Whangamarino and Waikare Water Quality Annotated Bibliography

Waikato Regional Council

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Making Sustainability Happen

Revision Record

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0.1	6 May 2024	Nicola Pyper	Katrina Browne	
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Basis of Report

This report has been prepared by SLR Consulting New Zealand (SLR) with all reasonable skill, care and diligence, and taking account of the timescale and resources allocated to it by agreement with Waikato Regional Council (the Client). Information reported herein is based on the interpretation of data collected, which has been accepted in good faith as being accurate and valid.

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Acronyms and Abbreviations

Al	Aluminium
C	Carbon
CHLA	Chlorophyll *a*
CMP	Catchment Management Plan
DOC	Department of Conservation
DRP	Dissolved Reactive Phosphorus
HRT	Hydraulic Residence Time
LINZ	Land Information New Zealand
LWLG	Lake Waikare Liaison Group
LWWFCS	Lower Waikato Waipā Flood Control Scheme
N	Nitrogen
NH_4^+	Ammonium
NIWA	National Institute of Water and Atmospheric Research
NNN	Total Oxidised Nitrogen
NO_2	Nitrogen dioxide
NOF	National Objectives Framework
NO_x	Nitrogen oxides
NPS-FM	National Policy Statement for Freshwater Management
P	Phosphorus
PSO	Peat Surface Oscillation
SAR	Sedimentation Accumulation Rate
SPI	Science, Policy, and Information
SS	Suspended Sediment
TKWWTP	Te Kauwhata Wastewater Treatment Plant
TLI	Trophic Level Index
TON	Total Organic Nitrogen
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Sediment
VSS	Volatile Suspended Solids
WRC	Waikato Regional Council
WWII	World War II

1.0 Introduction

Prior to human influence, the lower catchment of the Waikato River took the form of a low-lying floodplain that supported a system of wetlands and lakes[1]. Lake Waikare and the Whangamarino Wetland together represent part of this system and form a sub-catchment of the lower Waikato River. The Lake Waikare-Whangamarino Wetland catchment altogether comprises an area of 797.1 square kilometres[2], with Lake Waikare being the second-largest lake in the Waikato Region (Lake Taupō is the largest), and Whangamarino Wetland being the second largest wetland complex in the North Island. The Whangamarino River, Matahuru Stream, and Waerenga Stream also form part of the sub-catchment, which ultimately discharges from the mouth of the Whangamarino River on the true right bank of the mainstem of the Waikato River.

The Lake Waikare and Whangamarino Wetland catchment holds multiple values, including economic values (such as productive agricultural land), cultural values, ecological significance, and flood management functions. In the 1960s, Whangamarino Wetland and Lake Waikare were incorporated into the Lower Waikato-Waipā Flood Control Scheme (LWWFCS)[2]. Hydrological modifications were implemented in order to provide flood storage that would protect people and properties, while also facilitating intensive agricultural activity in areas where it had previously not been viable. Modifications to the catchment as part of the LWWFCS included the creation of the Pungarehu Canal, which allows for a controlled discharge (via flood gates) from Lake Waikare to the Whangamarino Wetland. Prior to this, Lake Waikare waters entered the wetland only during large flood events.

The Whangamarino Wetland is a highly-valuegd wetland complex, comprising a mosaic of swampland, peat bog, open water, and flowing waterways[3]. The wetland has been recognised as one of international significance under the Ramsar Convention, as it represents an outstanding example of a wetland that is characteristic of its region. Among other ecological values, the Whangamarino Wetland area supports the largest population of the Australasian bittern (*Botaurus poiciloptilus*, Threatened – Nationally Critical[4]) in the world[5], is a stronghold of the black mudfish[6] (*Neochanna diversus*, At Risk – Declining[7]), and represents the only

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[1] Lealand S, Hare R, Archer M, McKenzie A. 2018. Lower Waikato Zone Plan. Waikato Regional Council. DOI: https://www.waikatoregion.govt.nz/assets/WRC/LowerWaikatoZMP.pdf. 72 pp.

[2] Lawrence L, Ridley G. 2018a. Lake Waikare and Whangamarino wetland catchment management plan, Part 1. Waikato Regional Council. DOI: https://www.waikatoregion.govt.nz/assets/WRC/Council/Policy-and-Plans/CMP_Part_One_Catchment_Overview-WR.pdf. 123 pp.

[3] Cromarty P, Scott DA. 1996. A directory of wetlands in New Zealand. Wellington, N.Z.: Department of Conservation. ISBN 0478017766.

[4] Robertson HA, Baird KA, Elliot GP, Hitchmough RA, McArthur NJ, Makan TD, Miskelly CM, O'Donnell CFJ, Sagar PM, Scofield RP, Taylor GA, Michel P. 2021. Conservation status of birds in Aotearoa New Zealand, 2021. New Zealand Threat Classification Series 36. Department of Conservation. DOI: https://www.doc.govt.nz/globalassets/documents/science-and-technical/nztcs36entire.pdf. 47 pp.

[5] National Wetland Trust. Whangamarino. https://www.wetlandtrust.org.nz/get-involved/ramsar-wetlands/whangamarino/. Accessed 7 May 2024.

[6] Reeves P. 1994. 50 years of vegetation change in the Whangamarino Wetland [Masters]. University of Auckland. DOI: https://auckland.primo.exlibrisgroup.com/permalink/64UAUCK_INST/13vfdcn/alma99264794611502091. 162 pp.

[7] Dunn NR, Allibone RM, Closs GP, Crow SK, David BO, Goodman JM, Griffiths M, Jack DC, Ling N, Waters JM, Rolfe JR. 2018. Conservation status of New Zealand freshwater fishes, 2017. New Zealand Threat Classification Series 24. Department of Conservation. DOI: https://www.doc.govt.nz/Documents/science-and-technical/nztcs24entire.pdf. 15 pp.

remaining habitat for the endemic swamp helmet orchid[8] (*Corybas carsei*, Threatened – Nationally Critical[9]).

Anecdotal reports by historical users of Lake Waikare recall that it was once a 'clear' lake with a visible bed, submerged vegetation, and sandy beaches on the northern and eastern shores[10]. However, Lake Waikare now takes the form of a highly-degraded, hypertrophic waterbody[11]. The lake has poor water quality, high levels of inorganic suspended solids, and high turbidity[12]. It is also highly enriched with nutrients, experiencing large phytoplankton blooms throughout the year[11]. This poor-quality water is discharged to the Whangamarino Wetland via the Pungarehu canal, contributing sediment and nutrients to the wetland system.

The ecological degradation of the Waikare-Whangamarino complex is the result of several processes, including modified hydrological regimes (as a result of the flood scheme)[13], the invasion of pest plants and animals[11], and land use change within the catchment[14]. Rehabilitation and restoration of Lake Waikare and the Whangamarino Wetland is a complex and challenging task and has been the subject matter of many technical reports, consent processes, academic theses, and scientific articles. Therefore, the stakeholders of the Whangamarino Wetland and Lake Waikare catchment are seeking a synthesis of key water quality information relevant to these catchments to inform and support the development of a Response Plan, specifically in relation to recent anoxic events in the Whangamarino Wetland. SLR Consulting New Zealand (SLR) was, therefore, commissioned by the Waikato Regional Council (WRC) to synthesise relevant water quality information in the form of an annotated bibliography.

2.0 Scope

The aim of the review was to provide a compilation of material in the form of an annotated bibliography. The scope of this project was to provide an annotated bibliography synthesising the key information relating to water quality of the Lake Waikare and Whangamarino Wetland catchments. This included a summary of the key water quality information available, any information gaps identified by the reference authors, and what water quality management recommendations were made that may still be worthy of consideration. The development of

[8] de Lange PJ. (2024): *Corybas carsei* Fact Sheet (content continuously updated). New Zealand Plant Conservation Network. https://www.nzpcn.org.nz/flora/species/corybas-carsei/. (7 May 2024)

[9] de Lange PJ, Rolfe JR, Barkla JW, Courtney SP, Champion PD, Perrie LR, Beadel SM, Ford KA, Breitwieser I, Schönberger I, Hindmarsh-Walls R, Heenan PB, Ladley K. 2018. Conservation status of New Zealand indigenous vascular plants, 2017. New Zealand Threat Classification Series 22. Department of Conservation. DOI: https://www.doc.govt.nz/documents/science-and-technical/nztcs22entire.pdf. 86 pp.

[10] Reeves P, Hancock N. 2012. Ecological impacts of the flood control scheme on Lake Waikare and the Whangamarino Wetland, and potential mitigation options. Wildlands. DOI: https://www.waikatoregion.govt.nz/assets/WRC/Council/Policy-and-Plans/HR/S32/D/3154305.pdf. 60 pp.

[11] Lake Waikare Steering Group. 2007. Lake Waikare management options. Environment Waikato Internal Series 2007/12. Environment Waikato. 29 pp.

