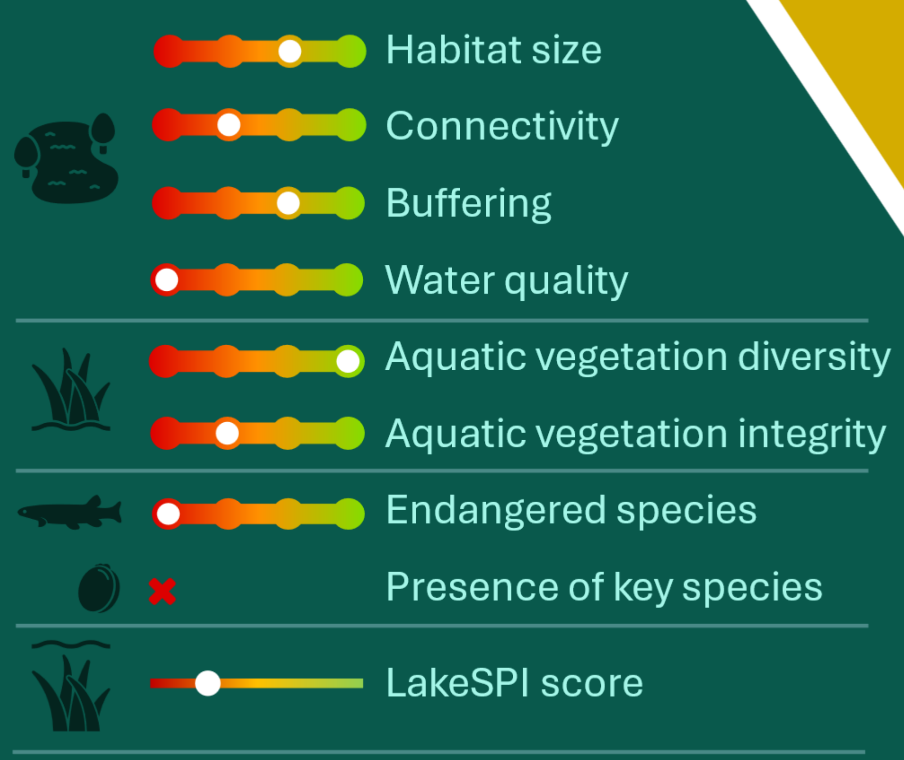
# Te Ketekete

02/05/2024

NRC Lake Number: 06




**ECOLOGICAL VALUE SCORE**

**9** /20

## Overall Rank: High to Moderate

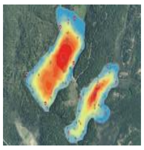
| Key impact | Management action |
| --- | --- |
| **Eutrophication:** There are signs of nutrient enrichment from the pasture dominant catchment. | Develop a farm environment plan and use the management tool box for immediate interventions. |
| **Invasive Macrophytes:** Hornwort and oxygen weed are outcompeting natives. | Develop and implement a targeted invasive macrophyte control plan. |
| **Stock access:** Stock have damaged the riparian margin through grazing and pugging. | Exclude stock and allow the riparian vegetation to regenerate. |
| **Gypsywort:** This invasive plant is established along the riparian margins. | Attempt to eradicate, Limit access to the lake and increase biosecurity awareness. |

### Did you know:

This is the only knownGypsywort site in Northland!


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

Te Ketekete (Te Werahi Lagoon) was assessed in 2004, 2013 and 2024.

Te Ketekete (34°28'32"S 172°42'46"E) is a large 127-hectare complex of wetlands and open water bodies. A maximum depth of 4 m has been recorded in the northern open waterbody where all surveys to date have been carried out. The wetland/lake complex is formed by a stream system impounded by dunes. Te Ketekete is the largest impounded waterbody on the Te Werahi Stream which flows from the south, draining land from Scott's Point and discharging to the north in Te Werahi Bay.

The majority of the open waterbodies are situated on private farmland that is used for dry stock.

