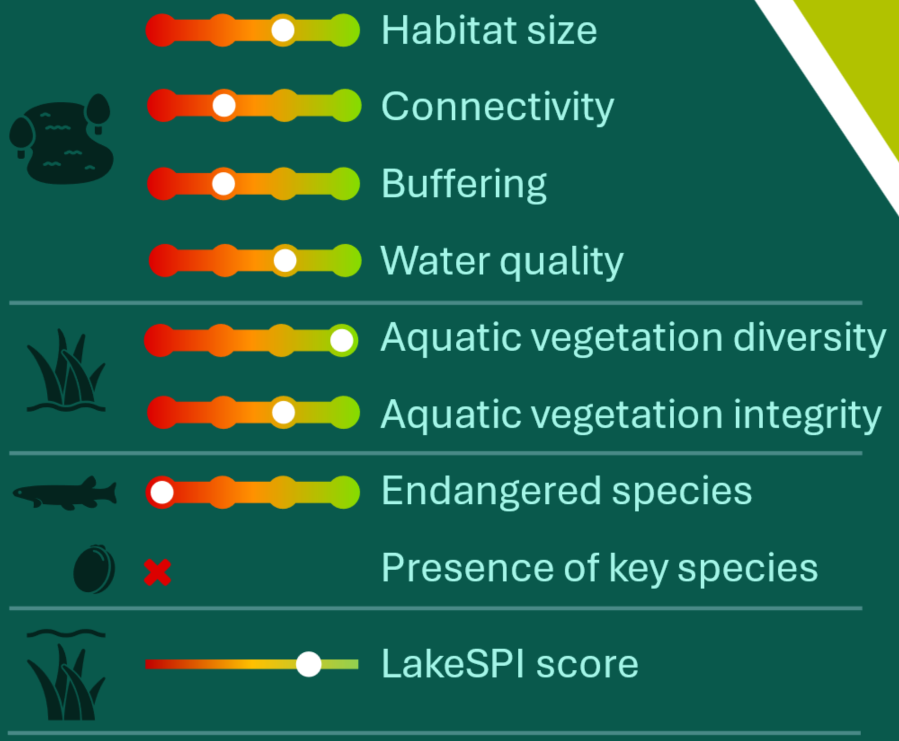
Shag Lake

03/05/2024

NRC Lake Number: 221



ECOLOGICAL VALUE SCORE

11 /20

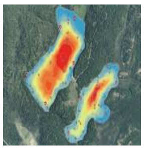
Overall Rank: High

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.
Poor riparian margins: Majority of the riparian margin is bare.	Densely plant the riparian margins with native species.
Increased sedimentation: Several steep slopes with erosional issues were seen surrounding the lake.	Stabilise erosion hot spots and plant riparian buffers at the base of the steep slopes.
Invasive Species: No invasive species are present but new introductions will cause significant damage.	Limit access to the lake and increase biosecurity awareness.

Did you know:
Shag Lake has no invasive macrophytes!

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

Shag Lake was assessed in 2001, 2010, 2018 and 2024.

Shag Lake is a deep (12 m) 17.5 ha dune lake located 2 km north of the Kai Iwi Lakes complex (35°47'28"S 173°36'24"E). It is situated in a pasture dominant catchment and the riparian margins have recently been fenced. This lake forms the northern most waterbody of a complex of lakes including Lake Kai Iwi, Lake Taharoa, Lake Waikare and Black Lake.