[12] Stephens S, de Winton M, Sukias J, Ovenden R, Taumoepeau A, Cooke J. 2004. Rehabilitation of Lake Waikare: Experimental investigations of the potential benefits of water level drawdown Hamilton: Environment Waikato. DOI: https://www.waikatoregion.govt.nz/assets/WRC/WRC-2019/TR04-25.pdf. 50 pp.

[13] Barnes G. 2002a. Lower Waikato Waipa flood control scheme: Compilation of ecological evidence provided to the Environment Court Hamilton East. Document # 758388. 151 pp.

[14] Lockyer C. 2015b. Whangamarino Wetland hydrology study. Jacobs New Zealand Limited. DOI: https://ftp.doc.govt.nz/public/folder/QnM3b1OEaU_bk3ahqEV8XA/outputs-2016-2017/047a-lockyer-2015.pdf. 56 pp.

new management recommendations and/or the determination of status of previous recommended actions are beyond the scope of this report.

The reviewed literature included scientific articles, technical reports, and other relevant documents (i.e., academic theses and informal letters/memoranda). Overall, the document list numbered approximately 50 written resources. This reference list was compiled in consultation with the Science, Policy, and Information (SPI) Unit of WRC, with support from Aareka Hopkins (Te Riu o Waikato representative on the Lake Waikare Liaison Group (LWLG)). We emphasise that this annotated bibliography by no means synthesises all the literature available on the subject of Lake Waikare and the Whangamarino Wetland, which far exceeds the 50 documents selected, nor was it intended to do so. The bibliography below is designed to be a stocktake of the most relevant information that is of interest to the LWLG.

3.0 Methodology

The list of documents for review was determined by selecting those that were most relevant to the objectives of the project, which was to synthesise water quality information for the Lake Waikare and Whangamarino Wetland catchment. The finalised reference list was determined in consultation with Mike Scarsbrook, Environmental Science Manager of the SPI Unit (WRC). Te Riu o Waikato representative Aareka Hopkins also provided input to the reference list. The documents were sourced primarily from the WRC Library, with additional resources provided by the Department of Conservation (DOC) and the LWLG. A small number of documents were obtained from online scientific journal databases.

Each document was reviewed and key water quality information was extracted. In addition, any relevant recommendations and knowledge gaps identified were recorded. Together, this information has been summarised in the annotated bibliography presented in Section 4.0 below. We note that recommendations extracted often had the potential to have multifaceted benefits (i.e., for water quality, ecology, cultural values, economic values), therefore, the recommendations extracted from each document do not necessarily apply solely to water quality management. However, those that are directly relevant to water quality have been presented in **bold** for ease of reference.

A full reference list without commentary is provided as Appendix A.

Due to project constraints, a small number of documents selected for review were unable to be summarised. These are included in the reference list so that the reader can access these documents if desired.

4.0 Annotated bibliography

Recommendations in **bold** relate directly to water quality management.

Abell JM, Özkundakci D, Hamilton DP, Reeves P. 2022. Restoring shallow lakes impaired by eutrophication: Approaches, outcomes, and challenges. Critical reviews in environmental science and technology. 52(7):1199-1246. DOI: 10.1080/10643389.2020.1854564.
Water quality information: This record does not provide any water quality information for Lake Waikare or the Whangamarino Wetland, but constitutes a review of literature on shallow lake restoration.
Recommendations:

No direct recommendations for the management of Lake Waikare and the Whangamarino Wetland are provided in this paper. However, approaches to the control of eutrophication in shallow lakes are detailed:

Proactive management

- **Prepare a lake nutrient budget and maintain external nutrient loads within sustainable limits;**
- **Protect healthy wetlands and riparian vegetation; and**
- **Prevent the spread of invasive species (e.g., non-native benthivorous fish).**

External nutrient load reductions

- **Point source (i.e., municipal wastewater discharges) control, by:**
  - **Sewerage reticulation;**
  - **Enhanced nutrient recovery during municipal wastewater treatment;**
  - **Use low-phosphate detergents.**
- **Diffuse (i.e., leaching from farmland) source control, by:**
  - **Fertiliser management (e.g., avoid applying at high-risk times);**
  - **Livestock management (e.g., reduce stocking rates);**
  - **Livestock effluent management (e.g., adopt batch storage);**
  - **Soil phosphorus (P) testing;**
  - **Use of low-solubility phosphorus fertilisers;**
  - **Floodwater/irrigation management;**
  - **Crop management (i.e., adopt practices that limit exposure of bare soil);**
  - **Use nitrification inhibitors;**
  - **Riparian fencing/planting;**
  - **Restoration of natural wetlands;**
  - **Constructed wetlands;**
  - **Grass buffer strips;**
  - **Sediment traps;**
  - **Detainment bunds; and**
  - **Denitrification beds.**

Hydrological alterations and manipulations

- **Inflow diversion to reduce external loads;**
- **Increase dilution/flushing to dilute poor-quality lake water with higher quality water; and**
- **Water level management to increase depth and reduce sediment resuspension.**

Biomanipulation

- **Removal and control of benthivorous fish to reduce bioturbation of benthic sediments and nutrient excretion;**
- **Removal and control of zooplanktivorous fish to increase cladoceran zooplankton biomass and reduce phytoplankton biomass;**
- **Promote bivalves (i.e., mussels) to increase filtration rates and phytoplankton grazing;**
- **Macrophyte harvesting of invasive species to remove nutrients present in plant tissues;**
- **Constructed floating wetlands to facilitate the uptake of dissolved nutrients;**
- **Algicides and cyanocides to directly reduce phytoplankton biomass; and**
- **Promote native rooted submerged macrophyte re-establishment.**

Physical methods of reducing internal nutrient loads ▪ **Dredging to remove nutrient-rich lakebed sediments and reduce sediment nutrient releases; and** ▪ **Passive sediment capping with inert materials (i.e., sands, minerals, or gravel) to create a physical barrier between benthic sediments and the water column.** *Chemical methods of reducing internal nutrient loads* ▪ **P adsorption (i.e., by use of aluminium (Al) salts); and** ▪ **Flocculation to remove organic material.** Decision support tools have been developed to identify the most appropriate lake restoration methods for a particular lake, such as the geoengineering assessment framework developed by Hickey and Gibbs (2009): "Lake sediment phosphorus release management – Decision support and risk assessment framework", *New Zealand Journal of Marine and Freshwater Research*. Successful shallow lake restoration projects typically involve many of the following: ▪ **Major controls on external nutrient loads;** ▪ **Additional controls on internal nutrient loads;** ▪ **Nutrient load reduction targets that address a range of sources;** ▪ **A lake restoration plan with quantitative targets**; ▪ Leadership but a dedicated water management agency; ▪ Regulation to achieve nutrient load targets; ▪ A political framework that supports a catchment-scale approach to management; ▪ Capital to support restoration, and funding for ongoing maintenance and monitoring; ▪ Presence of an active local restoration group; ▪ Engagement with motivated local groups; ▪ Good knowledge of the limnology of the lake; ▪ Reaction to a perceived environmental crisis; ▪ A robust monitoring programme to monitor and adapt to change; and ▪ Education to foster understanding of the issue. **Reducing external nutrient loads is fundamental to the successful and sustainable restoration of shallow lakes degraded by eutrophication; a failure to enact sufficient reductions to external nutrient loads is a major cause of poor lake restoration outcomes.**
Information gaps: No information gaps were identified by the authors.

Barnes G. 2002a. Lower Waikato Waipa flood control scheme: Compilation of ecological evidence provided to the Environment Court Hamilton East. Document # 758388. 151 pp.
Water quality information: High turbidity was observed in Lake Waikare in the 1940s, after World War II (WWII) and during a time of extensive land clearance in the Matahuru Catchment. Turbidity reduced when Waikato River flood waters entered the lake. This suggests that the majority of the sediment load entering the lake was from the Matahuru stream and turbid floodwaters running over recently cleared land. Turbidity around the lake shoreline remained low in the 1960s. Lake levels were lowered in 1965 as part of the flood control scheme. This is thought to have increased wave-induced sediment re-

suspension into the water column and reduced light penetration. Aerial photographs show that by 1977 both the main body and shoreline of the lake had become turbid.

WRC began undertaking routine measurements of water quality in Lake Waikare in 1982. The first water quality reports for the lake revealed very high suspended sediment concentrations (~120 g m^{-3}).

