Lake Waikanae

30/04/2024

NRC Lake Number: N/A

Habitat size

Connectivity

Buffering

Water quality

Aquatic vegetation diversity

Aquatic vegetation integrity

Endangered species

Presence of key species

LakeSPI score

ECOLOGICAL VALUE SCORE

8 /20

Overall Rank: High to Moderate

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.
Hornwort: Hornwort can rapidly overrun the lake and cause significant damage.	Develop and implement a targeted hornwort control plan.
Stock access: Stock have damaged the riparian margin through grazing and pugging.	Exclude stock and allow the riparian vegetation to regenerate.
Invasive Species: The lake is used for duck hunting so the risk of new invasive species introductions is high.	Limit access to the lake and increase biosecurity awareness.

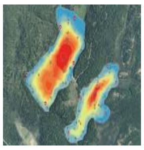
Did you know:

Waikanae has a variety of threatened wetland birds!

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

The 2024 survey was the first assessment carried out at Lake Waikanae.

Lake Waikanae is a small (2.3 ha) shallow (4.5 m) lake, located on the west coast, 26 km south of Cape Reinga (34°36'15"S 172°52'32"E). The lake consists of three basins formed by sand damming of the Waikanae Stream. The size of the basins is dynamic and likely to change as they are divided by floating rafts of wetland vegetation.

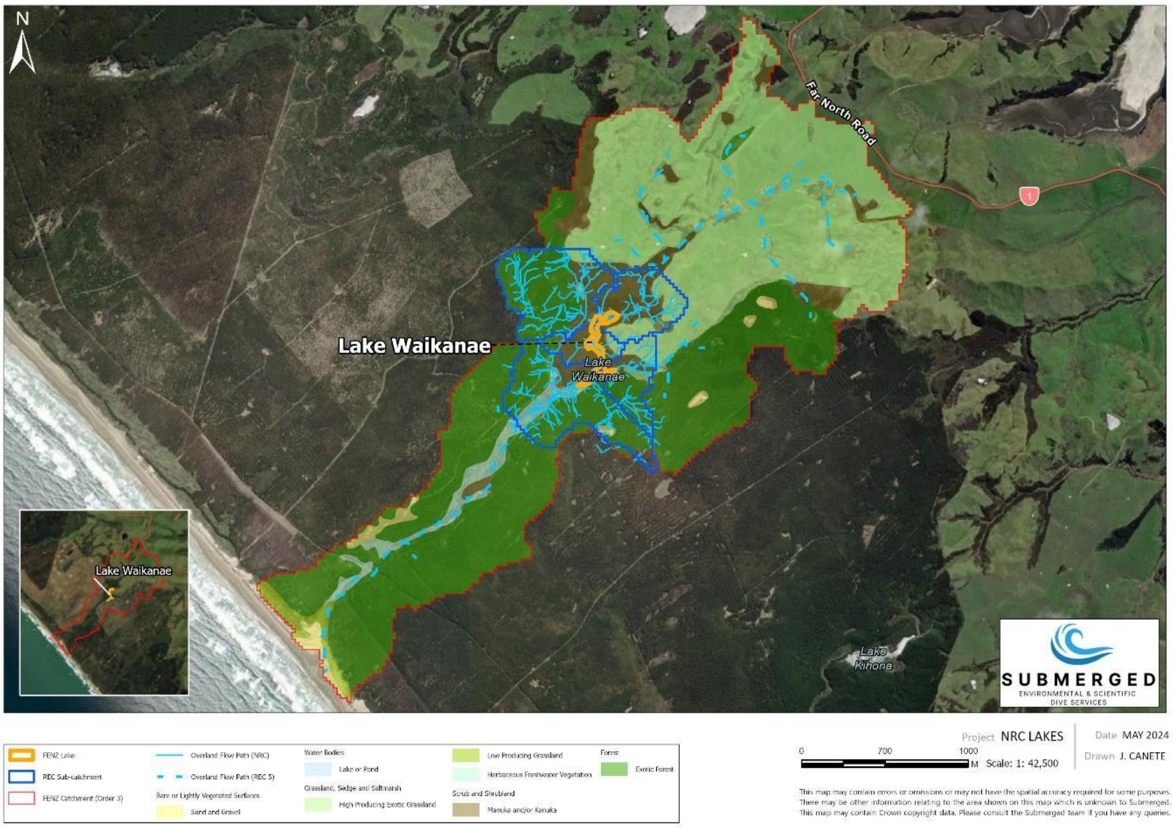
Lake Waikanae - Southwestern view indicating the densely vegetated riparian margin, native scrub sub-catchment and production forestry towards the west.