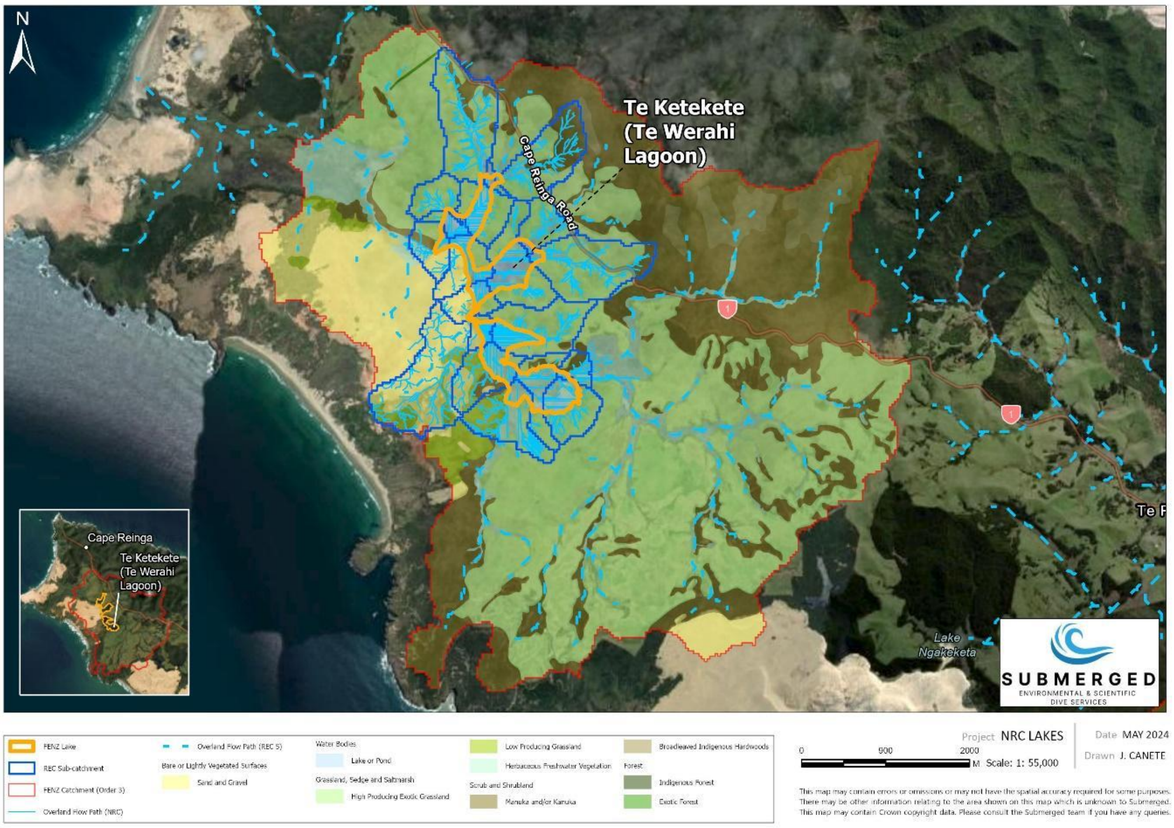
**Te Ketekete – Southern view across the northern basin indicating the pastoral land use and limited riparian buffer width**

## Catchment & sub-catchment description

The 3262.30-hectare catchment largely consists of pasture (50%) and native manuka/kanuka scrub (38%). The associated wetland features make up 9% of the total catchment area. The extensive wetlands serve as a buffer for incoming flows from the Te Werahi Stream.

The 717.39-hectare sub-catchment consists almost entirely of high producing exotic pasture (54% of the total sub-catchment) around the lake flanked by patches of native scrub (23%) and wetlands (15%). The majority of the wetlands in the sub-catchment are associated with the large southern water body but there are significant lacustrine wetlands across the wider system. These wetlands buffer contaminants and diffuse overland flows from the surrounding pasture.