Water quality measurements were referenced throughout the evidence document. The key ones have been summarised:

- Mean suspended sediment in Lake Waikare over the continuous data record (1993-2001) was 142 g m^{-3}, and an upward trend was apparent.
- Surface suspended sediment levels measured at an average of 14.5 g m^{-3} in summer but near the lakebed these levels increased 32-fold to 464.4 g m^{-3}.
- Suspended sediment measurements were correlated with turbidity, which is indicative of very fine-grained (silt or clay) inorganic particles being the dominant particle size class. These particles settle very slowly, efficiently scatter light, and, therefore, result in a decline in optical conditions.
- WRC turbidity and suspended sediment data for the lake showed variability related to wind events and inflows of floodwaters.
- Chlorophyll *a*, an indicator of phytoplankton biomass, was consistently high (median 28 mg m^{-3}) and indicative of a eutrophic system, bordering on hypertrophic. There was no apparent trend in chlorophyll *a,* but it was very weakly correlated with turbidity. This is typical of a limited light climate and suggested that algae are not a major contributor to lake optical character because the contribution of algae to light attenuation in the lake is masked by high levels of inorganic clay and silt.
- Median Total Nitrogen (TN) and Total Phosphorus (TP) concentrations for the continuous data record (1993-2001) were 1.1 g m^{-3} and 0.18 g m^{-3} respectively. Both measures were consistent with a highly eutrophic status and both parameters increased significantly during the observed period.
- Water clarity, measured by Secchi depth, declined significantly (-8 mm/y) over the continuous data record.

The primary inputs of both water flows and suspended sediments to Lake Waikare originate from:

- Matahuru Stream;
- The bed of Lake Waikare;
- The Waikato River via the Te Onetea Stream;
- The Waikato River via the Rangiriri Weir; and
- Runoff from the surrounding catchment.

The turbid water in Lake Waikare is most likely a product of a range of factors, such as land clearance within the lake catchment, consequent sediment and nutrient loading on the lake, grazing of the wetland margins, and lowering of the lake level. Controlling the water level within a small range has likely reduced periodic flushing from Waikato River flows, particularly during flood events. These flows previously provided flushed and diluted the high suspended sediment concentrations of the lake water.

The primary inputs of water flows and suspended sediments to the Whangamarino Wetland come from:

- Lake Waikare;
- The Whangamarino River;
- Mangatangi Stream; and
- Runoff from the surrounding catchment.

The compiled evidence document included a suspended sediment budget for Lake Waikare and the Whangamarino Wetland, published on page 47. The budget revealed that the Matahuru Stream is a major source of sediment to the lake. In contrast, flows through the Te Onetea gate contributed less than 3% of suspended sediment inputs to Lake Waikare, and so had little influence on the sediment budget of the lake or the Whangamarino Wetland. The sediment budget indicated that approximately 10,200 t of sediment arrived in the lake each year, and approximately 14,300 t left the lake towards the Whangamarino Wetland.

The budget shows that 30% of total sediment inputs to the Whangamarino Wetland came from Lake Waikare, while the Whangamarino River was the wetland's main source of sediment. The radial gates at the downstream end of the wetland appeared to have very little effect on sedimentation in the wetland area. It was estimated that approximately 33,500 tonnes per year settled in the wetland, indicative of a net sediment deposition rate of about 0.5 mm/year across the whole of the Whangamarino Wetland.

The Whangamarino Wetland deteriorated 50 years prior to the writing of this document due to changes to the hydrological regime, accelerated inputs of nutrients and sediments, and introduced plant and animal pests impacting on the abundance and diversity of indigenous species. The flood control scheme had an adverse effect on the water quality of Lake Waikare and it is probable that the discharge of silt laden water from Lake Waikare to the Whangamarino Wetland contributes to the process of accelerated sedimentation.

<u>Recommendations:</u>

Management options identified:

- **Riparian management/enhancement in the Matahuru Stream as a means to reduce contaminant inputs:**

  The overall effectiveness of this option was rated as 'medium' and would be expected to have major benefits to the water quality, instream habitat, and ecosystem health of the Matahuru Stream. It was recommended that riparian management in the catchment should be aimed at capturing sediment in overland flows before it reaches the waterways. It was also suggested that fencing off grassed buffer strips of between 5-15 m should be sufficient to filter out between 50-95% of sediment, prevent cattle from exacerbating bank erosion, and reduce nutrient loading on the lake. It was also recommended that actively eroding stream banks be stabilised with trees and shrubs that grow vigorously and have extensive root systems (e.g. non-invasive willows and poplars); and that these should be planted at 10 m intervals on stream banks where the stream is wide enough (>7-8 m) so that the streambanks would not be entirely shaded. Priority areas for riparian management in the Matahuru Stream catchment were identified:

  - Fencing and replanting the Matahuru Stream from the junction of Matahuru Road and Hoult Road to Lake Waikare (approximately 17 km). It was recommended that replanting focus on stabilising bank erosion.
  - Fencing tributaries, particularly in sub-catchments that do not have their headwaters in native forest.
  - It was also suggested that SS samples along the various inflow streams could be obtained to confirm areas of major focus and to monitor progress of the programme.

  It was suggested that an experimental zone of fencing and planting along the edge of Matahuru Stream could be initiated to establish setup costs, effectiveness of the works, maintenance costs, and acceptance by landowners. Satellite imagery, or aerial photography of the agricultural areas in the catchments could also be obtained to establish areas of major focus and to monitor progress of the proposed stream care programme.

  It was also suggested that areas of considerable stream erosion could be improved with the addition of rock fill rubble overflow weirs, as these can act as energy dissipaters within the streams and reduce the stream velocity.

- **Riparian management around the edges of Lake Waikare:**

  The overall effectiveness of this option was rated as 'low'. The evidence compilation recommended fencing to prevent stock access and planting of trees that can withstand strong wave action on actively eroding shorelines. This could be beneficial for stabilising areas of active lake edge erosion, encouraging the establishment of emergent vegetation and/or turf communities, and enhancing habitat for wetland fauna.

The priorities for fencing and replanting the margins of Lake Waikare were identified as:

- Along the northern shore, particularly properties 10, 11, 12, 15, 16, and the unplanted section of 19 (ref. Lake Waikare Margin Landowner Schedule) and
- Along the eastern shore, particularly properties 23 – 30, 37 – 43, and 45 of the Lake Waikare Margin Landowner Schedule.

- **Capture of catchment turbidity in wetlands:**

  It was suggested that the Matahuru Stream could be re-directed into a natural wetland adjacent to the last 500-600 m of the Matahuru Stream before it enters the lake. To reduce the amount of sediment entering the wetland, a sediment retention pond could also be constructed before the wetland to settle out a coarse fraction of the settlement load. However, the overall effectiveness of this option was rated as ‘low’.

- **Increasing the inflow from Te Onetea Stream**:

  The overall effectiveness of this option was rated as ‘low’, as a significant increase in the present flow of water through Onetea Stream would be required to substantially reduce the average hydraulic residence time (HRT) of the lake and significantly reduce lake water turbidity.

- It was suggested that wave baffles could be installed to protect inshore areas from wave action to aid the re-colonisation of specific lake margin areas by submerged vegetation:

  This option would also reduce inorganic suspended sediment within baffled areas. The western shore of Lake Waikare would be the most appropriate area to undertake such protection works. The northwestern shore also contains three shallow bays that could be effectively isolated from waves by baffles across their mouths. Within the compilation of evidence there is the suggestion that wave barriers be placed approximately 100 m from the shoreline. The overall effectiveness of this option was rated as ‘high’ it was noted that this is a high-risk option, as calmer conditions could lead to the development of blue-green phytoplankton blooms, potential anoxia during warm conditions, and phosphorus release from the lakebed.

- **Consolidation of lake suspended sediments by dropping the water level of the lake down to expose large areas of the lakebed, leaving them to dry out and consolidate before reflooding:**

  Not enough information was available at the time this document was produced to determine whether this would be effective and, therefore, it was considered a high-risk option.

- **Changes to lake water levels:**
  - Modelling showed that raising the lake level by 1 m would reduce near-bed-orbital velocities by 40-80%. This translates into a drop in the wave-induced suspended-sediment concentration at the lakebed of 95-100%, in other words, this could substantially reduce the impact of wave action on the lakebed in the areas of the lake where the water depth was more than one metre deep, which was about 80% of the lake. This reduced wave energy could lead to a significant increase in water clarity. However, it was recommended that, if this option were pursued, steps should be taken to help the impacted landowners adjacent to the lake construct stop banks to protect their land from flooding.
  - A return to a more natural water level fluctuation range (by artificial manipulation) with a larger water level range could be key for increasing the extent of emergent vegetation and amphibious turf plants. This would involve drawing lake levels down to expose the lake edges and stimulate vegetation regrowth. This would require the use of level control structures at the outlets of the lake, and active management of the vegetation succession process will ensure that desirable vegetation community types establish. However, it was recommended that, prior to implementing a major change to the present water regime, a site in Lake Waikare for an experimental drawdown should be identified. This zone should

