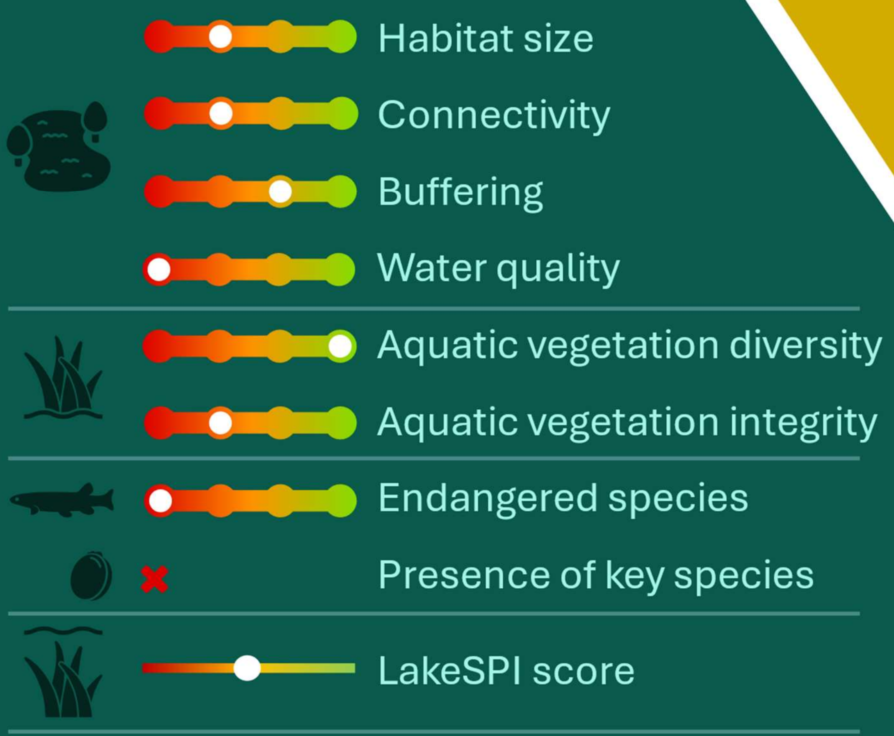
Black Lake

03/05/2024

NRC Lake Number: 226



ECOLOGICAL VALUE SCORE

9 /20

Overall Rank: High to Moderate

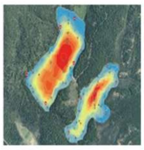
Key impact	Management action
Eutrophication: There are signs of nutrient enrichment from current & historic catchment activities .	Develop a farm environment plan using the management tool box and continue catchment restoration activities.
Invasive Species: *Gambusia* is present and new invasive species introductions will cause significant damage.	Attempt to control *Gambusia,* limit access to the lake and increase biosecurity awareness.
Trophic change: There are signs of a possible shift towards a higher trophic level.	Routine monitoring including monthly water quality testing as well as 3-5 yearly ecological assessments and invasive species surveillance.

Did you know:

Black Lake is 20 m deep and naturally stained with tannins!

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.