The lake itself has an almost continuous vegetated riparian margin that transitions into lacustrine wetlands.  These features will attenuate incoming contaminants however, the steeply sloped high impact nature of the catchment and stream network that drains pastoral land into the lake means the level of land use related impact to the lake is high.




Te Ketekete (Te Werahi Lagoon) catchment land cover and overland flow path network

## In-lake description

The lake was degraded but still had a narrow band of submerged vegetation along the margins.

The water had a lot of suspended matter and visibility was limited to 10 cm or less. The poor visibility is likely due to a combination of wind-induced sediment remobilisation, tannins from the emergent vegetation, and high suspended algal volumes.

There was a lot of decomposing organic matter along the edge of the emergent vegetation. The remainder of the substrate consisted of a consolidated sandy base with a thin layer of organic floc and fine silt, this surficial layer was thicker toward the centre of the lake and was more than 1 m thick in some of the deeper parts.

There was limited benthic algal growth however, the macrophytes were often coated with a thick layer of epiphyton.

The high concentration of suspended matter and poor water clarity have prevented submerged vegetation from establishing in deeper water despite the substrate being appropriate.

## Wetland vegetation

The majority of the lake was fringed with pasture and a narrow (< 10 m) band of riparian vegetation, The entire western lake edge backs on to mobile dunes that have prevented the establishment of riparian vegetation. Floating rafts of reeds were seen along the dune face.

The wetland vegetation was dominated by *Typha orientalis* with *Machaerina articulata, Eleocharis sphacelata, Carex maorica* and *Phormium tenax*. The nationally threatened herb *Mazus novae-zeelandiae* sp*. impolitus* was collected from this area in 1966 but has not been recorded since. In 2013 the first record of the invasive marginal species gypsywort (*Lycopus europaeus*) in Northland was discovered at this water body but had limited distribution. During the 2024 survey gypsywort was abundant throughout the riparian margin in the survey area (northern basin). This plant is listed as an Eradication Plant in the Northland Regional Pest Management Plan and Te Ketekete remains its only known location in Northland.

The riparian margin is narrow and impacted by stock, the vegetation is dense but offers limited buffering considering the nature of the surrounding catchment. The wetland vegetation provides habitat for avifauna but is prone to edge effects.

## Submerged vegetation

The general submerged vegetation establishment pattern in the lake consists of a narrow (2 – 3 m) band of macrophytes that run along the shallow margin at the base of the emergent vegetation. All three waterbodies that make up the Te Ketekete complex were not surveyed, and the 2024 assessments were done in the northern basin. Based on the in-lake observations it is likely that the same submerged vegetation pattern and assemblage extends across the other two waterbodies.

The macrophyte assemblage was a mix of native and invasive species. Dense clumps of *Nitella* sp. aff*. cristata* and *Chara australis* were found between 1.2 – 1.9 m deep and formed covers of up to 90%. The average cover for *Nitella* sp. aff*. cristata* and *Chara australis* was 26 – 50% and 6 – 25% respectively. The charophytes were low growing and rarely reached heights of over 30 cm. *Nitella* sp. aff*. cristata* was the tallest charophyte with an average height of 21 cm and a maximum height of 65 cm whereas, *Chara australis* had an average height of 15 cm and a maximum height of 28 cm. *Potamogeton ochreatus* was the only native vascular species recorded and it never formed covers higher than 25% (average cover was estimated at 15%). It was the tallest species observed and some stands reached heights of up to 86 cm, the average height was 39 cm.

*Egeria densa* and *Ceratophyllum demersum* were common across the vegetated depth extent and regularly formed covers of 51 – 75%. *Ceratophyllum demersum* largely occupied the shallows (1.2 – 1.6 m) whereas *Egeria densa* was found down to 1.9 m. Both species were relatively short with average heights of approximately 27 cm. The tallest stands of invasives ranged from 45 - 50 cm. A single strand of *Potamogeton crispus* was found near transect A but only consisted of 3 short stems.