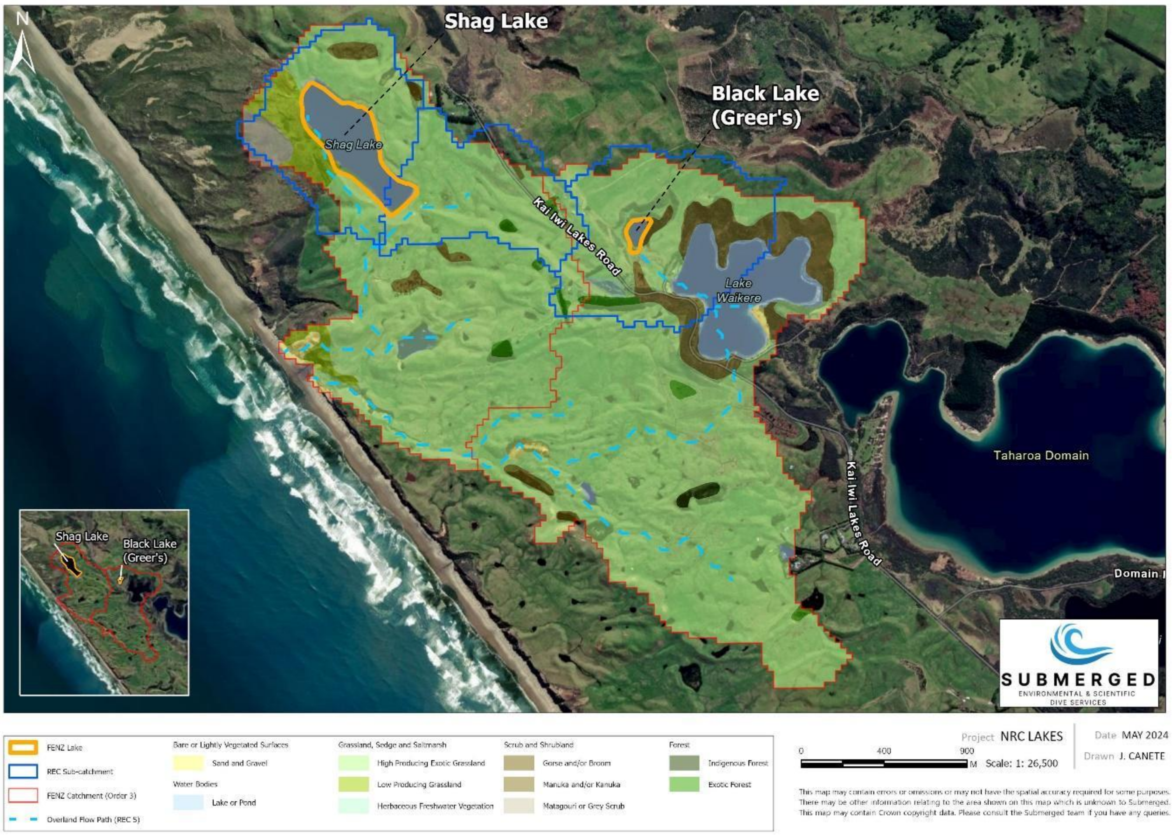
Shag Lake - Northwestern view indicating the pasture dominated land use and fragmented riparian vegetation

Catchment & sub-catchment description

The lake has a 242.99-hectare catchment that is almost entirely pastoral (85% of the catchment area) with small strips of exotic shelter belts (1%) and pockets of manuka/kanuka scrub (4%). Most of the native vegetation surrounds the neighbouring Black Lake and Lake Waikare. However, an assessment against updated aerial imagery indicates that some of the smaller manuka/kanuka stands in the catchment now resemble wetlands. With this in mind, wetlands make up approximately 3% of the catchment.

The 125.77-hectare sub-catchment has a similar make up to the wider catchment and is dominated by pasture (78% of the sub-catchment). There are no significant wetland buffers and diffuse overland flow drains the surrounding pasture directly into the lake.

The catchment land use is likely having a significant impact on this lake.



Shag Lake catchment land cover and overland flow path network

In-lake description

The lake was stratified at the time of the survey with a 2°C temperature difference below the 6 m thermocline. The underwater visibility is estimated at 1.5 – 2 m in the epilimnion and 0.5 m below the thermocline (> 6m).

The substrate in the shallows (0.1 – 1.2) was firm, sandy and coarse which is likely a result of the wind induced remobilisation of fine particles. A thin surficial layer of fine silt developed near the base of the slope and gradually became thick toward the maximum lake depth. At 10 m the lakebed plateaued and there was a distinct deposition zone consisting of a thick band of fine silt. Past 10 m the substrate was consolidated with a 5 – 10 cm thick surficial layer of fine silt and organic floc.

There was almost no deposited detritus and very limited benthic algal growth. The lake is exposed and prone to high winds which creates a high energy environment across the littoral zone. Wind induced scouring can often limit the establishment of benthic algal mats and increase the dispersal of organic matter.

A large amount of avian faeces was seen and it is clear that the lake supports high numbers of waterfowl. Numerous shotgun shells were seen along the shallow margin which confirms the use of the lake as a duck shooting location.

