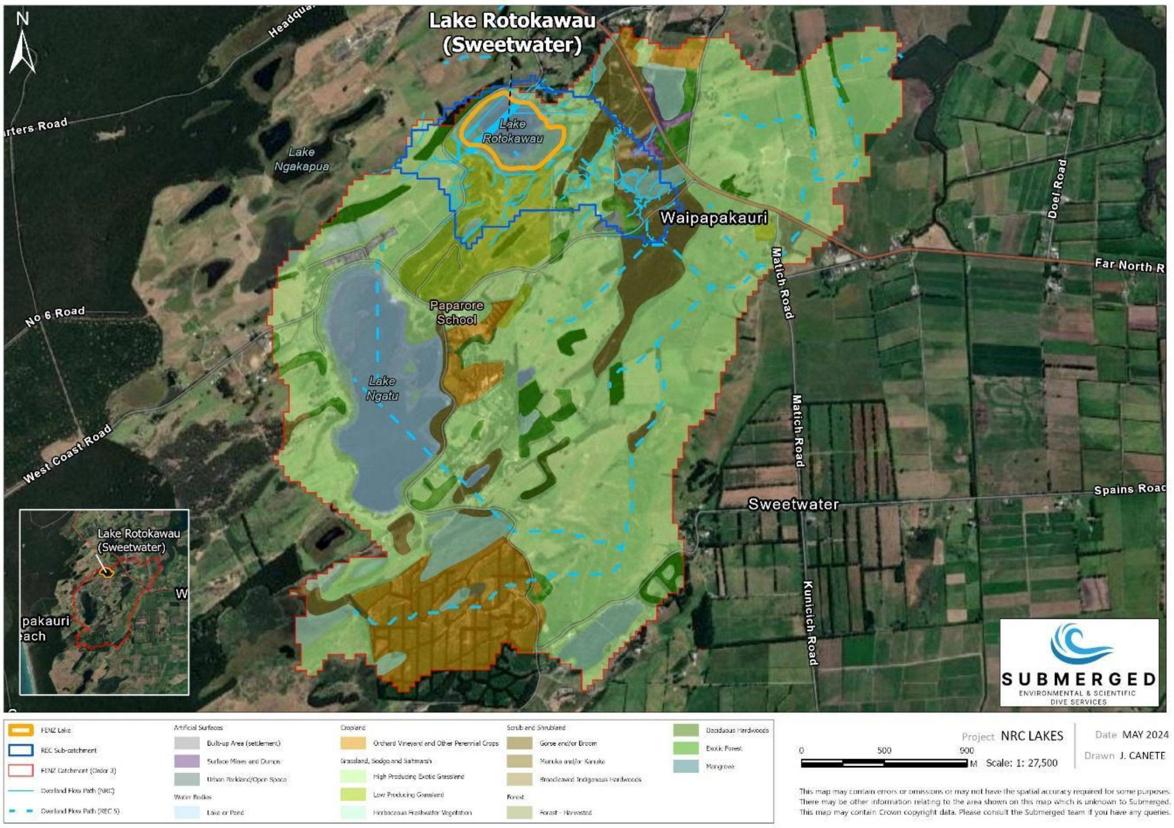
Catchment & sub-catchment description

The 793.46-hectare catchment consists of 76% exotic vegetation. Pasture (62% of the catchment area) is the dominant land cover followed by three orchards/perennial crops (9%) and slivers of exotic forestry and deciduous hardwoods (5%). The exotic forestry and hardwoods exist as shelter breaks rather than production forestry blocks which lessens their overall impact on the catchment waterways. Native vegetation makes up

14% of the total catchment and 8% of that is classified as wetlands. There is a patchwork of wetlands across the catchment however, most of these are not in line with the overland flow paths that drain into the lake. As a result, they do not provide significant catchment level buffering.

The 87.57-hectare sub-catchment is largely pastoral (48%) with exotic shelter belts (7%) and pockets of manuka/kanuka scrub (11%) downstream of the lake. The most significant native vegetation feature in the sub-catchment is the lacustrine wetland that surrounds the lake (17% of the total sub-catchment). This wetland provides significant buffering capacity and biodiversity values.

Despite the high impact catchment land use, the lake is well buffered by an extensive lacustrine wetland, shelterbelts, and a lower intensity of grazing in the surrounding pasture. As a result, the land use related impacts are likely to be less significant than in other lowland lakes with agricultural catchments.