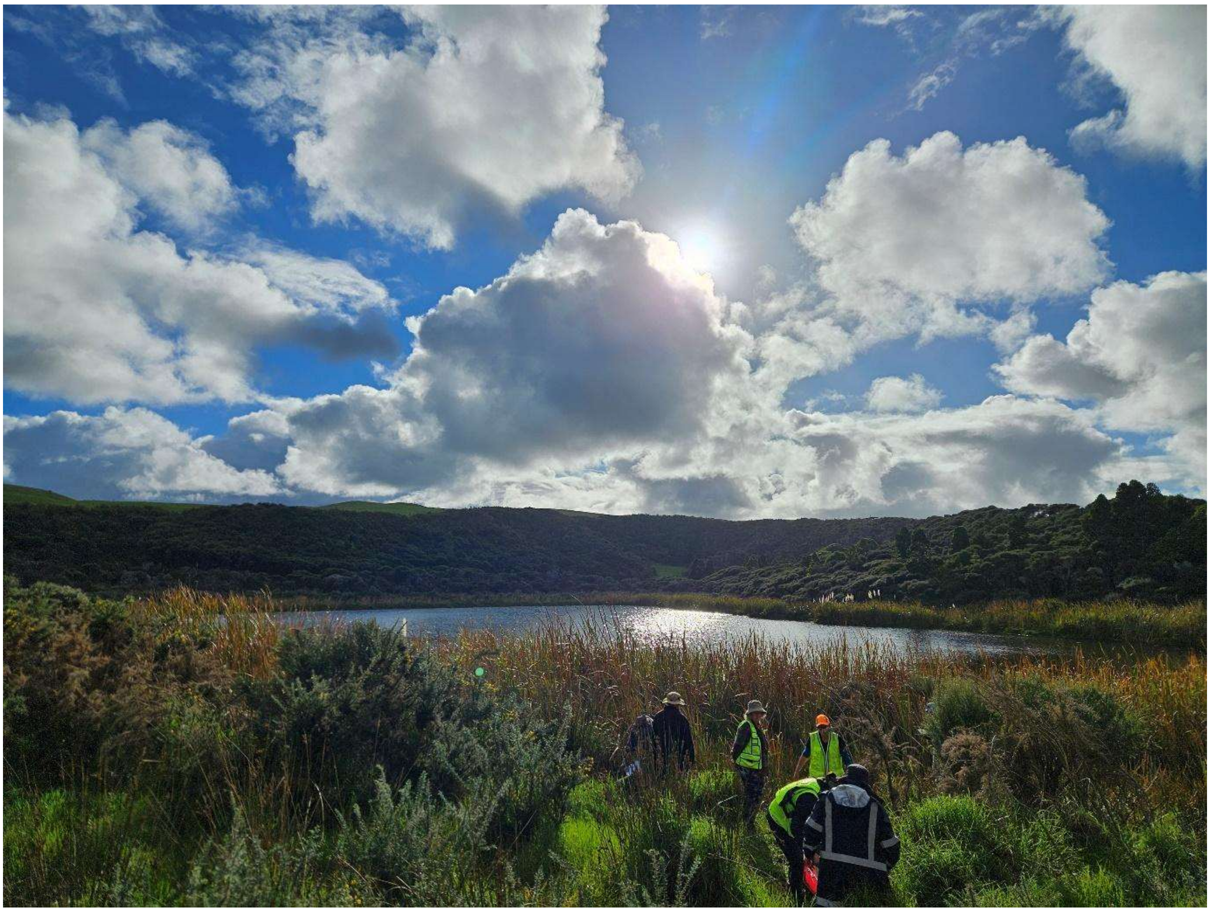
Presence of key species: This score is based on the presence of freshwater mussels (kakahi or torewai). These mussels are important for lake health because they filter the lake and remove algae.

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

Black Lake (Greer's) was assessed in 2018 and 2024.

Black Lake is a small (1.5 ha) dystrophic lake located north of the Kai Iwi Lakes complex (35°47'44"S 173°37'27"E). The lake is on private land with restoration planting around it and pasture in the remainder of the property. It is surprisingly deep considering its size and has a maximum depth of 19.8 m. The water is heavily stained with tannins from the dense wetland and riparian vegetation that surrounds the lake.



Black Lake (Greer's) - Northeastern view showing the densely vegetated riparian margin and native bush that mostly surrounds the lake.