Wetland vegetation

Emergent vegetation had established further since the previous assessment and now covers approximately 20% of the lake perimeter. The remaining lake margin was either bare or had fragmented small clumps of emergent vegetation.

The dominant emergent species occupying the shoreline was *Eleocharis sphacelata*, which formed 15 - 20 m wide bands in parts, but either a narrow band or absent elsewhere. These emergent beds extended to depths of 1.5 m.

Turf communities were exposed during the 2024 survey and the following species were noted: *Glossostigma elatinoides, Gratiola sexdentata, Lilaeopsis novae-zelandiae, Limosella lineata, Myriophyllum votschii and Myriophyllum propinquum.* Other indigenous species occupying the open lake margins were *Alternanthera nahui, Centipeda aotearoana and Cotula coronopifolia.*

The emergent vegetation provides good habitat where it forms dense beds, but the overall lake margin is still considered poorly vegetated. The depauperate nature riparian margin provides limited buffering of incoming contaminant loads from the surrounding pasture.

Submerged vegetation

The submerged vegetation started at 0.5 m deep and extended to a maximum depth of 5.9 m. Small isolated clumps of macrophytes were seen from 6 – 7 m deep in some parts, but they were sparse with covers less than 1%. The lakebed was largely bare past 5.8 m. The maximum vegetated depth was 7.4 m during the 2018 assessment and the reduction could be a result of deteriorating water clarity.

The macrophyte assemblage changed along the depth profile and formed distinct zones. The shallow areas (0.5 – 1.8 m) were dominated by charophytes, the mid-section of the depth profile (1.8 – 4.2 m) had large stands of tall pondweed and sparse charophyte cover, the lower vegetated extent (4.2 – 5.8 m) was dominated by *Chara australis.*

Glossostigma elatinoides and *Limosella lineata* were the only turf species recorded. A bed of *Limosella lineata* was found at 0.5 m deep along transect D, the bed was approximately 4 m^2 with an average height of 5 cm and a maximum cover of 25%. This was the only location where it was found. *Glossostigma elatinoides* was found at 0.5 – 0.6 m deep along transects C and E, in both cases it formed small beds with covers of 25%.

Nitella sp. aff. *cristata* was the dominant submerged vegetation species, it formed high covers (96 – 100%) across the vegetated depth profile. The average lake-wide cover was estimated at 26 – 50%. The tallest bed reached 75 cm, but the average lake-wide height was 34 cm.

Chara australis preferentially occupied the lower sections of the macrophyte depth extent (4.2 – 5.8 m) where it formed covers of 76 – 95%, small clumps were also occasionally found amongst the shallower *Nitella* sp. aff. c*ristata* beds (2.5 – 4.2 m). The average lake-wide cover was estimated at 6 – 25% with an average height of 12 cm, the tallest bed measured 25 cm.

Nitella pseudoflabellata was found along transects C (0.7 – 1.9 m deep) and E (0.5 – 1.1 m deep), in both locations the cover was estimated at 65%. This species was not found in any other survey locations and the lake-wide cover is estimated at less than 10%. *Nitella leonhardii* was only found along transect E between 1.3 – 2.0 m deep. A maximum cover of 76 – 95% was achieved by a dense bed at 1.5 m deep, this bed had a maximum height of 77 cm. The average cover was 1 – 5% and the average height was 43 cm.

Potamogeton cheesemanii and *Potamogeton ochreatus* were common across the lake and were found at every transect. *Potamogeton cheesemanii* regularly formed stands in the mid-section of the vegetated depth profile (1.2 – 3.8 m). The maximum cover was 26 – 50% but the lake-wide average was 1 – 5%. The tallest bed recorded was 104 cm and the average lake-wide height was 33 cm. *Potamogeton ochreatus* typically formed a band between 1.5 – 4.8 m deep with maximum covers of 6 – 25% however, the lake-wide average cover was estimated at 1 – 5%. The tallest stand was 35 cm and the average height was 20 cm.

No exotic macrophyte species were found during the 2024 survey, which is surprising considering the lake is regularly used by duck shooters that move between various waterbodies that contain invasive macrophytes.

The macrophyte condition was good with limited epiphytic growth. Some of the deeper *Chara australis* beds were coated with a thin layer of benthic algae but this was only seen in a few locations.