Previous surveys reported high covers of invasive species, and it was expected that the lake would have been overrun by now. This was not the case, and there is still a high proportion of native macrophytes. Furthermore, these invasive species have not formed large dense beds as they typically do in other waterbodies. The exact reason for this is unknown but may be attributed to the very low water clarity and wind induced turbulence.

The macrophyte condition was good despite the low light conditions however, there was a lot of epiphytic growth on the vegetation.

## LakeSPI

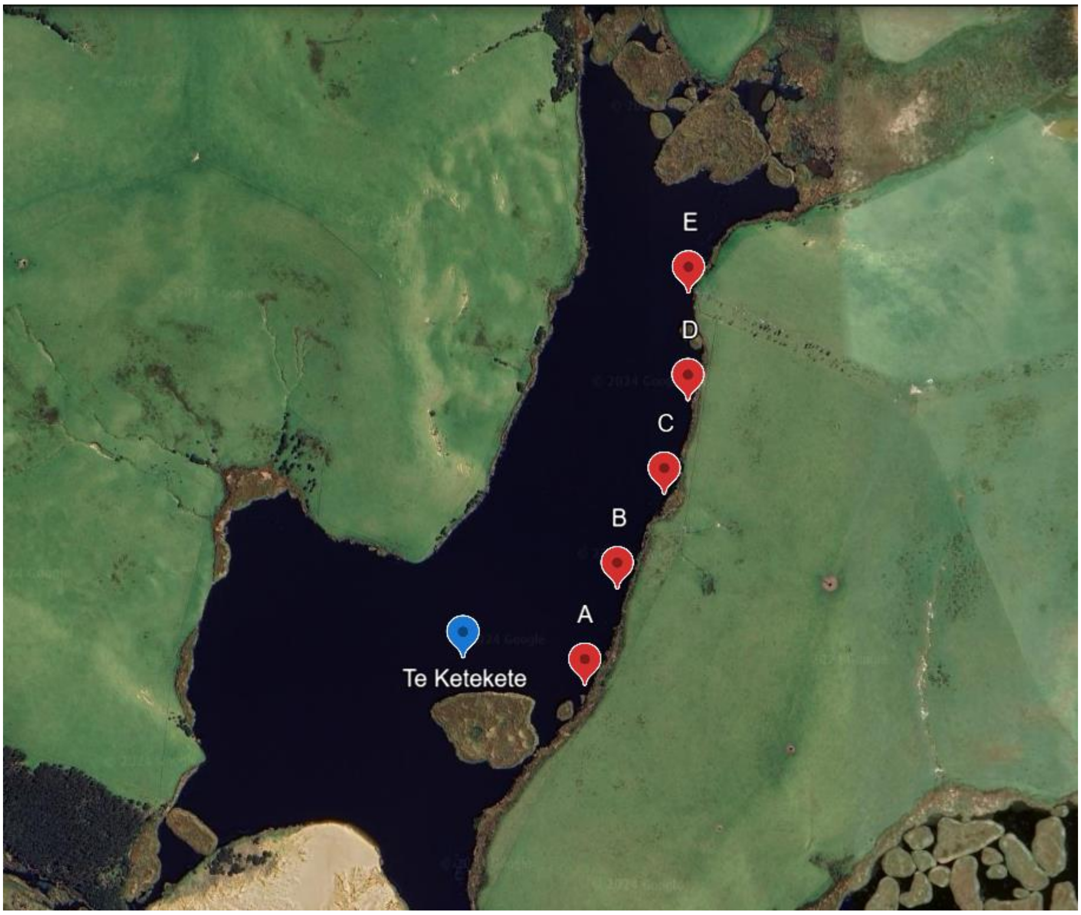
Te Ketekete is categorised as being in moderate condition with a LakeSPI Index of 30%. In 2013 the lake was assessed as poor due to the impacts of invasive species but the 2024 survey results are closer to the 2004 assessment.