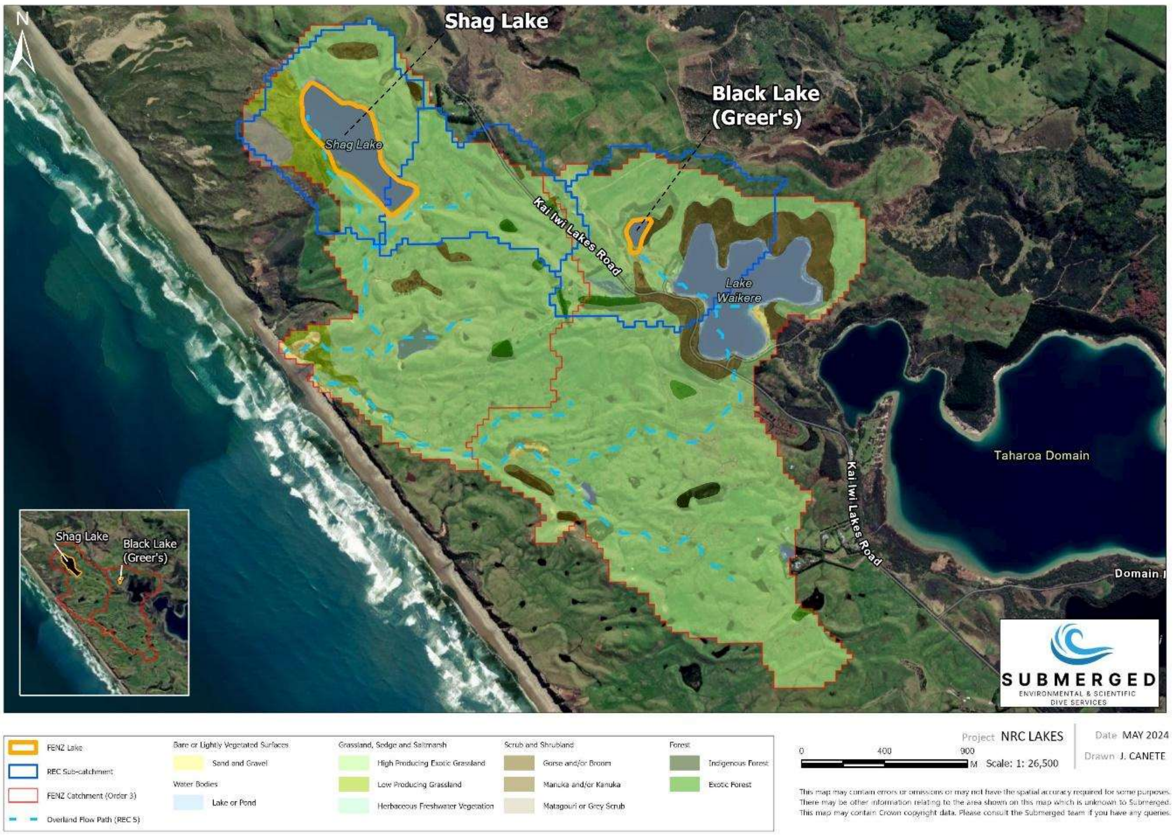
Catchment & sub-catchment description

The lake has a 326.51-hectare catchment that is 78% pasture with small strips of exotic shelter belts (1%) and patches of manuka/kanuka scrub (9%). Most of the native catchment vegetation surrounds the neighbouring Lake Waikare. An assessment against updated aerial imagery indicates that some of the smaller manuka/kanuka stands in the catchment now resemble wetlands. As a result, it is estimated that wetlands make up approximately 3% of the catchment.

The 85.14-hectare sub-catchment is similar to the wider catchment and is dominated by pasture (65% of the sub-catchment). The topography of the sub-catchment resembles a steep sided bowl that channels diffuse overland flow into the lake.

The lake is bordered by restoration planting consisting of manuka/kanuka scrub and dense emergent riparian vegetation. The lake is fenced, and the mature riparian vegetation/wetland features are indicative of long-term stock exclusion.

This vegetation buffer will attenuate diffuse overland flow draining from the surrounding pasture. The lake depth adds to the in-lake buffering capacity and as a result, the catchment impacts are likely to be less severe than in the neighbouring Shag Lake.



Black Lake catchment land cover and overland flow path network.