Rotokawau (Sweetwater) catchment land cover and overland flow network

In-lake description

The lake was isothermal at the time of the survey but was noticeably warmer in the shallow areas amongst the emergent vegetation.

The water clarity was good and underwater visibility was estimated at 3 m throughout the lake. As a result, the whole lake was within the photic zone and macrophytes grew across almost the entire lakebed.

The bathymetry resembles a shallow bowl with a gradual slope from the shore toward the maximum depth. The lake margin is wide and shallow with extensive emergent vegetation growth.

The substrate in the shallows (0.1 – 1.5) was firm, coarse, and sandy however, there were discrete pockets of softer sediment amongst the emergent vegetation. A surficial layer of fine silt developed at 1.5 m and gradually became thicker toward the maximum lake depth. The substrate in the centre of the lake was looser and had a thick layer of fine silt and highly mobile organic floc below the macrophytes. The eastern portion of the lake appears to be a deposition zone, it was shallower, and the accumulation of sediment extended into the centre of the lake where it formed a large bare patch. Macrophyte cover throughout this area was sparser than the rest of the lake. Recent deposits of sediment were also noted in the southwestern sections of the lake. The macrophytes in these areas were smothered but still green and firm indicating that the burial had occurred recently. The exact reason for this sediment deposition is not known however it does seem to correspond with areas that have less emergent vegetation and are bordered by bare slopes with noticeable erosion issues.

The general in-lake conditions reflect a relatively healthy lake with an almost completely vegetated lakebed, low cover of benthic algal growth, limited signs of persistent anoxia, and low concentrations of suspended and deposited organic matter.

Wetland vegetation

Majority of the lake (~90%) was bordered by a wide band of *Eleocharis sphacelata that* extended 10 - 30 m into the water, reaching depths of up to 2 m. Other species included *Machaerina arthrophylla, Machaerina articulata, Machaerina juncea, Apodasmia similis,* and *Eleocharis acuta*.

A small patch of raupo (*Typha orientalis*) was noted for the first time in 2014 but was not seen during the 2024 survey.

Submerged vegetation

The submerged vegetation grew across most of the lakebed (~95%) from 0.1 – 3.1 m deep. The macrophyte cover was sparse in and around the wide band of emergent vegetation but charophytes formed tall dense beds below 1.2 m deep.

Turf communities were not represented as highly as in previous surveys however. The Threatened - Nationally Critical *Trithuria inconspicua* still occurs in reasonable covers along the shallow northern shore and a small patch of *Glossostigma elatinoides* was seen along the western bank.

Utricularia gibba was the only exotic macrophyte detected and it dominated the submerged vegetation assemblage. It formed tall (70 – 100 cm), dense covers of more than 95% in most parts of the lake and the overall lake wide cover was estimated at 76 - 95%. Despite forming thick blankets over the charophyte beds, this invasive species did not appear to be affecting the underlying macrophyte condition.

Chara fibrosa was the dominant native species and formed dense meadows across the lakebed with small stands of *Chara australis* sparsely distributed in between. *Chara fibrosa* formed high covers (76 - 95%) in sections of the lake and established from the base of the emergent vegetation (0.3 m) to the maximum lake depth (3.1 m). The average lake wide cover was estimated at 6 – 25% and the highest covers were seen in the shallows (0.8 – 1.4 m).

Chara australis was found throughout the lake where it formed low covers (< 25%) amongst the *Chara fibrosa* and *Utricularia gibba* beds. The average lake wide cover was estimated at 1 – 5% with the larger stands occurring along the deeper contours (1.5 – 3.1 m). The tallest stands reached 85 cm, but the average height was 40 cm and was often overgrown by taller *Chara fibrosa* and *Utricularia gibba*.

Potamogeton cheesemanii was common across the lake but rarely formed significant covers. Some large stands reached maximum covers of 51 – 75% but the lake wide average was 1 – 5%. Most of the growth was seen as either short stems at the base of emergent vegetation (1.1 – 1.2 m) or as discrete stands along the deeper sections of the charophyte and *Utricularia* beds (~ 2 m). Tall, isolated stems were also seen amongst the shallower charophyte and *Utricularia* beds, but the covers were insignificant. The established stands reached heights exceeding 1 m, but the majority of the growth had an estimated height of 75 cm.

The macrophyte condition was good despite the overgrowth of *Utricularia gibba* and there was limited benthic algal matting and epiphyton. Macrophyte burial had occurred in a few parts and as a result there are now bare patches of lakebed.