The maximum Potential Native Condition Score for this lake is 15 and the current assessment score is 6 (Native Condition Score of 40%). This score is a significant increase from the previous survey and reflects the recent establishment of native macrophytes. The maximum Potential Invasive Condition Score is 27 with a current assessment score of 20.7 (Invasive Condition Score of 74.81%). This is a drop from the previous 2013 survey but is similar to the 2004 assessment. *Egeria densa* and *Ceratophyllum demersum* are still well established in the lake but have not yet overrun or displaced the native assemblages.

The maximum Potential LakeSPI Score is 35 and the current score is 10.4 (total LakeSPI Score of 29.71%). This score is an increase from the last survey (2013) which is driven by the persistence of native macrophyte beds despite the high level of invasive species impact and deteriorating vegetation extent.

**Te Ketekete 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 | 30 | 40 | 75 |
| April 2013 | Poor | 20 | 33 | 93 |
| Nov 2004 | Moderate | 34 | 67 | 78 |




Te Ketekete LakeSPI survey transects

## Wetland birds

The large areas of wetland provide good habitat for many aquatic birds, although grazing access may disturb some species. Black swans (*Cygnus atratus*) and a flock of Canada geese (*Branta canadensis*) were sighted during the 2024 survey and have been a common occurrence in previous assessments.

Twenty-five weweia (dabchick) (*Poliocephalus rufopectus*) and one black shag (*Phalacrocorax carbo novaehollandiae*) were seen during the survey. Two mātātā (fernbird) (*Poodytes punctatus vealeae*) were heard in the marginal vegetation of the lake.

The following priority conservation species have been sighted near the lake: weweia (dabchick) (*Poliocephalus rufopectus*), black shag (*Phalacrocorax carbo novaehollandiae*), and mātātā (fernbird) (*Poodytes punctatus*).

Most of these species were sighted within 10 km of the lake between 2016 and 2020. 9 km northwest of the lake. Several threatened bird species have been sighted in the area between Te Ketekete and Spirits Bay so it is possible that these species use wetlands/lakes across the northern tip of the region. Black shags and pied shags are also commonly sighted species in the far north so they likely occupy the Te Ketekete complex.

## Fish

The limited underwater visibility resulted in no fish being sighted during the 2024 survey.

Grey mullet (*Mugil cephalus*), common bully (*Gobiomorphus cotidianus*) shortfin eel and inanga records date back to 1999 and these species were detected using eDNA analysis during the 2024 survey.

## Aquatic invertebrates

No aquatic invertebrates were observed during the 2024 survey due to the poor underwater visibility.

No freshwater mussels were found and there is no record of them in this lake. The substrate is suitable however the high concentration of suspended matter would likely prevent this species from establishing in the lake.

## Endangered species

No endangered plants or fish were noted during the 2024 survey however, the lake provides extensive habitat for a variety of threatened birds including weweia (dabchick) (*Poliocephalus rufopectus*) and black shags (*Phalacrocorax carbo novaehollandiae*).

## Lake ecological value

Te Ketekete was assessed as having “High to moderate” ecological value with a score of 9 out of 20. This score was based on the size of the lake, the high diversity of emergent species in the riparian margins, and the increase in native macrophyte cover.

Te Ketekete is a large (127 ha) shallow (4 m) lake, so it scores a 2 out of 3 for the Habitat Size metric. This score reflects the large surface area which allows the lake to cope with high levels of catchment impacts. There are several large waterbodies and wetland complexes south of the lake, so it gets an additional point for connectivity to other waterbodies.

The lake scores a 2 out of 3 for the Buffering Metric. Majority of the lake perimeter is lined with mature emergent vegetation and 9% of the wider catchment is considered as wetlands. The wider catchment is 50% pasture however the surroundings have a moderate percentage of native vegetation (23% of the sub-catchment and 38% of the total catchment area) which raises the buffering overall score.

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. In-lake observations indicate that the lake is likely eutrophic and prone to seasonal algal blooms.