In-lake description

Despite the natural tannin staining the underwater visibility was still 1.5 – 2 m. There was a noticeable thermocline at 6 m and a 1 m thick sulphide layer at 5 m. The sulphide layer is likely a result of decomposing organic matter that settled on top of the cold dense hypolimnion.

Visibility deteriorated rapidly through the sulphide layer (5 – 6 m) but returned to an average of 1.5 m past 6 m deep. Light penetration was largely confined to the top 5 m with no surface light passing beyond 6.5 m.

The substrate varied along the depth profile of the lake. There were large amounts of decomposing detritus and soft silt along the flat areas at the base of the emergent vegetation which is reflective of the densely vegetated riparian margin. The substrate gradually became firmer on the face of the steep slopes but still retained a surficial layer of fine silt. There was a distinct deposition zone along the 7 m depth contour that formed a narrow flat rim around the lake. This area had a thick layer of loose silt and organic floc. The in-lake surveys stopped at a maximum depth of 8 m but it is assumed that the accumulation of fine silt and organic floc would increase toward the deepest point of the lake, forming a central deposition zone.

Benthic algal mats were prevalent across the lake with covers reaching 75 – 90%. Majority of the charophytes were smothered by thick algae and the mats extended onto the bare sediment beyond the maximum vegetated depth extent.

Considering the light limitation, substrate characteristics and benthic algal growth it is unlikely that the lake can support significant macrophyte establishment deeper than 7 m.

Wetland vegetation

The emergent vegetation formed an approximately 20 m band around the entire lake and extended to a depth of 1.5 m.

Raupo (*Typha orientalis*) was the dominant emergent vegetation, with associated harakeke (*Phormium tenax*), *Machaerina rubiginosa*, *Isolepis prolifera, Persicaria decipiens, Ranunculus amphitrichus* and *Isachne globosa.*

This riparian vegetation transitioned into the surrounding native bush and created a good series of habitat types for native fauna.

Submerged vegetation

The general submerged vegetation establishment pattern consisted of *Utricularia gibba* just below the surface then *Potamogeton ochreatus* stands at the base of the emergent vegetation that disperses with depth, *Chara australis* and *Nitella* sp. aff. *cristata* dominate the mid to deep sections of the profile.

Chara australis and *Nitella* sp. aff. *cristata* were the dominant submerged vegetation species, small clumps of *Nitella leonhardii* were found amongst the other charophytes but did not establish high covers. These species formed high covers from the base of the emergent vegetation (1.3 – 2.1 m) to the maximum vegetated depth extent of 7.2 m.

Chara australis preferentially occupied the shallow littoral zone from 1.3 m to a maximum of 3.8 m where it formed dense beds exceeding >95% cover. The average depth extent across the lake was 1.9 – 3.2 m. The average lake-wide cover was 51 - 75% with an average height of 31 cm. *Nitella* sp. aff. *cristata* was found across the entire vegetated extent but was the only species that established high cover along the lower vegetated boundary (4.5 – 7.2 m). The average depth range for this species was 2.0 – 5.9 m. The average lake-wide cover was estimated at 26 – 50% with an average height of 13 cm. *Nitella leonhardii* grew sparsely within an average depth range of 1.8 – 2.6 m, an average lake-wide cover of less than 5% and an average height of 11 cm.

The charophyte beds were not continuous but large and frequent enough to be considered a significant vegetation feature, often exceeding 75% cover.

Potamogeton ochreatus was common across the lake, with an average depth of 1.6 – 2.9 m, but did not exceed 25% cover. The average lake-wide cover was estimated to be less than 5%. It was the tallest species recorded and with maximum heights exceeding 1 m, several stands consisted of young plants and runners which brought the average height down to 64 cm. A small stand of *Potamogeton cheesemanii* was found in the northern corner of the lake along transect D. This single stand started 0.8 m and extended down the slope to 1.8 m, it had a maximum height of 80 cm and an average height of 30 cm.