The nationally critical *Utricularia australis* was present at low covers during the 2014 survey and an intensive lake wide search was done during the 2024 assessment but none was found. The proliferation of *Utricularia gibba,* loss of species diversity and diminishing covers of native charophytes are a concern for the future state of the lake.

LakeSPI

Rotokawau (Sweetwater) is categorised as being in moderate condition with a LakeSPI Index of 45%. The 2024 LakeSPI score is higher than the 2014 assessment due to the increase in the maximum vegetated depth extent from 2.7 m to 3.1 m. All the assessments to date are similar and portray a relatively stable lake state with a high degree of invasive species impact resulting from the proliferation of *Utricularia gibba*.

The maximum Potential Native Condition Score for this lake is 15 and the current assessment score is 7.75 (Native Condition Score of 51.67%). This score is reflective of the predominantly native species assemblage and the vegetated depth extent reaching the maximum lake depth. The maximum Potential Invasive Condition Score is 27 with a current assessment score of 16.0 (Invasive Condition Score of 59.26%). This is largely due to the widespread establishment of *Utricularia gibba* across the lake. The maximum Potential LakeSPI Score is 35 and the current score is 15.75 (total LakeSPI Score of 45.0%). This score appears low considering the fully vegetated nature of the lake however, the proliferation of *Utricularia gibba,* loss of species diversity, and diminishing covers of native charophytes reduce the overall score.

Rotokawau (Sweetwater) LakeSPI scores as a percentage of the maximum Potential LakeSPI score, Native Condition Index, and Invasive Impact Index

Survey Date	Status	LakeSPI %	Native Condition %	Invasive Impact %
May 2024	Moderate	45	52	60
May 2014	Moderate	36	37	68
April 2009	Moderate	42	50	63
Nov 2004	High	56	70	51

Figure 17: Rotokawau (Sweetwater) LakeSPI survey transects

Wetland birds

Three black swans (*Cygnus atratus*), several mallards (*Anas p. platyrhynchos*) and a large flock (c.80) of Canada geese (*Branta canadensis maxima*) were seen on the lake. Five little shags (*Microcarbo melanoleucos brevirostris*) and a single weweia (dabchick) (*Poliocephalus rufopectus*) were the only threatened birds seen during the 2024 survey.

The extensive emergent beds and adjacent scrub areas provide good habitat for wetland birds and the following priority conservation species have been sighted near the lake between 2009 – 2020: weweia (dabchick) (*Poliocephalus rufopectus*), matuku

(Australasian bittern) (*Botaurus poiciloptilus*), grey duck (*Anas superciliosa superciliosa*), black shag (*Phalacrocorax carbo novaehollandiae*) and white heron (*Ardea alba*).

The lake is 1 km away from Lake Ngatu which is a hotspot for wetland birds with matuku (bittern) being recorded between 1969 - 1991. Matuku (bittern) were recently recorded 7 km southeast of the lake in 2019 and 15 km northeast in 2021. Black Shag and mātātā (fernbird) have been regularly sighted across the northern part of the region since 2014. White heron have been sighted between 2013- 2021 near Spirits Bay and Rangaunu Bay estuary so it is possible that they use wetlands/lakes across this part of the region. weweia (dabchick) and black shags were sighted at the lake and the surroundings including Lake Ngatu from 2008 – 2023.

Fish

Common bullies (*Gobiomorphus cotidianus*) and the exotic pest fish gambusia (*Gambusia affinis*) were abundant and have been observed during previous assessments.

There have been historic reports of a landlocked population of inanga (*Galaxias maculatus*) although none have been recorded during any of the lake ecological surveys.

Aquatic invertebrates

Water boatmen (*Sigara arguta*) and common macroinvertebrate taxa were abundant, the introduced snail *Physella acuta* was also seen during the 2024 survey.

No freshwater mussels were found and there is no record of them in this lake. The in-lake conditions are suitable and there are high numbers of host fish so it is possible that these key species could establish in the lake if introduced. The limiting factor would be the extent of submerged vegetation cover, mussels typically prefer sandy non-vegetated beds so there is limited habitat availability in Rotokawau.