Catchment & sub-catchment description

The wider 1092.12-hectare catchment is dominated (83%) by exotic vegetation. Only 12% of the area consists of native vegetation, largely in the form of manuka/kanuka scrub. The exotic vegetation consists of 42% pasture and 41% forestry which represent a high level of impact across the catchment. Three percent of the catchment is classified as wetlands; however, they are concentrated downstream of the lake and are thus not contributing to the buffering of incoming contaminants.

The sub-catchment is 203.75 hectares and has a similar land use split to the wider catchment. The land use in the western and southern parts of the sub-catchment is predominantly production forestry (53% of the total sub-catchment). The southern forestry is below the lake and the majority of the overland flow drains downstream toward the coast and away from the main lake. The western forestry area drains into a stream that channels flow away from the lake. There is likely to be a degree of impact from the forestry however, the sub-catchment stream network diverts the majority of the overland flow past the lake and out to the coast.

There are large sections of high producing pasture along the eastern and northern sections of the sub-catchment. The stream network drains these areas and channels the flow from the northern part of the sub-catchment into the lake. The immediate area surrounding the lake consists of steep slopes covered in native manuka/kanuka scrub (33% of the sub-catchment) and lacustrine wetlands which provides some buffering for these incoming flows.



Lake Waikanae catchment land cover and overland flow path network

In-lake description

The majority of the lake is shallow (< 2 m) with a flat lakebed. Two deeply cut bowls occur in the centre of the southern and northern sections of the lake. These bowls abruptly drop, almost vertically, to a maximum depth of 4.5 m. The straight vertical walls of the bowl appear manmade but could mark the edge of the historic wetland extent at a time when the water level was lower.

The lake was partially stratified at the time of the survey with a slight difference in temperature (~ 1°C) between the surface water and the bottom of the deeper bowls (4.5 m). The majority of the lake was isothermal as the average lake depth was estimated at 2 m.

The emergent vegetation caused tannin staining of the water, resulting in an estimated underwater visibility of 1.5 m. The visibility deteriorated to 0.5 m in the deeper central bowls of the lake, this was a result of suspended organic matter, sulphide precipitate and light limitation.

The lakebed was littered with decomposing organic matter with an increased accumulation in the deeper bowls. This decomposition created suspended layers of sulphide precipitate in the base of the deep bowls (3.9 – 4.5 m).

The submerged vegetation formed a 1 – 1.5 m continuous band along the base of the emergent vegetation. The non-vegetated sections of the lakebed had thick benthic algal mats exceeding 75% cover in parts of the lake.

The substrate in the shallows (1.5 – 2.1 m) was firm with a surficial layer of fine silt and organic floc. This surficial layer was homogenous across most of the lake but became much thicker (~ 1 m thick) in the base of the deeper bowls where it formed a deposition zone. The substrate in these bowls was also a lot looser and highly mobile.

Wetland vegetation

The lake is surrounded by a wide 10 – 20 m band of mature emergent vegetation that extends into the lake to a depth of 1.5 m. Raupō (*Typha orientalis*) dominates the marginal vegetation, growing to 2.5 m tall. Occasional stands of kuta (*Eleocharis sphacelata*) occurred on the lakeward margin of raupō, with local *Machaerina articulata*, *Machaerina juncea* and *Schoenoplectus tabernaemontani*. Understory species included swamp millet (*Isachne globosa*), *Carex maorica*, *Isolepis prolifera*, the non-native *Ludwigia palustris* and both native and non-native willow weed (*Persicaria*) species.

Raupō dominated the lacustrine wetland that extends north across the Waikanae Stream valley, upstream from the lake basin.

The wide, densely vegetated riparian margins and lacustrine wetlands provide an ideal environment for wetland birds and this lake could serve as critical nesting habitat for threatened avifauna.