be isolated from the lake body with a dyke. It should then be drawn down by pumping to confirm the response of the lakebed to exposure to the sun. It should also be flooded to a level about one metre higher than the present lake level to confirm the survival of the established emergent vegetation in the temporarily deeper water. ▪ This option could be impractical, as it would require extensive stop banking to mitigate raised lake levels. However, it could be possible to establish a wider fluctuation regime by lowering the current minimum lake level, exposing areas of the lakebed (particularly on the northwestern side of the lake) to colonisation by wetland plant communities. ▪ **Delaying the operation of the Waikare gate during the peaks of floods from Matahuru River:** This would allow sediment-laden water to be channelled through the Whangamarino Wetland and prevent the flood flows from being coincident with those from the Wetland's immediate catchment. ▪ Invasive fish management: The removal of carp from the lake was raised as a potential option. This could be carried out by inoculation of the lake using pesticides such as rotenone or sappanin. These carp removal procedures should be tested before use. However, the cost of the quantity of piscicide required to achieve this likely makes this unfeasible. ▪ **Changing farming practices:** ▪ Farming techniques in the catchment could be modified to reduce sediment and nutrient inflow to the streams. A grazing management programme to reduce sediment movement would include additional internal fencing to control livestock access to the edge of streams or the lake, provision of off-site watering facilities, and grazing management by rotating livestock through various paddocks. ▪ It was recommended that the entire upland area surrounding Lake Waikare and the Whangamarino Wetland be fenced to prevent livestock access. It could also be possible to divert sediment-laden stream water to crown land nearby. This would reduce suspended sediment and provide a source of seeds for marginal plants in these areas. However, this approach should be tested experimentally before general application. ▪ A programme could also be implemented to provide technical advice and economic incentives to farmers to encourage them to introduce forage strips adjacent to their streams. ▪ **Diverting Lake Waikare water directly to the Waikato River:** Sediment reduction in the Whangamarino Wetland could be accomplished by diverting lake water back to the Waikato River via the Te Onetea Stream. However, this would likely require an increase in the capacity of the existing channel and the control structure on the stream. However, this may not be feasible, considering the current techniques available and due to the fact that the levels of the Waikato River exceed the water level of Lake Waikare most of the time. It was recommended that inflows through the Te Onetea gate be monitored over a year to inform a decision around diversion of the Lake Waikare water. ▪ **Increasing the capacity of the Te Onetea culvert and the Lake Waikare outflow** This could improve the quality of Lake Waikare by increasing the inflow of higher quality water from the Waikato River, with the Te Onetea culvert promoting a localised improvement in water quality in the northwestern area of the lake. ▪ Alternative mitigation options: ▪ Lake edge fencing and planting to enhance habitat for fish and birds. This should focus on the low-lying areas around the lake that are periodically wet. ▪ The physical characteristics of the lake within a heavily modified catchment, combined with the high levels of eutrophication, make water quality restoration less realistic than wetland enhancement. Enhancement of the remaining wetland areas on the western margin of the lake, particularly the margins of properties 1, 3, 69-71 on the Lake Waikare

Margin Landowner Schedule was raised as an option. It was suggested that this could include fencing to exclude stock and control of weeds such as crack (*Salix x fragilis*) and grey willow. This could be a more realistic goal that restoring lake water quality.

- Re-creation of the wetland extent adjacent to Lake Waikare. Crown land could be reserved for this purpose and, where possible, easements could be obtained on private land, perhaps by making a major funding contribution for any required stop bank works.
- Restoration of submerged vegetation in either one of the smaller lakes nearby (e.g., Lake Kopuera, Lake Rotongaro, Lake Waahi, Lake Whangape, or Lake Ohinewai), where there is a much greater chance of restoration success.

The evidence compilation also included a recommendation to shift the water level recorder to be adjacent to the radial gate so that the records would be of value in estimating both water and sediment output from the lake.

<u>Information gaps:</u>

Across the evidence compilation, experts noted areas where there were data gaps, or where future data collection could be useful:

- Data on the proportions of suspended sediment entering Lake Waikare from the Matahuru Stream catchment via overland flow versus bank erosion;
- Suspended sediment background concentrations for the natural wetland adjacent to the final 500-600 m of the Matahuru Stream before it enters the lake;
- The period of time lakebed sediments would stay consolidated after a period of drying and re-flooding of lake sediments is not known, but experiments could inform predictions of sediment suspension;
- Records of Lake Waikare radial gate openings;
- Information on fish biomass in Lake Waikare;
- No analysis had been done (at the time the document was compiled) on the mineral or nutrient composition of the lakebed sediments;
- At the time the document was compiled, little information was available on flow and suspended sediment for the Whangamarino Wetland after 1996;
- Up until the time the document was compiled, no suspended sediment samples had been taken from the Mangatangi River since 1995, or from the Whangamarino River since 1997;
- Outflows from the Whangamarino Wetland had not recorded at the time the document was prepared;
- A need for a water-level recorder in the Te Onetea Stream was highlighted. This would increase knowledge of flow direction and flow rates so that the contribution to both the water and sediment budgets can be more accurately established; and
- One expert opined that there had been no large-scale collection of field data in response to a well-structured research programme focussed solely on Lake Waikare.

Barnes G. 2002b. Water quality trends in selected shallow lakes in the Waikato region, 1995-2001. Environment Waikato. ISSN: 117-4005. 23 pp.

<u>Water quality information:</u>

Lake Waikare has extremely high inorganic SS levels. It is generally accepted that SS levels are the main factor limiting the biological productivity of the lake, due to the associated restrictions on light penetration.

Between 1995 (when water quality monitoring commenced in Lake Waikare) and 2002, water quality and trophic level in Lake Waikare deteriorated. Parameters with a deteriorating trend included visual clarity (Secchi depth), total nitrogen (TN), total phosphorus (TP), total organic nitrogen (TON), TP minus dissolved reactive phosphorus (DRP), total suspended solids (TSS), and volatile suspended sediment (VSS). Only total oxidised nitrogen (NNN) measurements improved. The increase in TP was accounted for a by a similar increase in particulate P, while the increase in TN coincided with an increased conversion of NNN into TON. Additionally, the increase in particulate matter over the sampling period was likely due to increased phytoplankton growth efficiency (manifested in a change in phytoplankton population structure rather than biomass), as more NNN would have been converted into TON with time. Increased particulate matter is also likely to occur due to increased resuspension of sedimented materials. Sediment contributions to the lake are sourced from erosion at the base of the Matahuru catchment. Sediments are then resuspended from the lakebed by wave action. Anecdotal evidence suggested that suspended sediment levels became persistently higher from the 1940s and increased further after the collapse of submerged aquatic plants between 1977 and 1979. Overall, analysis of the four principal indicators of trophic status indicated that Lake Waikare had eutrophied since 1993.
<u>Recommendations:</u> The report offered two relevant recommendations: ▪ **Water quality monitoring should continue at Lake Waikare; and** ▪ **The shallow lakes water quality monitoring programme should be reviewed in 2006/07**. In addition, the report made more general comments about pathways to lake recovery: ▪ **Large scale changes to riparian management would be required to ensure sufficient reduction in external nutrient loads**; and ▪ The protection of remaining submerged plant communities and the re-establishment of collapsed populations was considered an important priority for buffering the impacts of land use intensification and for maintaining and enhancing in-lake biodiversity.
<u>Information gaps:</u> No information gaps were identified.

Blyth JM. 2011. Ecohydrological characterisation of Whangamarino Wetland. Hamilton, New Zealand: University of Waikato. DOI: https://hdl.handle.net/10289/5344. 189 pp.
<u>Water quality information:</u> The Whangamarino Wetland is subject to continued inundation with nutrient- and sediment-rich flood waters from the Whangamarino River and Lake Waikare. Larger flood events can also reach into zones of pristine, low-nutrient bogs, depositing dissolved nutrients in flood waters, which could ultimately diminish their size and extent. Nutrient inputs sourced primarily from hydrological processes could be having a large-scale effect on the Whangamarino Wetland. Leaching of nutrients to the Whangamarino River and Pungarehu Canal (and upstream tributaries) leads to greater nutrient fluxes in the wetland. Nutrient leaching coupled with the effects of the flood storage scheme, results in a greater impact on the wetland from nutrients and sediment. Poor water quality in turn affects vegetation (alters species composition) and aquatic and terrestrial communities, and diminishes the overall health of the wetland. A flood event in 2010 revealed that TSS followed a similar pattern to the flood hydrograph, which is what would be expected, as higher volumes of water carry greater quantities of eroded sediment from riverbanks and surrounding farmland. During the flood event, high concentrations (260 mg