Endangered species

The Threatened - Nationally Critical *Trithuria inconspicua*, recorded in 2019, was still present in 2024. Plants occupied an area of 30 m^2 in 0.1 m deep water. An average cover of 8% was estimated based on an assessment of five representative 25 x 25 cm quadrats in the area. The total population was assessed as containing 2,650 individuals. This compares with the 2019 assessment of 600 m^2 of habitat, with an average cover of 10%. In 2024, deeper water adjacent to the *Trithuria inconspicua* population was occupied by dense submerged growths of the non-native *Juncus bulbosus*. The *Trithuria inconspicua* population appears to rely on disturbance from horse grazing to keep taller vegetation (both emergent and other submerged species) from displacing the low stature *Trithuria inconspicua.*

Little shags (*Microcarbo melanoleucos brevirostris*) (At Risk - Relict) and weweia (dabchick) (*Poliocephalus rufopectus*) (At Risk - Nationally Increasing) were the only threatened birds seen during the 2024 survey.

Lake ecological value

Rotokawau (Sweetwater) was assessed as having “High” ecological value with a score of 11 out of 20. This score was based on the almost fully vegetated lakebed, presence of the Threatened - Nationally Critical *Trithuria inconspicua,* and buffering from the surrounding emergent vegetation.

Rotokawau is a moderate size (14.3 ha), shallow (3.1 m) dune lake, so it scores a 1.5 out of 3 for the Habitat Size metric. There are several large lakes, including Lake Ngatu, as well as smaller waterbodies and wetland complexes west of Rotokawau, so it receives an additional point for connectivity to other waterbodies.

The lake scores a 2 out of 3 for the Buffering Metric, it has extensive emergent vegetation around the entire lake perimeter and a large amount of wetlands in the catchment relative to the lake size. The wider catchment consists of 76% exotic vegetation (62% pasture & 5% forestry) which reduces the buffering score.

No recent water quality data is available for the lake, so it is automatically assigned a 0 out of 3. This is done to ensure a standardised approach when scoring unmonitored lakes and is representative of the worst-case scenario. From the in-lake observations, it is likely that the lake is in a mesotrophic state.

The lake scores a 2 out of 3 for the Aquatic Vegetation Diversity Metric because 19 indigenous emergent, free-floating, and submerged vegetation species were recorded during the survey.

The Aquatic Vegetation Integrity metric is taken from the LakeSPI Native Condition and the resulting score is a 2 out of 3. This score is reflective of the predominantly native species assemblage and the vegetated depth extent reaching the maximum lake depth.

The Threatened - Nationally Critical *Utricularia australis* was not seen during the 2024 survey despite being present in 2014. The Threatened - Nationally Critical *Trithuria inconspicua* has re-established in 2024 and is one of the three known populations in Te Hiku lakes. The presence of this rare species means the lake scores a 2 out of 3 for the Endangered Species Metric. No endangered fish were seen during the survey, but matuku (bittern), weweia (dabchick), and mātātā (fernbird) have been regularly reported. Considering the number of wetlands and waterbodies in the wider catchment, Rotokawau (Sweetwater) is likely used by a variety of threatened wetland bird species.

Overall, the lake appears to be in a stable condition but exhibits signs of deterioration in the form of increased establishment of *Utricularia gibba*, loss of Threatened - Nationally Critical *Utricularia australis,* large deposits of sediment, and nutrient enrichment from the pasture dominant catchment.

Threats

Lake Rotokawau (Sweetwater) is moderate in size and shallow, so it cannot adequately dilute inflowing contaminant loads from the pasture dominant catchment. The wide vegetated riparian margin provides a good level of buffering, but there are signs of stock access along parts of the lake which reduces the riparian buffering capacity.

Considering the high impact catchment land use and the direction of overland flow, the sediment and nutrient loads entering the lake are likely to be high however, the extensive submerged vegetation is performing critical nutrient and sediment attenuation functions, and the lake is likely to be in an upper mesotrophic state.

The lakebed is almost entirely vegetated however a large portion of this is the invasive *Utricularia gibba.* This pest species is out-competing native macrophytes and has displaced the majority of the native short-growing shallow-water macrophytes.

Access to the lake is through private land which minimises the risk of further exotic plant introductions but the proximity to the road means there is still a significant risk.

Management recommendations

The primary threats to Rotokawau (Sweetwater) are invasive species, stock access, and eutrophication. The following management actions are recommended:

Stock exclusion

There are signs of stock access along the lake margin and riparian vegetation damage. Excluding stock will prevent erosion, stabilise the lake margin and allow riparian vegetation to establish.