Utricularia gibba was the only invasive macrophyte recorded during the survey. It was commonly seen just below the surface amongst the emergent reeds as well as at the base of the riparian vegetation where it intertwined with the root masses. It also formed clumps that draped over the charophytes. The average depth range was 1.0 – 1.9 m. It forms covers up to 51% but has a lake-wide average cover of 5%. Fortunately, this invasive species has not overrun the lake as seen in other Northland waterbodies.

The macrophyte condition was good along the shallower sections of the lake but deteriorated with depth. Thick mats of benthic algae smothered large sections of the deeper charophyte beds, and the taller pondweeds were coated with epiphyton.

The submerged vegetation became sparse between 4 – 5 m and the growth was noticeably stunted and bleached. This is possibly a result of a persistent sulphide layer. A 1 m thick sulphide layer was seen during the survey at 5 m, just above the thermocline. Considering the depth and amount of suspended organic matter this sulphide layer likely persists throughout the stratification period.

LakeSPI

Black Lake is categorised as being in high condition with a LakeSPI Index of 52%. The 2024 survey results are almost the same as the initial 2019 survey which indicates that the lake is in a relatively stable condition.

The maximum Potential Native Condition Score for this lake is 29 and the current assessment score is 14.25 (Native Condition Score of 49%). This score is reflective of the native species dominance and diversity. The maximum Potential Invasive Condition Score is 27 with a current assessment score of 10.25 (Invasive Condition Score of 38%). This is largely due to the widespread establishment of *Utricularia gibba* across the lake. The maximum Potential LakeSPI Score is 49 and the current score is 25.25 (total LakeSPI Score of 51.53%). This score appears low considering the nature of the submerged vegetation however, the maximum potential scores are based on the lake depth.

Black Lake is almost 20 m deep but is dystrophic, so the photic zone is shallow relative to the depth. Macrophytes have established throughout the expected vegetated depth extent however, there are signs of a receding maximum vegetated boundary and charophyte bed fragmentation. Thick benthic algal mats and persistent sulphide layers might cause permanent fragmentation and recession of vegetation at and below the thermocline.

Black Lake (Greer's) 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 %
2024	High	52	49	38
2019	High	52	48	36

Black Lake (Greer's) LakeSPI survey transects

Wetland birds

A matuku (Australasian bittern) (*Botaurus poiciloptilus*) was seen in the western margin of the lake and the distinctive calls of spotless crake (*Porzana tabuensis tabuensis*) and mātātā (fernbird) (*Poodytes punctatus vealeae*) were heard in the same area.

Black Lake and Shag 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. 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 cormorant (*Phalacrocorax varius*), banded rail (*Gallirallus philippensis assimilis*) and mātātā (fernbird) (*Poodytes punctatus*).

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 abundant throughout the lake, large schools appeared to aggregate below the thermocline. A wide range of size classes were observed which is indicative of healthy recruitment.

Small numbers of *Gambusia affinis* were seen in the shallows against the emergent vegetation. It is likely that this invasive species entered the lake via a drain that intermittently connects to Lake Waikare. *Gambusia* have not established in the same numbers seen in the neighbouring waterbodies which could be a result of poor habitat. Black Lake is deep and has a steep well shaded littoral edge. As a result, the surface water temperature and lack of shallow areas are likely unfavourable to gambusia.

Longfin eels (Anguilla dieffenbachii) were detected in the lake during the 2024 survey using eDNA analysis.

Aquatic invertebrates

Freshwater sponges were noted on the lakebed and the roots of the emergent vegetation. Large numbers of water boatmen (*Sigara arguta*) were seen amongst the root of the emergent vegetation and the undercut banks.

No freshwater mussels were found during the 2024 survey and there is no record of them in this lake. The substrate is suitable and there is an abundance of host fish however the benthic algal growth, high concentration of suspended matter and signs of persistent anoxia would likely prevent this species from establishing in the lake.

Endangered species

No endangered fish or vegetation was seen during the 2024 survey however, the wide densely vegetated riparian margins and secluded nature of the lake support a wide variety of threatened birds including the Threatened - Nationally Critical matuku (Australasian bittern) (*Botaurus poiciloptilus*) and At Risk - Declining spotless crake (*Porzana tabuensis tabuensis*) and mātātā (fernbird) (*Poodytes punctatus vealeae*).