L^{-1}) of sediment were measured in the Whangamarino River, nearly twofold that of the Pungarehu Canal (86 mg L^{-1}, with the Lake Waikare control gate was closed). Flood nutrient sampling showed that dissolved nutrient patterns exhibited some similarities to the increased sediment load, but were not entirely consistent. Ammonium (NH_4^+) and DRP increased in the Whangamarino River as the flood event proceeded. Increases in DRP were more pronounced, with the highest concentration observed at the biggest flood peak. Nitrogen oxides (NO_x) increased significantly toward the tail of the hydrograph, as the flood peak decreased, but changed little throughout most of the flood event. In the Pungarehu Canal, NH_4^+ and DRP increased towards the tail of flood sampling, while nitrogen dioxide (NO_2) and NO_x followed a pattern similar to TSS. Flood driven imports of nutrients and sediment were thought likely to be the main cause of higher nutrient concentrations in peat and foliage measurements.
<u>Recommendations:</u> The Whangamarino Wetland requires ongoing monitoring and mitigation actions to ensure any significant ecosystem changes can be halted or reversed. Recommendations for future management included restoration of catchment water quality and improved management of the flood control regime: ▪ Sediments and nutrients deposited in the wetland due to flooding have a primary impact on vegetation composition, and should to be mitigated. The document suggests that **mitigation could involve riparian planting and restrictions on farming and cropping practices in the upper Whangamarino River catchment**. This would reduce sediment loads entering the wetland. **Significant inputs to Lake Waikare (primarily from Matahuru Stream) also ultimately enter the wetland, and, therefore, it was recommended that this catchment be treated with a similar approach**. ▪ Fencing of farmland directly adjacent to the wetland was considered important for ensuring cattle do not encroach into the pristine restiad bog and encourage weed invasion through disturbance and nutrient inputs.
<u>Information gaps:</u> Suggested pathways for further data gathering and research include: ▪ Ongoing wetland monitoring to identify any further effects the hydrological regime may be having on wetland condition, such as effects on vegetation composition and nutrient inputs. A controlled flood regime has been established at the Whangamarino Wetland and further research would be required to assess its impact over the next 5 – 10 years. ▪ A detailed study of flood water quality (during various flood events) would be useful to determine the possible sources and concentrations of nutrients and sediment coming into Whangamarino Wetland from flood events. Additionally, while it was thought that Lake Waikare may contribute significant sediment loads, as it is highly turbid, to confirm this flood sampling would need to be undertaken during pronounced hydrographs in the Pungarehu Canal. ▪ Nutrient and sediment analysis could be undertaken for other areas of the Whangamarino Wetland where it is likely that the flood inundation distance would differ. Depth profiles (cores) along transects assessing nutrient and sediment concentrations could reveal the longer-term impacts of the flood control regime. Yearly deposition rates could also be identified and changes in inundation distance or peat degradation could be elaborated on. ▪ Vegetation composition is an important indicator of wetland class and regular monitoring locations or transect lines through areas of the Whangamarino Wetland would ensure changes caused by the complex hydrological regime could be identified. ▪ Further study of the possible encroachment of the mānuka (*Leptospermum scoparium*) zone into the ombrotrophic restiad bog was considered important, and was recommended to occur over a few years to identify any change that is a direct response to flooding.

- As flooding was considered to have the primary impact on the wetland, mapping potential inundation across the entire wetland would be beneficial. This could be undertaken through spatial modelling. The knowledge of zones that are regularly inundated with nutrient and sediment-rich water could provide an insight into areas that are most likely to be degrading over time and most sensitive to weed invasion. Management and restoration efforts could target these areas that are most at risk.
- A detailed study of peat surface oscillation (PSO) at various sites would give a better understanding of surface changes. The existing research indicated there may have been a decline in surface elevation over one year at Whangamarino Wetland. This could be due to peat degradation, it was highlighted that this requires long-term study to be confirmed.

Bodmin KA, Champion PD. 2010. Review of Whangamarino Wetland vegetation response to the willow control programme (1999 - 2008) Hamilton, New Zealand: National Institute of Water Atmospheric Research. DOI: https://ftp.doc.govt.nz/public/folder/QnM3b1OEaU_bk3ahqEV8XA/outputs-2016-2017/051a-bodmin-2010.pdf. 73 pp.

Water quality information:

This report provided no water quality information but reviewed willow management in the Whangamarino Wetland and associated management outcomes.

Recommendations:

- The value of pursuing a continued widespread grey willow (*Salix cinerea*) control programme was questioned, as its long-term success is highly unlikely.
- It was recommended that high-value sites within the Whangamarino Wetland at risk of, or in the early stages of, willow invasion should be selected, prioritised, and managed to prevent willow impact at such sites. These high-value sites should include the areas that support threatened species and declining vegetation types, for example, sedgeland.
- The point was raised that protection of the largest remaining sedgeland area could be confounded by land tenure, as it is owned by Fish & Game. The continuous spread of grey willow has reduced open sedgeland area, with the potential for it to be lost entirely if there is no intervention. Discussion with Fish & Game regarding management of the site was recommended. The DOC could oversee willow and sensitive management of the sedgeland could be undertaken by Fish & Game.
- It was recommended that highly-selective control methods be used in high value sites. These methods include cut and paint, drill and fill, or single-nozzle spot spraying. Boom spraying is only appropriate where dense canopies of willow occur.
- It was highlighted that there was a need for a planned monitoring programme to be implemented pre- and post-weed control to ensure management actions are measured and modified (as required) to achieve the desired objectives.

Information gaps:

No information gaps were identified.

Champion PD, Bodmin KA. 2009. Whangamarino weed surveillance Hamilton, New Zealand: National Institute of Water and Atmospheric Research. DOI: https://ftp.doc.govt.nz/public/folder/QnM3b1OEaU_bk3ahqEV8XA/outputs-2016-2017/051b-champion-2009.pdf. 32 pp.

<u>Water quality information:</u> No water quality information was provided. This report presented a weed species surveillance list, provided the key identification features for those species, identified habitats threatened, assessed the risk of invasion, identified responsibility for control, and proposed an active surveillance and incursion response (weed-led control) for the Whangamarino Wetland.

<u>Recommendations made:</u>
It was recommended that active surveillance of weeds be concentrated at the sites most susceptible to plant incursion, including:
▪ Roadsides and tracksides, particularly the ends of roads or any area where rubbish is likely to be dumped;
▪ Developed areas, i.e., near railways, quarries, disturbed habitats, old homesteads, and settlements;
▪ Areas affected by introduced animals;
▪ In or near rivers and streams (it was recommended that boat surveillance along all navigable waterways be undertaken);
▪ High-value sites, such as habitats of threatened plants; and
▪ Along boundaries, particularly reserve boundaries, and near areas of habitation.
Six-monthly checks (every November and April) of these areas were recommended, especially areas close to known weed sources (e.g., Pungarehu Canal, railways, road ends, and areas adjacent to settlements where garden rubbish is habitually found). The shoreline of Lake Waikare and Te Onetea Stream were routinely surveyed for alligator weed, therefore other species could also be monitored on these occasions.
In the instance an incursion was found, the recommended response was:
▪ Confirm weed identification (DOC weed technical officer, WRC, biosecurity staff, NIWA, Landcare, AgResearch);
▪ Contact the appropriate management agency (WRC if the plant is a target for eradication);
▪ Delimit the extent of the incursion (GPS, photo points, etc.);
▪ Attempt to contain the incursion (e.g., contain the area with nets), especially if found in flowing water;
▪ Evaluate management options (contain, control, eradicate, or do nothing):
    ▪ If continued invasions were predicted and no control tools were available (e.g., for bladderwort), management should be restricted to physical removal of plants from high value sites;
    ▪ Hand-weeding or digging – ensure all plant material is collected, securely bagged, and disposed of by deep burial or incineration;
    ▪ Herbicide application – ensure applicators are appropriately qualified, that herbicides are selective for the identified species, and that damage to non-target vegetation, contamination of waterbodies, etc. is prevented (seek advice from DOC weed technical officer, WRC biosecurity staff, NIWA, or AgResearch);
    ▪ Where application over water is required, ensure a resource consent is obtained (or a waiver from WRC is issued); and
    ▪ Where eradication is pursued, continue to monitor the site for an appropriate length of time after weed removal to ensure eradication is achieved (usually a minimum of 5 years).

<u>Information gaps:</u> No information gaps were identified.