Land/farm management plan

The impacts from the surrounding pasture can be managed through an effective land/farm management plan. An initial assessment should be done to identify intermittent/ephemeral waterways entering the lake, key areas of diffuse overland flow, critical source areas for contaminants, and land use activities that do not follow best practices. Management interventions can then be selected from Management tool box section to minimise the impacts from the catchment.

Pathways assessment & biosecurity control plan

High-risk invasive species occur in several waterbodies across the region, so it is essential that the incursion pathways are identified, and a plan is developed to limit new incursions. Direct communications with the landowners, iwi, local hunters/fishermen, and wider engagement with industry bodies (Fish & Game, local hunting and fishing clubs) is recommended as a first step.

Routine monitoring

Rotokawau still has a fully vegetated lakebed and a population of the Threatened - Nationally Critical *Trithuria inconspicua*. There has been a reduction in native macrophyte diversity and an increase in invasive *Utricularia gibba* cover. This coupled with deteriorating water quality can result in rapid changes in lake health. It is recommended that routine monitoring includes monthly water quality sampling as well as 3 – 5 yearly ecological assessments and invasive species surveillance.

Management tool box

The interventions are grouped in tables (tool box) according to the contaminant they manage. Phosphorus, nitrogen, sediment, and *E. coli* were identified as the primary contaminants that drive deteriorating lake health.

The management interventions in the tool boxes are listed in order of efficacy and cost effectiveness e.g., the first option in the table is the most efficient and/or cost-effective way to manage that specific contaminant whereas, the last option is the least efficient and/or most costly intervention. The actual costs and efficiency will differ between farms as it depends on the specific land use activity, scale of the activity/issue, level of existing infrastructure, existing interventions, underlying topography and expected outcomes. For this reason, all interventions should be considered when drafting an environmental management plan.

Management Interventions for Phosphorus			
Intervention	**Description**	**Co-benefit**	**Comments**
Stock exclusion/ Fencing	Preventing livestock access to the lake, decreases bank damage, reduces sediment inputs via bank erosion and prevents direct deposition of faces. All of which reduce *E. coli*, N and P loads.	Allows riparian vegetation to establish which provides filtration capacity, shading, habitat, and organic matter input.	Excluding stock from the stream network reduces impacts to the downstream receiving environment. Most cost-effective intervention considering the wide range of co-benefits.
Tile drain amendments	Use of P-sorbing Ca, Al and Fe materials as backfill for artificial drainage systems. This reduces the nutrient load entering the lake.	Additional filtration of sediment and faecal bacteria.	This is a potentially costly intervention but is very effective. It should be considered if there is a lot of overland flow paths draining into the lake.
Controlled release fertiliser	Use low-water-soluble P fertiliser. Less fertiliser-P is lost in runoff due to the low water solubility of products such as reactive phosphate rock resulting in increased P use efficiency.	Increases efficiency and P retention which lowers the overall amount of fertiliser required, resulting in large cost savings.	These types of fertilisers are not appropriate for soil pH < 6.0 or rainfall > 800 mm. Also, cannot be used for capital applications and must gradually replace highly-water soluble P applications at a rate of one-third per year.
Dams and water recycling	Recycling systems that divert irrigation outwash for use in others part of the farm reduces nutrient	More efficient use of flood irrigation water and increased nutrient recycling.	Could require a change in irrigation infrastructure so should only be considered if water