Submerged vegetation

The submerged vegetation was largely confined to a narrow 1 – 1.5 m wide band that ran along the base of the emergent vegetation between 1.5 – 2.1 m deep. In some parts, the macrophytes extended to the edge of the steep central bowls. The macrophyte cover reduced toward the two central bowls and eventually reached the maximum vegetated depth of 3.2 m at the top edge of the deeper northern bowl.

Nitella sp. aff. *cristata* was the only native macrophyte species recorded during the survey. It was the dominant species and formed a monoculture across the vegetated zone. It formed 96 - 100% cover along the base of the emergent vegetation (1.5 - 1.8 m) and 51 – 75% cover at the maximum vegetated depth extent (2.1 – 3.1 m). The tallest beds reached 62 cm, but the average lake-wide height was estimated at 30 cm.

The invasive *Utricularia gibba* was the next most prevalent species and it was seen throughout the shallows (0.1 – 1.8 m) and amongst the emergent reeds. It formed tall (55 – 102 cm), dense mats with up to 50% cover in parts but the overall cover was estimated at 6 - 25%. Fortunately, this invasive species has not overrun the lake to the same degree as seen in other Northland waterbodies.

The highly invasive *Ceratophyllum demersum* (hornwort) was found along the western lake margin. Majority of the growth occurred as isolated single stems amongst the *Nitella* sp. aff. *cristata* beds. Small clumps (1.0 - 1.5 m^2) of hornwort were seen along LakeSPI transects C and D. Two smaller clumps (< 1m^2) were also seen in the deeper northern bowl at 4.5 m deep. The tallest recorded stem was 32 cm but the average height across the lake was estimated at 20 cm. The growth is sparse and the lake-wide cover is estimated at 1 - 5%.

The hornwort was in poor condition, the stems were sparsely foliated, brittle and yellow in colour. The deeper clumps were covered with benthic algal mats and the shallower stems had epiphytic growth coating the leaves. Fortunately, this invasive species does not appear to be thriving in this lake, but its introduction is cause for concern. Hornwort can quickly overrun a lake and the existing plants should be removed as soon as possible.

The general macrophyte condition was good along the shallower margin of the lake but thick benthic algal mats were seen smothering large sections of the deeper *Nitella* sp. aff. *cristata* beds. This could result in fragmentation of macrophyte beds and a reduction in vegetated extent over time.

LakeSPI

Lake Waikanae is categorised as being in moderate condition with a LakeSPI Index of 33%. The 2024 survey is the first assessment in this lake so no comparisons to previous data could be made.

The maximum Potential Native Condition Score for this lake is 15 and the current assessment score is 6.4 (Native Condition Score of 42.67%). This score is reflective of the high native species dominance but is impeded by the low species diversity, shallow vegetated depth extent in relation to the maximum lake depth and the presence of invasive species. The maximum Potential Invasive Condition Score is 27 with a current assessment score of 18.8 (Invasive Condition Score of 69.63%). This is largely due to the widespread establishment of *Utricularia gibba* across the lake and the low-level incursion of hornwort (*Ceratophyllum demersum*). The maximum Potential LakeSPI Score is 35 and the current score is 11.6 (total LakeSPI Score of 33.14%). This score indicates that despite the lake being dominated by native macrophytes, the lack of native species diversity and the presence of two invasive submerged species is causing noticeable impacts that could worsen over time.

Macrophytes have established across most of the available habitat however, there are signs of a receding maximum vegetated boundary. Thick benthic algal mats and persistent sulphide layers might cause permanent fragmentation and recession of vegetation. If the conditions shift to favour hornwort, it is possible that it could overrun the lake and displace the single native macrophyte species (*Nitella* sp. aff. *cristata*). Hornwort control will be effective at the current cover and should be considered.

Lake Waikanae 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	33	43	70

Lake Waikanae LakeSPI survey transects

Wetland birds

Two At Risk - Declining mātātā (fernbird) (*Poodytes punctatus vealeae*) were seen in the marginal vegetation of the lake. A single black swan (*Cygnus atratus*) and a small flock of Canada geese (*Branta canadensis maxima*) and mallards (*Anas p. platyrhynchos*) were seen on the lake.

The following priority conservation species have been sighted near the lake: weweia (dabchick) (*Poliocephalus rufopectus*), matuku (Australasian bittern) (*Botaurus poiciloptilus*), black shag (*Phalacrocorax carbo novaehollandiae*), white heron (*Ardea alba*) and mātātā (fernbird) (*Poodytes punctatus*).