Despite the good condition, the average lake-wide cover for all species was low. *Nitella* sp. aff. *cristata* and *Chara australis* were the only species to consistently have covers above 25%, the remaining species had average covers of less than 10%.

LakeSPI

Shag Lake is categorised as being in excellent condition with a LakeSPI score of 80%. The 2024 survey results are higher than the previous 2018 survey (LakeSPI score of 71%) but similar to the 2010 (LakeSPI score of 80%) and 2007 (LakeSPI score of 88%) surveys which indicates that the lake is in a relatively stable condition. The increase in score from the 2018 survey is due to the increased cover of native macrophytes and the absence of invasive species.

The maximum Potential Native Condition Score for this lake is 24 and the current assessment score is 15 (Native Condition Score of 62.5%). This score is reflective of the native species dominance and diversity. No invasive/exotic macrophyte species were detected during the 2024 survey so the Invasive Condition Score is 0%. The maximum Potential LakeSPI Score is 44 and the current score is 35 (total LakeSPI Score of 79.55%). This score appears high however, the average lake-wide cover for all species was low and there is a reduction in the maximum vegetated depth.

The sparse cover and reduction in maximum vegetated depth could be attributed to the poor water clarity. The lake is prone to the effects of eutrophication and without proper management the macrophyte extent is likely to recede further.

Shag Lake 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	Excellent	80	63	0
May 2018	High	71	50	4
April 2010	Excellent	80	62	0
April 2007	Excellent	88	91	11

Shag Lake LakeSPI survey transects

Wetland birds

This lake is commonly used for duck hunting and supports large flocks of waterfowl. Approximately 200 paradise shelducks (*Tadorna variegata*), 94 mallards (*Anas p. platyrhynchos*) and 30 grey teals (*Anas gracilis*) were seen on the lake, a small flock of 23 black swans (*Cygnus atratus*) were also sighted.

Several At Risk wetland birds were noted during the 2024 survey including seven weweia (dabchick) (*Poliocephalus rufopectus*), two little shags (*Microcarbo melanoleucos brevirostris*) and mātātā (fernbird) (*Poodytes punctata vealeae*). A single Threatened - Nationally Critical matuku (Australasian bittern) (*Botaurus poiciloptilus*) was seen at the lake.

The lake is regarded as an important refuge for birds disturbed from the Kai Iwi lakes when used for water skiing and the following priority conservation species have been sighted near the lake: weweia (dabchick) (*Poliocephalus rufopectus*), matuku (Australasian bittern) (*Botaurus poiciloptilus*), grey duck (*Anas superciliosa superciliosa*), black shag (*Phalacrocorax carbo novaehollandiae*), pied shag (*Phalacrocorax varius*), banded rail (*Gallirallus philippensis assimilis*) and mātātā (fernbird) (*Poodytes punctatus*).

Shag Lake and Black Lake are adjacent waterbodies and form part of a lake/wetland complex with the Kai Iwi Lakes. Wetland birds regularly move between these waterbodies and as a result, all bird observations within a 1.5 – 5 km radius were seen as equally applicable to both lakes.

Majority of the sightings used for this assessment came from 2013 – 2023 surveys. There are older survey records, however, the repeat surveys during the past 10 years are a more accurate portrayal of the species that inhabit the wider area.

Fish

Common bullies (*Gobiomorphus cotidianus*) were the only species sighted during the 2024 survey and they were abundant across the entire lake. Eels were noted in previous surveys and there are records of both longfin and shortfin eels (*Anguilla dieffenbachii* and *Anguilla australis*) as well as the exotic *Gambusia affinis*.

Aquatic invertebrates

Water boatmen (*Sigara arguta*) were the only invertebrate species sighted during the 2024 survey.

No freshwater mussels were found and there is no record of them in this lake. The substrate and water quality are suitable and there is an abundance of host fish, so it is possible that these key species could establish in the lake if introduced.

Endangered species

No Endangered plants or fish were seen during the 2024 survey however, the At Risk - Declining longfin eel (*Anguilla dieffenbachii*) has been previously recorded in the lake and is likely to still be present. Several At Risk and Threatened wetland birds were noted during the 2024 survey including weweia (dabchick) (*Poliocephalus rufopectus*), little shags (*Microcarbo melanoleucos brevirostris*), mātātā (fernbird) (*Poodytes punctata vealeae*) and matuku (Australasian bittern) (*Botaurus poiciloptilus*).