	loads/discharges to the lake.		loss/discharges are a significant impact.
Precision/variable rate application of fertiliser	Precision fertiliser application using remote sensing of the nutrient status of the land to determine where & what nutrients should be targeted. This reduces the overall mobile nutrient load in the catchment and prevents excess nutrient loads entering the lake.	Reduction in the amount of fertiliser required, resulting in large cost saving.	Requires a change to the fertiliser application strategy and can present a higher initial implementation cost. Costs should reduce once the system is in place as less fertiliser will be required.
Precision irrigation	Use sensors to automate irrigation and nutrient inputs and optimises crop utilisation at fine scale.	Reduces the overall water and nutrient requirements, optimised applications result in better yields.	The initial infrastructure can be costly and requires active monitoring to ensure the process is optimised effectively.
Strategic grazing of pasture/crops within critical source areas	Identify the critical source areas of phosphorus and avoid grazing those areas during wet seasons.	Allows high P areas to be utilised for arable crops and allows a maximum yield from the land.	Requires more regular stock movement and an assessment of critical source areas.
Refurbish and widen flood irrigation bays	Water exiting flood irrigation bays as outwash represents about 20-50% of that applied. Re-contouring irrigation bays, and/or preventing outwash/wipe-off from accessing the stream network decreases P loads to the lake.	Recycling the water for use elsewhere on the farm reduces overall water consumption and nutrient requirements.	Recontouring can be costly and may result in a minor loss in yield.
Apply aluminium sulphate to pasture, forage cropland or crops in critical source areas	P-sorbing aluminium sulphate (alum) sprayed onto a winter forage crop just after grazing, or sprayed onto pasture a week before grazing, will prevent surface runoff losses of P and reduce nutrient loads to the lake.	Reduces overall catchment phosphorus load.	Presents an additional annual cost.
Restrict grazing of winter forage crops	Restrict grazing of forage crops in winter to reduce deposition of faeces and surface erosion. This limits the amount of phosphorus entering the lake during the wet season.	Better conditions for stock and less pasture damage.	Requires active stock movement and planning. Must be accompanied by a stand-off area that has no connection to a waterway.
Cover/ catch crop	Grow cover/catch crops on the same field in the	Enhances soil health, prevents erosion,	This will improve the year-round use of the

	same year, often used after the main crop or grass has been grazed or machinery has exposed the soil. This reduces nutrient and sediment loads to the lake.	reduces nutrient leaching, and improves yield.	pasture and can be designed in a way to maximise yields.
In-stream sorbents	Use of P sorbing material textile bags and place them on the stream bed to remove P from baseflow. This reduces the amount of P entering the lake from overland flow paths.	Additional filtration of other contaminants and reduces the catchment contaminant load.	Installation might require in-stream works. The focus should be on streams that flow into the lake and/or drain high impact land use.
Phosphorus matching to crop requirements	Matching soil Olsen P concentrations to pasture and forage crop requirements avoids excessive soil P concentrations and reduces the P load to the lakes and stream network.	An agronomic optimum phosphorus dosing reduces the amount of fertiliser required and the overall annual cost.	Will require targeted soil investigations but the analysis is low cost and can be coupled with other soil health tests.
Vegetated buffers/planting below critical source areas	Vegetated buffer below critical source areas and at the base of steep sloped pastures work to decrease contaminant loss in surface runoff by a combination of filtration, deposition, and improving infiltration.	Stabilises land, provides habitat for fauna and helps create wildlife corridors across the landscape.	Choose vegetation types based on the outcomes and site details. Use different planting mixes for erosion protection than for nutrient attenuation.
Constructed/natural seepage wetlands	Modification of landscape features such as depressions and gullies to form wetlands creates additional catchment buffering. Restoring natural seepage wetlands at the heads and sides of streams will reduce the contaminant load entering the stream/lake network.	Enhanced flood attenuation and increased habitat and biodiversity values.	These wetland features need to be fenced and restored to a good ecological condition for them to provide a high level of ecosystem services.
Sediment traps/retention ponds/bunds	In-stream sediment traps and retention ponds will allow coarse sized sediment and associated N and P to settle out. Bunds constructed along paddock edges creates ponds of water at the bottom of fields where	Potential to buffer storm events and downstream flooding.	Typically, only effective on cropping land with slope greater than 3 degrees.

	sediment settles out which prevent excess contaminants from entering the lake.		

Management Interventions for Nitrogen			
Intervention	**Description**	**Co-benefit**	**Comments**
Stock exclusion/ Fencing	Preventing livestock access to the lake, decreases bank damage, reduces sediment inputs via bank erosion and prevents direct deposition of faces. All of which reduce *E. coli*, N and P loads.	Allows riparian vegetation to establish which provides filtration capacity, shading, habitat, and organic matter input.	Excluding stock from the stream network reduces impacts to the downstream receiving environment. Most cost-effective intervention considering the wide range of co-benefits.
Change animal type	Animal type influences nitrogen leaching due to differences in the spread of urinary nitrogen. Nitrogen leaching from sheep and deer is approximately half that from beef cows at the same level of feed intake.	Also leads to decreased N2O emissions.	Careful consideration of the animal type is required as some species exacerbate other contaminant issues e.g., a change to deer may lead to greater sediment and P loss.
Constructed/natural seepage wetlands	Modification of landscape features such as depressions and gullies to form wetlands creates additional catchment buffering. Restoring natural seepage wetlands at the heads and sides of streams will reduce the contaminant load entering the stream/lake network.	Enhanced flood attenuation and increased habitat and biodiversity values.	These wetland features need to be fenced and restored to a good ecological condition for them to provide a high level of ecosystem services.
Cover/ catch crop	Grow cover/catch crops on the same field in the same year, often used after the main crop or grass has been grazed or machinery has exposed the soil. This reduces nutrient and sediment loads to the lake.	Enhances soil health, prevents erosion, reduces nutrient leaching, and improves yield.	This will improve the year-round use of the pasture and can be designed in a way to maximise yields.
Reduce nitrogen in critical source areas	Reduced use of nitrogen fertiliser on winter forage crops coming out of long-term pasture and avoid	Decrease emissions of greenhouse gases, reduce overall fertiliser requirements and an	Will require targeted soil investigations to ensure an accurate soil nitrogen profile.