Most of these species were sighted in 2018 5 km east of the lake. Black shag and mātātā (fernbird) have been regularly sighted in the area 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 the northern tip of the region. Weweia (dabchick) were sighted to the north of Waikanae at Lake Ngakeketo and the surroundings in 2023, black shags and pied shags are also commonly sighted species in the far north so likely occupy the adjacent waterbodies.

Fish

Eels were observed in the lake during the 2024 survey, but the species was not determined. No other fish species were sighted and there are no recent records of fish observations in the wider catchment.

The adjacent catchments have recent records of banded kokopu (*Galaxias fasciatus*), redfin bullies (*Gobiomorphus huttoni*) and longfin eels (*Anguilla dieffenbachii*) so it is possible that these species could exist in the lake and/or surrounding wetlands.

Both shortfin and longfin eels were detected in the lake during the 2024 survey using eDNA analysis.

Aquatic invertebrates

Water boatmen (*Sigara arguta*) and common macroinvertebrate taxa were abundant during the 2024 survey. Three exotic snails were also frequently encountered (*Physa, Gyraulus* and *Lymnaea*). The emergent vegetation and undercut banks provide ideal habitat for these species. The eDNA samples indicate low levels of detection for New Zealand freshwater clams (*Sphaerium novaezelandiae*).

No freshwater mussels were found and there is no record of them in this lake. The water quality and parts of the substrate are suitable, but the lack of host fish is a limiting factor. It is possible that these species could establish in the lake if introduced along with host fish.

Endangered species

An At Risk - Declining mātātā (fernbird) (*Poodytes punctatus vealeae*) was seen in the marginal vegetation bordering the lake. Longfin eels (*Anguilla dieffenbachii*), ranked as At Risk - Declining, are found in nearby areas and were detected in 2024 using eDNA. An eel was sighted during the 2024 survey but could not be identified to species level. The eDNA detect for longfin eels were omitted from the Lake Ecological Value Score because the detections are low and the results have not been verified.

No endangered plants were found during the 2024 survey.

Lake ecological value

Lake Waikanae was assessed as having “High to moderate” ecological value with a score of 8 out of 20. This score was based on the predominantly native submerged vegetation and extensive emergent vegetation bordering the entire lake.

Lake Waikanae is a small (2.3 ha) waterbody with a maximum depth of 4.5 m, so it scores a 1 out of 3 for the Habitat Size metric. It is adjacent to a wetland complex, and a cluster of small lakes so receives an additional point for connectivity to other waterbodies.

The lake scores a 2 out of 3 for the Buffering Metric. It has mature 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 83% exotic vegetation (42% pasture & 41% forestry) which reduces the buffering score. The Buffering Metrics are calculated at a catchment scale and considering the native scrub dominant surroundings, the sub-catchment scores are likely to reflect the true nature of the buffering. Regardless of the buffering, the stream network drains predominantly pastoral land, so the land use impact is likely to be high.

No 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, the lake is likely in the upper mesotrophic to early eutrophic range.

The lake scores a 3 out of 3 for the Aquatic Vegetation Diversity Metric because 21 indigenous emergent, free-floating, and submerged vegetation species were recorded during the survey. The lake supports a rich diversity of wetland plants, and the intact riparian margins have a variety of emergent reeds.

The Aquatic Vegetation Integrity metric is taken from the LakeSPI Native Condition and the resulting score is a 1 out of 3. This score is reflective of the native species dominance but integrates the lack of diversity, the presence of invasive species and limited vegetated depth relative to the maximum lake depth.

No endangered plants or fish were seen during the survey, so the lake scores a 0 out of 3 for the Endangered Species Metric. The eDNA survey indicated low level detections of longfin eels in the lake but they were omitted from the Lake Ecological Value Score because the detections are low and the results have not been verified. Fern birds were the only endangered bird species sighted during the assessment; however, records from the wider catchment indicate that the lake is likely used by a variety of wetland birds.

Overall, the lake appears to be in moderate condition but exhibits signs of deterioration in the form of invasive species incursions, excessive benthic algal growth, suspended sulphide precipitates, large deposits of decomposing organic matter and signs of nutrient enrichment.