Cooke J, Cox T. 2015. Lake Waikare Water Quality modelling: Using a new model to investigate flushing strategies. DOI: https://www.waternz.org.nz/Attachment?Action=Download&Attachment_id=3576. 19 pp.
<u>Water quality information:</u> The nutrient concentrations of the Waikato River are significantly lower than those Lake Waikare. Therefore, flushing Lake Waikare with large volumes of river water on a continuous (or near-continuous) basis, could, theoretically, benefit lake water quality by: 1. Reducing nutrient concentrations in the water column by dilution; 2. Flushing polluted sediments and sediment-bound nutrients out of the lake; and 3. Inhibiting phytoplankton growth by reducing lake residence times. Observed TP concentrations in the lake historically ranged from 0.03 to 1.1 mg L^{-1}, with an average concentration of 0.22 mg L^{-1} and a standard deviation of 0.15 mg L^{-1}. Total nitrogen concentrations ranged from 0.6 to 5.2 mg L^{-1}, with an average concentration of 2.4 mg L^{-1} and a standard deviation of 1.0 mg L^{-1}. Generally speaking, nutrient and phytoplankton concentrations were highest during the summer months and lowest during the winter. However, short-term spikes occurred throughout the year. There was evidence that the lake is laterally well-mixed and, given its shallowness, it was also considered highly likely that it was vertically well-mixed. Nitrogen (N) to P ratios in the lake indicated that the lake shifted between N and P limitation over the period of record. However, it appeared to be predominantly P-limited, having changed from being predominantly N limited in c. 2005. Tributary sampling results showed that the smaller lake tributaries had higher nutrient concentrations compared to Matahuru Stream (the largest tributary inflow to the lake) by factors of approximately two and four for N and P, respectively. Tributary nutrient concentrations also generally exceeded lake water column concentrations. Modelling indicated that the predominant source of nutrients to the lake was diffuse catchment runoff. Loads from the non-Matahuru portion of the catchment comprised approximately 64% and 45% of the total annual load to the lake for P and N, respectively. The Matahuru catchment contributed approximately 30% and 43% of the total load of the two nutrients, respectively. External loads were highest during the wet winter months (during high flows) and lowest during the summer and autumn months (when the hydrology is drier). The Te Kauwhata Waste Water Treatment Plant (TKWWTP) contributed approximately 1% and 0.3% of the total loads of P and N, respectively. Therefore, the vast majority of nutrient inputs (c. 99% nitrogen, 95% phosphorus) came from wider catchment land use (dairy, sheep, and beef farming), in comparison to the small contribution from the TKWWTP. A large portion of the external loads settle as particulates, forming an active sediment layer. They then re-emerge as dissolved, biologically internal loads later in the year (summer and autumn months). Internal loads from the sediments were highest during the summer months and lowest during winter. Modelling revealed that the proposed flushing strategies had the potential to produce significant improvements in nutrient and phytoplankton concentrations in the lake, as well as improvements in overall trophic status. For the lowest flow scenario (5 m^3/s), reductions of 35%, 46%, and 47% were projected for mean annual TP, TN, and phytoplankton concentrations, respectively, compared to the status quo. For the high flow scenario (50 m^3/s), reductions of 53%, 63%, and 80% were projected for the three water quality parameters, respectively. These improvements would occur as a result of a mass dilution, flushing of nutrient-rich lake sediments and suspended particulates, and inhibition of phytoplankton growth due to reduced residence times. However, while these projected reductions in TP, TN, and chlorophyll *a* (CHLA) are impressive, there may be no discernible difference in the quality of the lake to the public. The lake trophic status would shift from "hypertrophic" to "supertrophic", with trophic level indices (TLI) improving moving from 7 to below 6 (for the higher flushing rate alternatives). Thus, the lake would remain turbid and highly enriched with algae. However, the incidence of toxic blue-green algal blooms would be expected to decrease.

These predicted lake improvements represented the displacement of pollutant load to downstream waterways (i.e., ultimately back to the Waikato River), rather than resolution of the root cause, which is runoff from agricultural areas within the catchment. The assimilative of capacity of the river, with respect to nutrient loads, is higher than that of the lake. However, there would be consenting issues associated with discharging additional nutrient loads to the Waikato River. Moreover, whilst the Whangamarino Wetland downstream of the lake could provide significant filtration of the lake discharge load prior to water being discharged to the Waikato River, the bog and fen components of these wetlands are particularly sensitive to nutrients.
Recommendations: **Collect time-varying sediment nutrient concentration data for the lake, as well as water quality and flow data associated with the lake's smaller tributaries.** **Differences in assimilative capacities between the lake, river, and intermediary wetlands (Whangamarino) should be considered in a broader modelling analysis in any future studies on lake flushing.**
Information gaps: It was noted that there is a lack of historic sediment quality data, which created uncertainty around the depth of the microbially active sediment layer in the model. Additional sediment nutrient data over an extended monitoring period would help refine the model calibration and the representation of sediment-water column interactions. Water quality and flow data associated with the lake's smaller tributaries (non-Matahuru) were considered lacking.

Davenport MW. 1980. Setting of control levels for Lake Waikare. Waikato Valley Authority. Internal Report No 80/MWD/2. 7 pp.
Water quality information: Although there is little evidence available on the lakes' water quality prior to lowering and controls being imposed, it was visually of a higher quality before artificial modifications. It has been recorded that exotic oxygen weed (*Elodea canadensis*), was present before imposing control of lake levels, which is considered an indication of the superior quality of the lake water in the past, as this plant is not normally successful in eutrophic or turbid waters. In 1977-78 there was a major die off of these beds, and although a cause for this is difficult to define, the high sediment load in the lake was likely a significant factor. Stable water levels and consequent wave action have contributed to the erosion of parts of the shoreline, particularly on the Eastern side of the lake. This contributed to the suspended sediment load of the lake. The lower water quality created by the factors mentioned above is further compounded by the closure of the Te Onetea Stream.
Recommendations: ▪ A control regime of some benefit to the parties discussed in the report (Wildlife Service, Auckland Acclimatisation Society, and the eel fishery) could be designed to regain and promote seasonal wetland. This would require the reversal of the present nominal conditions of higher summer than winter levels. Additionally, to approximate natural seasonal changes a greater difference between the two would be necessary. ▪ It was recommended that the possibility of opening the Te Onetea Stream should be fully evaluated, to allow for the free migration of fish and shrimp, and to facilitate the maintenance and/or improvement of water quality.

▪ **Any further permanent lowering of the lake would be detrimental to both wildlife and fisheries values, as well as to water quality**. ▪ Any significant permanent raising of lake levels could be beneficial to its wildlife values by increasing the amount of existing wetland. It would also be beneficial to the eel fishery through the creation of more shallow water feeding areas. Raising levels significantly could also improve water quality through a reduction of wave-induced sediment load.
Information gaps No information gaps were identified.

Dean S. 2014. Whangamarino weir resource consent report. Department of Conservation. DOCDM-1505756. 53 pp.
Water quality information: The report was prepared in compliance with resource consent conditions for a weir installed on the Whangamarino River, which was installed with the purpose of ensuring a minimum water level is maintained in the Whangamarino Wetland. The report presents the results of a monitoring programme designed to detect any adverse effects of the weir, and therefore, relates primarily to the weir's performance, river siltation, and vegetation monitoring. No relevant water quality information is provided, however some information relevant to the siltation of the Whangamarino Wetland is touched on briefly: The primary cause of sediment accumulation in the Whangamarino Wetland is the unnaturally high sediment loads coming from the Whangamarino catchment, as well as Lake Waikare during flood flows. Sediment accumulation throughout the wetland can also be attributed to the restricted channel conveyance downstream of the weir and the backing up of water against the Whangamarino control gates and the Waikato River during flood.
Recommendations: No relevant recommendations were provided.
Information gaps: The report provides suggestions for research and monitoring priorities at Whangamarino Wetland that will fill information gaps, including: ▪ Ground level surveys at bog margins and modelling work to improve understanding of bog inundation at different water levels; ▪ Expanding knowledge of fish populations in the wetland (cf. Lake et al. 2011 "Fish survey of the Whangamarino Wetland 2007/2008"); ▪ Investigating how koi carp (*Cyprinus rubrofuscus*) utilise the Whangamarino Wetland in order to inform control programmes; ▪ Investigating the implications of aerial willow (*Salix sp.*) control on native fish species; ▪ Finalising the 2014 vegetation map based on high-resolution aerial photography and assessing changes in extent of vegetation (including willow); ▪ Repeat vegetation mapping at five yearly intervals; and ▪ Re-survey vegetation plots in the willow spray area to assess vegetation recovery.

Duggan K, Roberts L, Beech M, Robertson H, Brady M, Lake M, Jones K, Hutchinson K, Patterson S. 2013. Arawai kakariki wetland restoration programme. Wellington: Department of Conservation. DOI: https://www.doc.govt.nz/Documents/conservation/land-and-freshwater/wetlands/whangamarino-outcomes-report.pdf. 76 pp.

Water quality information:

The connection to Lake Waikare results in regular influxes of sediment laden water to the Whangamarino Wetland. Together with inputs from other rivers, streams, and drains feeding to the wetland, this has increased levels of sediment and nutrients.

WRC regularly monitors stream and river water quality at several locations in the wider Whangamarino catchment. One of these (Whangamarino at Island Block Road) is within the wetland and near its outlet. Average water quality at this site was assessed as 'Unsatisfactory' over 50% of the time between 2007-2011 (with reference to ecological standards set by WRC). Nutrient, turbidity levels, and dissolved oxygen concentrations were also 'Unsatisfactory' over 90% of the time, and the site was considered 'Unsatisfactory' for swimming 100% of the time. It is important to note that the criteria used by the WRC to assess stream and river quality may not be as relevant to wetlands.

Water samples collected during a flood event in September 2010 showed that the concentration of total suspended solids peaked within the Whangamarino River at 260 mg/L, which is more than double the concentrations in Pungarehu Canal. However, the total load of sediment transported down the Pungarehu Canal is likely to be significant.