	excessive nitrogen inputs to effluent blocks. This reduces the nitrogen load entering the lakes during high rainfall events.	improvement in energy use.	
Strategic grazing of pasture/crops within critical source areas	Identify the critical source areas of nitrogen and avoid grazing those areas during wet seasons.	Allows high nitrogen areas to be utilised for arable crops and allows a maximum yield from the land.	Requires more regular stock movement and an assessment of critical source areas.
Precision/variable rate application of fertiliser	Precision fertiliser application using remote sensing of the nutrient status of the land to determine where & what nutrients should be targeted. This reduces the overall mobile nutrient load in the catchment and prevents excess nutrient loads entering the lake.	Reduction in the amount of fertiliser required, resulting in large cost saving.	Requires a change to the fertiliser application strategy and can present a higher initial implementation cost. Costs should reduce once the system is in place as less fertiliser will be required.
Precision irrigation	Use sensors to automate irrigation and nutrient inputs and optimises crop utilisation at fine scale.	Reduces the overall water and nutrient requirements, optimised applications result in better yields.	The initial infrastructure can be costly and requires active monitoring to ensure the process is optimised effectively.
Controlled release fertiliser	Use slow-release nitrogen fertiliser. Less mobile nitrogen is lost in runoff due to the low water solubility and slow release resulting in increased nitrogen use efficiency.	Increases efficiency and nitrogen retention which lowers the overall amount of fertiliser required, resulting in large cost savings.	These types of fertilisers may result in a lower initial yield and might not be as effective in cold dry soil.
Denitrification beds	Large containers filled with woodchips that intercept drain flow and denitrify nitrate in water to nitrogen gas which is released to the atmosphere. These reduce the concentrations of bioavailable nitrogen entering the lake.	Provides additional filtration of other contaminants.	Suitable for tile/sub-surface drains or small surface drains. Can create hydrological blockages in larger channels.
Restrict grazing of winter forage crops	Restrict grazing of forage crops in winter to reduce deposition of faeces and surface erosion. This limits the amount of phosphorus entering the	Better conditions for stock and less pasture damage.	Requires active stock movement and planning. Must be accompanied by a stand-off area that has no connection to a waterway.

	lake during the wet season.		

Management Interventions for Sediment			
Intervention	**Description**	**Co-benefit**	**Comments**
Stock exclusion/ Fencing	Preventing livestock access to the lake, decreases bank damage, reduces sediment inputs via bank erosion, and stabilises the stream network.	Allows riparian vegetation to establish which provides filtration capacity, shading, habitat, and organic matter input. Prevents direct deposition of faces and reduces *E. coli*, N and P loads.	Excluding stock from the stream network reduces impacts to the downstream receiving environment. Most cost-effective intervention considering the wide range of co-benefits.
Cover/ catch crop	Grow cover/catch crops on the same field in the same year, often used after the main crop or grass has been grazed or machinery has exposed the soil. This reduces nutrient and sediment loads to the lake.	Enhances soil health, prevents erosion, reduces nutrient leaching, and improves yield.	This will improve the year-round use of the pasture and can be designed in a way to maximise yields.
Contour cultivation	Cultivation along contours of cropping land with slopes greater than 3 degrees reduces the speed and eroding power of runoff water.	Stabilises slopes and prevents slips. Increases yield by farming steep areas. Reduces nutrient loads from highly mobile soils during high rainfall events.	Requires new techniques and earthworks. This practice should be combined with detention ponds/bunds at the base of the slopes to further enhance contaminant attenuation.
Restrict grazing of winter forage crops	Restrict grazing of forage crops in winter to reduce surface erosion. This limits the amount of sediment entering the lake during the wet season.	Better conditions for stock and less pasture damage.	Requires active stock movement and planning. Must be accompanied by a stand-off area that has no connection to a waterway.
Sediment traps/retention ponds/bunds	In-stream sediment traps and retention ponds will allow coarse sized sediment to settle out. Bunds constructed along paddock edges creates ponds of water at the bottom of fields where sediment settles out which prevent excess contaminants from entering the lake.	Potential to buffer storm events and downstream flooding.	Typically, only effective on cropping land with slope greater than 3 degrees.