The At Risk - Declining longfin eels (Anguilla dieffenbachii) were detected in the lake during the 2024 survey using eDNA analysis. They were omitted from the Lake Ecological Value Score because the detections were low and the results have not been verified.

Lake ecological value

Black Lake (Greer's) was assessed as having a "High to moderate" ecological value with a score of 9 out of 20. This score was based on the densely vegetated riparian margin and submerged charophyte meadows.

Black Lake is small (1.2 ha) but deep (19.8 m), so it scores a 1.5 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 2 out of 3 for the Buffering Metric despite having mature emergent vegetation around the entire lake perimeter. Only 0.4% of the wider catchment is considered as wetlands however, due to the small lake area the relative percentage of wetlands is high. The immediate surroundings have a moderate percentage of native vegetation (18% of the sub-catchment) however, the wider catchment is dominated by pasture with only 9% native vegetation which brings down the overall score.

No water quality data is available for Black 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 the upper mesotrophic range and may slip into a eutrophic state during summer.

The lake supports a rich diversity of wetland plants, and the intact riparian margins have a variety of emergent reeds. Twenty-six 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 1 out of 3. This score reflects the native species dominance and diversity but integrates the limited vegetated depth relative to the maximum lake depth.

No threatened plants or fish were seen during the 2024 survey however, the wide densely vegetated riparian margins support a variety of threatened birds. The At Risk - Declining longfin eel (*Anguilla dieffenbachii*) was detected using eDNA analysis during the 2024 survey, but was omitted from the Lake Ecological Value Score because the detections were low and the results have not been verified. The densely vegetated riparian margins support a wide variety of threatened birds including the Threatened - Nationally Critical matuku (Australasian bittern).

Threats

The potential increase of the *gambusia* population in the lake could lead to significant ecological impacts. Their voracious appetite for aquatic invertebrates can disrupt in-lake species assemblages and cause a breakdown in ecosystem function.

The proliferation of *Utricularia gibba* could further exacerbate ecological imbalances. Its rapid growth can outcompete native vegetation, leading to habitat degradation and reduced biodiversity.

The potential risk of new invasive species incursions is low because the lake is secluded on private property and the access is restricted. That being said, the property has bookable accommodation and is close to the Kai Iwi Lakes complex, so public interactions with this lake could be higher than other private lakes.

Considering the high impact catchment land use and drainage network, the nutrient loads flowing into the lake are likely to be high, the native scrub in the sub-catchment and the dense emergent vegetation are attenuating some of these contaminants and the lake is likely to be in an upper mesotrophic state.

Management recommendations

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

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 iwi, landowners, local hunters/fishermen, and wider engagement with industry bodies (Fish & Game, local hunting and fishing clubs) is recommended as a first step. An additional step could be to block the drainage channels that feed into the lake; it is assumed that gambusia entered the lake through these channels. Blocking them will prevent further incursion from the neighbouring waterbodies.

Land/farm management plan

The impacts from the surrounding pasture can be better 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 the Management tool box section to minimise the impacts from the catchment.

Routine monitoring

Black Lake has exhibited signs of decline and could deteriorate further with new invasive species incursions and increased nutrient loads. 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.

SUBMERGED ENVIRONMENTAL & SCIENTIFIC DIVE SERVICES

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	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.		
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 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.	Potential to buffer storm events and downstream flooding.	Typically, only effective on cropping land with slope greater than 3 degrees.

	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.		

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 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	Better conditions for stock and less pasture damage.	Requires active stock movement and planning. Must be accompanied by

	surface erosion. This limits the amount of phosphorus entering the lake during the wet season.		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 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	Potential to buffer storm events and downstream flooding.	Typically, only effective on cropping land with slope greater than 3 degrees.

	contaminants from entering the lake.		
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.