The turbidity meter installed on the Pungarehu Canal in 2010 shows turbidity reached a peak daily average of 957 NTU (turbidity measurement scale) at the end of December 2010 and did not drop until the 23rd of January 2011. This was likely due to unusually high rainfall and waterflows. Following this event, turbidity averaged 127 NTU through to the end of November 2011. Turbidity levels greater than 5 NTU are classified as being unsatisfactory for supporting plant growth.

Recommendations:

Generally speaking, relatively few recommendations were made in the report. Rather, it outlines priorities that are to be actioned by DOC. However, a few recommendations include:

- Regular monitoring of key inflow sites, and commercial fishing and recreational access sites to target current weed species and potential weed species not yet found in the wetland.
- Development of a landowner engagement plan, taking into account the needs of rural owners.
- Importantly, it is noted that no singular mitigation option represents a solution to improving water quality in Lake Waikare and the Whangamarino Wetland. The solution will require a combination of measures.

Information gaps identified:

- Improved quantification of sediment inputs and outputs;
- Quantification of the extent of surface flooding within the Whangamarino Wetland at different water levels; and
- Better understanding of the impacts of introduced fish on suspended sediment concentrations.

Future research priorities at Whangamarino Wetland were highlighted:

- Ongoing investigations into the effects of the Flood Control Scheme on the Whangamarino Wetland. Investigations should include nutrient and sediment fluxes as well as the development of practical mitigation options;
- Characterisation of the ecohydrology of larger areas of the wetland to complement hydrological models;
- Assessment of methods for the management of swamp helmet orchid (*Corybas carsei*), in particular, assessments should focus on translocation and propagation methods and use of managed fire to prevent competition with other vegetation;

▪ A study of the impacts of other (i.e., excluding willow) invasive weeds (e.g. royal fern/*Osmunda regalis*) on native species and habitat, and development of new management techniques. In particular, further research on the environmental drivers of royal fern are key; ▪ Expansion of our knowledge of the fish populations in the wetland; ▪ Investigation into how koi carp utilise Whangamarino Wetland in order to inform control programmes; ▪ Investigation of the implications of aerial willow control on native fish species; ▪ Research into visitor numbers and satisfaction; and ▪ Quantification of the ecosystem services provided by the Whangamarino Wetland. Future priorities for the development of monitoring and management tools include: ▪ Development of cryptic bird call recognition software; ▪ Guidelines for monitoring wetland hydrology; ▪ Guidelines for determining water requirements of wetland systems; and ▪ Improved methods for the control of pest fish in wetlands.

Duncan MJ. 1997. Lake Waikare consents project: sediment issues - interim report. Christchurch National Institute of Water and Atmospheric Research. NIWA Client Report No: CHC97/21. 23 pp.
<u>Water quality information:</u> The report presents sediment budgets for both Lake Waikare and the Whangamarino Wetland. The average suspended sediment concentration of 59 samples taken between 1982 and 1997 in Lake Waikare was 117 mg/L (range 10.5 – 341 mg/L). The main source of Lake Waikare's sediment is the Matahuru Stream. The annual sediment load of the Matahuru Stream is estimated at about 7000 t/y. Once this is corrected to include runoff from the ungauged area, this equates to 10,874 t/y. The suspended sediment in the lake is fine and well mixed. This suggests that sediment coming into the lake from the Matahuru Stream is evenly distributed about the lake. The Te Onetea Stream contributes very little sediment to the lake because it has a low flow, is remote to the lake (approximately 1.3 km) and Waikato River waters have a low suspended sediment concentration (averaging 20 mg/L at Rangiriri, with a maximum of 120 mg/L). Therefore, the Te Onetea Stream gate has very little influence on the sediment budget of the lake or the wetland. The overall sediment contribution from Te Onetea Stream to Lake Waikare was estimated to be 278 t/y. The lake is shallow and exposed and the bed and incoming sediment is fine. Therefore, the lake waters are constantly turbid, which enhances sediment export. It appears that marginally more sediment is leaving Lake Waikare than is entering it, implying some resuspension and export of the sediments of the lakebed. The sediment itself has little impact on with the lake in terms of deposition or erosion as it passes through it. However, the constant high turbidity must be having drastic ecological effects. The shallowness of the lake, its lack of macrophytes, and its exposure to wind results in the turbidity rather than the incoming sediment. Bed lowering of 0.08 mm/year is implied. The mean suspended sediment concentration in the Pungarehu Canal is 117 mg/L. This suggests the sediment outflow via the Pungarehu Canal was approximately 13,800 t/y. This implies the bed of Lake Waikare is contributing 2626 t of sediment per year to the Whangamarino Wetland. This represents 28% of the Whangamarino Wetland's sources of sediment. The predominant sediment inflow is the Whangamarino River, which contributes more than twice the sediment that is

conveyed by Pungarehu Canal. The Mangatangi Stream makes only a minor contribution to the sediment budget the wetland, presumably because flows from its headwaters are retained behind reservoirs. The sediment deposition rate of the Whangamarino Wetland was estimated at 0.5 mm/y, which equates to a total of 38,300 t. The contribution of inflows from Lake Waikare to the sediment deposition in Whangamarino Wetland is difficult to quantify, but it is probably less than its proportion of sediment input to the wetland. This is due to the delay in conveyance of lake flood flows, as Matahuru flood waters are stored in the lake until floods in the wetland have receded, and because some of the lake's contribution occurs at low flows when the sediment is conveyed directly through the wetland. In contrast, other sources contribute most sediment during floods. The main effect of the Lake Waikare radial gate is to allow sediment laden Lake Waikare water to be conveyed to the Whangamarino Wetland. The contribution of Waikato flood waters over the Rangiriri spillway to Whangamarino Wetland sedimentation is argued to be small because of the rarity of such flood events and the relatively low concentration of suspended sediment in Waikato River flood waters. In contrast, the flat channel of the Whangamarino River through the wetland causes the river to flow slowly and any large or dense sediment presumably settles out as it enters the wetland or the flatter reaches of the rivers immediately upstream. The radial gate at the outlet of the wetland has little influence as it is normally fully open to allow drainage from the swamp and is only closed when water from the Waikato begins to flow into the swamp. The report concludes that most of the time the channels (including Pungarehu Canal) simply convey suspended sediment through the wetland and have very little influence on deposited sediment in the wetland. However, at high water levels, some sediment-laden water will infiltrate the wetland and sediment may deposit out.
<u>Recommendations:</u> Recommendations weren't provided. However, the report provides commentary around a potential mechanism to promoted conveyance of sediment from Lake Waikare through the Whangamarino wetland, rather than being deposited in it: The Lake Waikare radial gate is to controls the discharge of sediment laden lake water into the Whangamarino Wetland. However, Matahuru flood waters are stored in the lake to delay outflows until floods in the wetland have receded. Therefore, sediment from Lake Waikare is more likely to be conveyed directly through the wetland. Hence, there is the potential to enhance this effect by closing the gate during times when wetland water levels are high, and opening the gate more when the water levels are low, thus allowing the sediment laden water to pass through the wetland rather than flowing over it and resulting in deposition. However, this caused land to be flooded above normal lake levels for longer periods of time.
<u>Information gaps:</u> Identified information gaps and recommended future data gathering included: ▪ SS samples from the major inflows during floods (Matahuru Stream, Pungarehu Canal, and Whangamarino River), as well as from the wetland outflow and the lakebed could be taken for particle size analysis. This will allow the behaviour of the sediment to be predicted, i.e., how long does each size fraction take to settle out? ▪ More SS samples should be collected during floods. Calculated sediment loads are very sensitive to magnitudes of concentrations during floods, and there are too few samples from very high flows to be confident about computed sediment loads. ▪ Samples collected should be analysed for suspended sediment concentrations, not only turbidity. Turbidity measurements can be misleading, especially at high suspended sediment concentrations. ▪ More suspended sediment samples are required for the Mangatangi at SH2 site to enable a relationship to be drawn between suspended sediment and turbidity.

- A lake water level recorder at the Lake Waikare radial gate and a computerised record for gate openings would be useful for calculating outflows. The recorder should be set to register water level at frequent intervals to avoid aliasing of the record. The existing recorder is not considered suitable because the lake levels are wind-induced.
- More gaugings are required on the Te Onetea Stream to confirm or establish a stage discharge rating.
- More high flow gaugings and concurrent sediment samples need to be taken at the Whangamarino River at Slackline site to confirm the sediment rating.

Gibbs M. 2009. Whangamarino Wetland pilot study: sediment sources. Hamilton: National Institute of Water and Atmospheric Research. DOI: https://ftp.doc.govt.nz/public/folder/QnM3b1OEaU_bk3ahqEV8XA/outputs-2016-2017/036b-gibbs-2009.pdf. 39 pp.