Constructed/natural seepage wetlands	Modification of landscape features such as depressions and gullies to form wetlands creates additional catchment sediment buffering. Restoring natural seepage wetlands at the heads and sides of streams will reduce the sediment load entering the stream/lake network.	Enhanced flood attenuation and increased habitat and biodiversity values.	These wetland features need to be fenced and restored to a good ecological condition for them to provide a high level of ecosystem services.
Vegetated buffers/planting below critical source areas	Vegetated buffer below critical source areas and at the base of steep sloped pastures work to decrease sediment loss in surface runoff by a combination of filtration, deposition, and improving infiltration.	Stabilises land, provides habitat for fauna and helps create wildlife corridors across the landscape.	Choose vegetation types based on the outcomes and site details. Use different planting mixes for erosion protection than for nutrient attenuation.
Strategic grazing of pasture/crops within critical source areas	Identify the critical source areas of sediment and avoid grazing those areas during wet seasons.	Allows high sediment areas to be utilised for arable crops and allows a maximum yield from the land.	Requires more regular stock movement and an assessment of critical source areas.
Minimum tillage/ direct drilling of seed	Direct drilling of seed into stubble or pasture reduces the proportion of time that land is bare and erodible during the growing cycle. This greatly reduces the sediment loads entering the lakes/streams.	Enhanced soil condition and stability. Less erosional issues and increased productivity.	May not be suitable for all crop types.
Increasing forested area/ windbreaks	Combination of retirement and pole planting on highly erodible land. Introduction of tree roots to soil regolith protects soil on steep slopes from mass movement erosion.	Stabilises slopes and prevents slips. Increases yield by farming steep areas. Reduces nutrient loads from highly mobile soils during high rainfall events.	This intervention should be planed with other re-vegetation interventions to create blue-green networks and wildlife corridors across the landscape.

Management Interventions for *E. coli*			
Intervention	**Description**	**Co-benefit**	**Comments**
Stock exclusion/ Fencing	Preventing livestock access to stream and lake banks reduce stream bank damage and stops the direct deposition of excreta (*E. coli*) into the waterways.	Allows riparian vegetation to establish which provides filtration capacity, shading, habitat, and organic matter input. Prevents direct deposition of faces and reduces *E. coli*, N and P loads.	Excluding stock from the stream network reduces impacts to the downstream receiving environment. Most cost-effective intervention considering the wide range of co-benefits.
Strategic grazing of pasture/crops within critical source areas	Identify the critical source areas near waterways and avoid grazing those areas during wet seasons.	Allows these areas to be utilised for arable crops and allows a maximum yield from the land.	Requires more regular stock movement and an assessment of critical source areas.
Restrict grazing of winter forage crops	Restrict grazing of forage crops in winter to reduce the amount of deposited excreta during the wet season. This limits the amount of *E. coli* entering the lake during high rainfall events.	Better conditions for stock and less pasture damage.	Requires active stock movement and planning. Must be accompanied by a stand-off area that has no connection to a waterway.
Sediment traps/retention ponds/bunds	In-stream sediment traps and retention ponds will allow faeces settle out. Bunds constructed along paddock edges creates ponds of water at the bottom of fields where excreta accumulate. This prevents excess *E. coli* from entering the lake.	Potential to buffer storm events and downstream flooding.	Typically, only effective on cropping land with slope greater than 3 degrees.
Vegetated buffers/planting below critical source areas	Vegetated buffer below critical source areas and at the base of steep sloped pastures work to decrease excreta (*E. coli*) loss in surface runoff by a combination of filtration, deposition, and improving infiltration.	Stabilises land, provides habitat for fauna and helps create wildlife corridors across the landscape.	Choose vegetation types based on the outcomes and site details. Use different planting mixes for erosion protection than for nutrient attenuation.