Lake ecological value

Shag Lake was assessed as having a “High” ecological value with a score of 11 out of 20. This score was based on the large size of the lake, high aquatic plant diversity and lack of invasive species.

Shag Lake is a relatively large (17.5 ha) deep (12 m) lake, so it scores a 2 out of 3 for the Habitat Size metric. It is adjacent to the Kai Iwi Lakes complex and Shag Lake, so it gets an additional point for connectivity to other waterbodies.

The lake scores a 1 out of 3 for the Buffering Metric because it has poorly vegetated riparian margins and is situated in a pasture dominant catchment (85% of the catchment area). Furthermore, only 1% of the wider catchment is considered as wetlands which brings down the overall score.

Water quality data from the Northland Regional Council indicate that the lake is mesotrophic with a trophic level index (TLI) score of 3.4. As a result, the lake scores a 2 out of 3 for the Water Quality Metric.

The lake supports a rich diversity of aquatic plants despite the fragmented nature of the riparian margin and the sparse submerged macrophyte cover. Thirty-one indigenous emergent, floating and submerged plant species were recorded, resulting in a 3 out of 3 for the Aquatic Vegetation Diversity Metric.

The Aquatic Vegetation Integrity metric is taken from the LakeSPI Native Condition and the resulting score is a 2 out of 3. This score reflects the native species diversity and lack of invasive species.

No endangered plants or fish were seen during the 2024 survey however, the lake is adjacent to the Kai Iwi Lakes complex and is utilised by several threatened bird species.

Threats

The lake has been fenced since the previous assessment but the riparian vegetation has not recovered yet. The fence is damaged in places and could allow stock in if left unmaintained. If stock have easy access to the lake, they will damage the riparian margins and further impede the recovery of emergent vegetation.

The poorly vegetated riparian margins and high-impact catchment land use are threats to the water quality and ecological value of the lake. The steep sloped pasture dominant sub-catchment is likely delivering large nutrient and sediment loads to the lake during high rainfall events. The contaminant ladened overland flow enters the lake freely as the majority of the riparian margin has no vegetated buffers. The high nutrient loads combined with the poor macrophyte cover and bare riparian margins puts this lake at great risk of rapidly shifting to a turbid algal dominated state.

Several steep slopes with slips, bare earth and other erosion issues were noted during the 2024 assessment. These slopes deliver sediment straight to the lake where they impact riparian vegetation and smother shallow water macrophytes.

Access to the lake is through private land which minimises the risk of invasive species introductions but, the high level of hunting and fishing in the area means there is still a significant risk. Shag Lake has an abundance of habitat for invasive species (fish and plants) and if introduced they could rapidly outcompete native species and cause cascading ecological effects, resulting in a degraded system.

Management recommendations

The primary threats to Shag Lake are eutrophication, invasive species incursions and the poor condition of the riparian margins. The following management interventions are recommended to address these impacts:

Stock exclusion & riparian enhancement

Stock have previously damaged the riparian margin and ensuring they continue to be excluded will prevent erosion, stabilise the lake margin, and allow riparian vegetation to establish. Additional riparian planting should be done to help stabilise the lake edge and buffer incoming contaminants. The focus should be on planting the areas at the base of the steep exposed slopes.

Erosion control

The bare exposed slopes create a source for sediment and should be stabilised. This can be done by installing geotextiles over the erosion hot spots and/or replanting the hill sides. Creating wide densely planted riparian buffers at the base of the slopes will act as a sediment bund that will attenuate incoming deposits.

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

Several waterbodies in the surrounding areas have invasive species 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 iwi, landowners, local hunters/fisherman and wider engagement with industry bodies (Fish & Game, local hunting and fishing clubs) is recommended as a first step.

Routine monitoring

Shag Lake appears relatively stable but is at risk of rapid deterioration if the key impacts are not managed appropriately. 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	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

	resulting in increased P use efficiency.		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 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	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.

	load entering the stream/lake network.		
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	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.
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 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	Provides additional filtration of other contaminants.	Suitable for tile/sub-surface drains or small surface drains. Can create hydrological blockages in larger channels.

	reduce the concentrations of bioavailable nitrogen entering the lake.		
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 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	Potential to buffer storm events and downstream flooding.	Typically, only effective on cropping land with slope greater than 3

	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.		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.