Te Ketekete is a large complex of lakes and wetlands that support a rich diversity of wetland/emergent plants. Twenty-four 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, the resulting score is a 1 out of 3 which is reflective of persistent native vegetation and high level of impact from the invasive *Egeria densa* and *Ceratophyllum demersum*.

No endangered plants or fish were noted during the 2024 survey; however, the lake and surrounding wetlands provide extensive habitat for a variety of threatened bird species.

No freshwater mussels were seen during the 2024 survey and the in-lake conditions are unlikely to be able to support this species.

## Threats

The highly invasive submerged weed species *Ceratophyllum demersum* and *Egeria densa* have established in high covers however, they have not yet overrun the lake and there is still a notable presence of native macrophytes. The increasing spread of these invasive species poses a significant ecological threat.

Gypsywort (*Lycopus europaeus*) is apparently restricted to this site in Northland. It is likely to have been introduced on the waders of duck shooters or fishermen from the Waikato and poses a major threat to similar wetland margins throughout Northland.

The lake was fenced although it was breached in places allowing stock access to the marginal vegetation. Livestock are likely to have assisted in the spread of gypsywort (*Lycopus europaeus*) around the wider lake but have also caused damage to the riparian areas.

The lake is in a pasture dominated catchment and is poorly buffered by narrow riparian margins along large sections of the lake perimeter. The high catchment nutrient loads combined with the shallow lake depth and invasive weeds, puts this system at great risk of rapidly shifting to a turbid algal dominated state.

## Management recommendations

The primary threats to Te Ketekete are the expansion of invasive species, stock access, and eutrophication. The following management actions are recommended:

### Stock exclusion

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

### Pathways assessment & biosecurity control plan

The risk of additional invasive species entering Te Ketekete is high however, the two most detrimental species have already established in the lake, so any new incursion is unlikely to have as significant an impact.

The more pressing risk is the threat this lake poses to other waterbodies in the region. Te Ketekete is easily accessed from State Highway 1 which makes it a local source population of invasive macrophytes. Both *Ceratophyllum demersum* and *Egeria densa* are also located in the lakes near Te Paki (Ngakeketo and Wairaupo respectively). Transfer between these waterbodies and others could be from fishing and hunting activities.

Gypsywort is now well established around the lake, despite efforts to eradicate the only known site of this weed in Northland. The emphasis on managing this species should change to prevent the spread to nearby, unimpacted wetlands. Landowners and recreational users should be alerted to the risk of spread and livestock should be excluded from accessing areas infested by this plant. The seeds of gypsywort are small and easily contaminate footwear, aquatic equipment, and animal hooves.

Direct communications with the landowners, local hunters/fishermen, and wider engagement with industry bodies (Fish & Game, local hunting and fishing clubs) regarding the spread of these high-risk species is recommended as a first step. Considering this is the only know location of gypsywort in Northland, if manawhenua agree, a rāhui or other access restrictions are recommended to prevent the spread to adjacent waterbodies.

**Invasive macrophyte control plan**

A thorough invasive macrophyte delimitation survey should be done to assess the extent of the infestation. This will allow for a feasibility assessment and inform the selection of the most appropriate control options. Based on the 2024 survey, the invasive species occupy a narrow (2 – 3 m) band along the lake edge, starting from the base of the emergent vegetation and extending to a maximum depth of 2 m. Herbicide application in this narrow band along the entire lake perimeter will reduce the biomass however, the macrophytes were coated with epiphyton and there is a lot of suspended organic matter in the water so the effectiveness of the herbicide will be compromised.

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

**Routine monitoring**

Te Ketekete is at risk of rapid deterioration due to invasive species impacts and eutrophication. It is recommended that routine monitoring includes monthly water quality sampling as well as 3 – 5 yearly ecological assessments and invasive species surveillance. If any invasive macrophyte control is to be done, then a more frequent monitoring regime should be implemented to assess the effectiveness of the control.

## 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. |

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| 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. |

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| | 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. |

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| | 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 | | | |
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| **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. |

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| 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 |

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| | 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. |

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| | 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* | | | |
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| **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. |