Threats

Lake Waikanae is small and shallow, so it has a limited ability to dilute inflowing contaminant loads from the pasture dominant catchment. The extensive riparian vegetation and associated wetlands provide a good level of buffering but are still prone to the effects of eutrophication.

Considering the high impact catchment land use and drainage network the sediment and nutrient loads flowing into the lake are likely to be high, the native scrub in the sub-catchment and the dense emergent vegetation are clearly attenuating some of these contaminants but there is a risk of persistent nutrient enrichment.

The riparian margins support a diverse assemblage of native species, but the submerged vegetation is impacted. There is limited macrophyte diversity and a high degree of invasive species impacts. Aside from the establishment of *Utricularia gibba* the highly invasive hornwort (*Ceratophyllum demersum*) was detected in several locations across the lake. Hornwort has not overrun the lake and occurs in small clumps and isolated stems, a dense patch was seen in the area upstream of the main basin. The hornwort condition was low and it does not appear to be thriving however, if conditions change this species can rapidly outcompete native macrophytes and overrun the lake. This makes hornwort a priority threat to the long-term health of Lake Waikanae.

Hornwort is also present in several lakes north of Te Kao, including Te Ketekete Lagoon, Ngakeketo and Kihona. These water bodies are regularly used for duck shooting and eel fishing. There was evidence of duck shooting and regular access at Waikanae, so it is possible that hornwort was introduced via hunting activities. Control of hornwort in Waikanae should be done before the population increases; however, a control plan needs to be established for all affected lakes in the adjacent areas to prevent reintroduction.

The emergent vegetation near the pump shed appeared to be damaged by herbicide application and stock access. Stock watering can increase the sediment, nutrient, and *E. coli* concentrations in the lake; it also provides a clear access point for eel fishermen and other recreational activities. This increases the risk of invasive species incursions.

Management recommendations

The primary threats to Lake Waikanae are invasive species and eutrophication. The following management actions are recommended:

Hornwort delimitation survey & control plan

Hornwort (*Ceratophyllum demersum*) currently occurs in low covers across the southern basin and can be eradicated from here relatively easily. Hand pulling can be used for the isolated stems and deep-water clumps, localised diquat (Reglone) or Aquathol K applications may be required for the dense beds upstream of the lake. A large bed of hornwort was seen from the shore in the eastern basin and a detailed delimitation survey is required to ascertain the full extent of the incursion across all the basins. The delimitation survey will inform the level and type of control that is needed. It is crucial that hornwort is controlled in neighbouring waterbodies to prevent repeat incursions.

Pathways assessment & biosecurity control plan

Several waterbodies in the surrounding areas have hornwort and there appears to be frequent movement of people and equipment between them. It is essential that the incursion pathways are identified, and a plan is developed to stop the spread of invasive species. Direct communications with the landowners, local hunters/fisherman and wider engagement with industry bodies (Fish & Game, local hunting and fishing clubs) is recommended as a first step.

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 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 the management tool box section to minimise the impacts from the catchment.

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.

Routine monitoring

The lake has limited native macrophyte diversity and high-impact invasive species. 3 – 5 yearly ecological assessments and invasive species surveillance surveys are recommended.

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 loads/discharges to the lake.	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 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 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.
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	An agronomic optimum phosphorus dosing reduces the amount of	Will require targeted soil investigations but the analysis is low cost and

	excessive soil P concentrations and reduces the P load to the lakes and stream network.	fertiliser required and the overall annual cost.	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 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.

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 excessive nitrogen inputs to effluent blocks. This reduces the nitrogen load entering the lakes during high rainfall events.	Decrease emissions of greenhouse gases, reduce overall fertiliser requirements and an improvement in energy use.	Will require targeted soil investigations to ensure an accurate soil nitrogen profile.
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	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

	nutrient load in the catchment and prevents excess nutrient loads entering the lake.		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 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.

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	Enhances soil health, prevents erosion, reduces nutrient	This will improve the year-round use of the pasture and can be

	after the main crop or grass has been grazed or machinery has exposed the soil. This reduces nutrient and sediment loads to the lake.	leaching, and improves yield.	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	Potential to buffer storm events and downstream flooding.	Typically, only effective on cropping land with slope greater than 3 degrees.

	ponds of water at the bottom of fields where excreta accumulate. This prevents excess *E. coli* from entering the lake.		
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.