Water quality information:

There are three main sources of sediment for the Whangamarino Wetland:

1. The steep hill country of the Hapuakohe Range at the headwaters of the Whangamarino River catchment;
2. The low grasslands on lowland alluvial plains adjacent to the Waerenga Stream. These areas are periodically used for crops (i.e., maize); and
3. Lake Waikare via the Pungarehu Canal.

More specifically, there are two main sources of sediment to the southern Whangamarino Wetland:

1. Lake Waikare via the Pungarehu Canal, and
2. The Whangamarino River inflow from the upstream catchment.

The steep hill country and low grasslands are continuous sources of sediment to the wetland, while the sediment load from Lake Waikare can only enter the wetland when the control gate is open. On a day of sampling during a 2008 flood event, approximately 90% of the sediment entering the Whangamarino Wetland and watercourse system originated from Lake Waikare. Overall, the estimated mass load of sediment from Lake Waikare is approximately 730 t d^{-1}, while the load from the Whangamarino River catchment is approximately 100 t d^{-1}.

The suspended solids load was lowest in the headwater stream samples, with values increasing downstream toward Jefferies Road bridge, and then decreasing towards the Whangamarino Wetland. The difference between the sediment loads of the catchment streams and those of Lake Waikare is striking, as the Lake Waikare samples contain lakebed sediments that have been resuspended by wind-induced mixing. Overall, it is estimated that about seven times more sediment enters the wetland from Lake Waikare than from the Whangamarino River upper catchment.

The results also indicated that, under extreme flood conditions in the Waikato River and when the Pungarehu canal control gate is open, most of the sediment load entering the Whangamarino wetland system comes from Lake Waikare. However, at other times, i.e., when the control gate is closed, the majority of the sediment entering the wetland system most likely originates from the steep head water streams of the Whangamarino Catchment, in particular, the Waerenga Stream sub-catchment. Of particular interest was the high turbidity of water draining the soft alluvial plains at the foot of the steep headwater catchments, compared with the low turbidity of surface floodwater draining from areas of volcanic soil closer to the wetland. Suspended sediment data also show that, during the rising phase of a flood, when flow velocity in the Whangamarino River would be greatly reduced, sediment falls out of the water column into the river channel.

The sudden reduction in flow velocity as the Pungarehu Canal waters enter the open expanse of the wetland likely causes the bulk of the suspended sediments to settle out in a “river delta” formation

near the mouth of the canal. For example, suspended sediments reduce by about 20% at the mouth of the Pungarehu Canal compared with the suspended sediment load at the midpoint in the canal. A similar deposition regime could be invoked for suspended sediments in the Whangamarino River water. At its confluence with the Pungarehu Stream, the Whangamarino River water can spread out and rapid settling of the sediment load occurs. Carbon (C) and N content of soils, sediments, and suspended solids was highly variable, ranging from <1% to almost 20% for carbon, and 0.1 to 1.8% for nitrogen. The C and N content of the suspended sediment from Lake Waikare was significantly higher than all the other sediment samples, except for a site at Jefferies Road site and one of the core sites in the wetland. Water at the Jefferies Road site was clear had a very low sediment load, indicating that the high proportions of C and N were most likely attributable to fine plant matter and that erosion processes had a relatively low impact. Surface runoff from flooded, replanted grasslands on the flat, alluvial plains had a much higher sediment content, which is indicative of an easily mobilised soil type.
Recommendations: No recommendations were made with regard to management options. However, recommendations for further research and data collection were provided, these are detailed below under the ‘Information gaps’ heading.
Information gaps: There is a lack of flow data for the Whangamarino River / Lake Waikare / Waikato River flood diversion system and a lack of time-series suspended sediment data. At a minimum, accurate flow data is required from Lake Waikare and from the Whangamarino River upstream of Falls Road. Selection of the recording station location is critical and should be upstream of the backing up of flood waters in the Whangamarino River. Recording turbidity data calibrated for suspended sediment concentrations would also provide a continuous record of the sediment discharged into the Whangamarino Wetland from Lake Waikare and the Whangamarino River. Developing and understanding of the sedimentation regime in the wetland would require the sediment coring at a number of locations across the wetland, relative to the two main water inflows. This would allow measurement of the Sediment Accumulation Rate (SAR) at each location and enable accurate dating. Application of stable isotope forensic techniques to sediment from such cores would determine the relative contributions of different soil sources at each location and provide a better understanding of how sediment is moving through the wetland and how the Pungarehu Canal and Whangamarino River weir affect sediment deposition in the wetland. That understanding is fundamental to the development of management strategies to protect the Whangamarino Wetland from further degradation and essential for initiating recovery. There is a lack of understanding regarding how the engineering structures have influenced sedimentation. The report went some way toward addressing this information gap, but a more comprehensive study should be designed to answer specific questions. In addition, expanding the soil source library would enable identification of specific land-uses within the Whangamarino Catchment that produce disproportionately high sediment loads. Subsequently, management initiatives could be employed to mitigate those sediment loads.

Hicks D. 2005. Soil conservation survey of the Matahuru Catchment. Hamilton East: Environment Waikato. DOI: https://www.waikatoregion.govt.nz/assets/WRC/WRC-2019/tr05-39.pdf. 24 pp.
Water quality information: No water quality information is provided in this report. Rather, the report summarises the results of a survey carried out to ascertain the extent of vegetative soil cover in the Matahuru catchment. Key findings include that 65% of the Matahuru catchment comprises unstable land, meaning it exhibits signs of erosion. However, most of this land doesn’t show signs of fresh or recent erosion.

Eight-four percent of the land classified as "unstable" requires vegetative soil conservation measures to protect against streambank erosion or deposition, tunnelling (soil piping), landslides, and slumps. Vegetative soil conservation measures have already been installed or retained on 77% of the land where they are needed (42% of the catchment area). However, some of measures were rated as inappropriate or insufficient. Bare soil occurring as a result of natural erosion was calculated to be 1.6% of catchment area, while soil disturbance due to land use represented 5.1% of the catchment's area. Overall, between 1992 and 2002, erosion had declined across the catchment (from 2.0% to 0.7%).
Recommendations: No explicit recommendations were made in the report. However, it is noted that 54% of the catchment area (84% of land classified as "unstable") requires vegetative soil conservation measures to be installed to protect against streambank erosion or deposition, tunnelling (soil piping), formation of gullies, landslides, and slumping. In addition, 13% of installed soil conservation measures were rated as inappropriate or misplaced, and 37% of installed measures were rated as appropriate but insufficient in extent.
Information gaps: No information gaps were identified.

Hopkins A. 2011. Matahuru Awa riparian effects on the mauri of Lake Waikare. AM & Associates. 22 pp.
Water quality information: Lowering of lake water levels can result in ongoing suspension of sediment and, where lakes are exposed to prevailing winds, wave patterns can also change. Lowering of lake levels can also alter or remove invertebrate and fish habitat and cause ground water levels to change. Water quality in both the Matahuru Stream and Lake Waikare is declining. Since the 1970s, submerged macrophytes have been absent from the lake bed, and kaimoana (tuna / *Anguilla spp.* and kanae / grey mullet / *Mugil cephalus*) have been unsafe for consumption. The water has also remained turbid and nutrient runoff from the Matahuru Catchment has increased exponentially. The majority of Lake Waikare's sediment and nutrient inputs are sourced from the Matahuru catchment. In 2007, the Matahuru Awa was discharging sediments to the lake at a rate of 160,790 m^3 day^{-1}. At this time, the Matahuru catchment represented 95% of the lake's sediment inflows, 60% of its total nitrogen inputs, and 53% of its total phosphorus inputs. Water quality parameters were measured in the Matahuru Awa and several of its tributaries, and the monitoring data was compared. Mean dissolved oxygen saturation in the tributaries was 50.3% compared to 85% in the Awa. Mean dissolved oxygen concentration in the tributaries was also lower than in the awa, being 4.45 mg l^{-1} compared to 8.72 mg l^{-1}. Once dissolved oxygen concentrations fall below 5.0 mg l^{-1}, aquatic life becomes stressed. If dissolved oxygen falls below 1-2 mg l^{-1}, fish deaths can occur. Mean electrical conductivity in the tributaries was similar to that of the Awa, being 15.2 µScm and 14.72 µScm, respectively. Mean pH was also similar, being 6.95 in the tributaries and 7.02 in the Awa. Mean water clarity in the tributaries was 41.5 cm, compared with 0.26 cm in the awa. The Matahuru streambed was visible in at a depth of 250 mm, 15 km from the headwaters. However, it has previously been reported that the Awa was turbid ~3 km downstream of the headwaters. Overall, water quality in the Matahuru Awa was higher than that of the tributaries, however, mean visual water clarity in the tributaries was significantly higher (160 times). General observations include: ▪ Slump erosion sites with the potential to deposit sediment into the Awa were numerous;

▪ Beef cattle have access to the awa; ▪ Fallen trees exacerbate flooding during storm events; ▪ The area of the catchment has increased over time; ▪ A range of farming activities were observed on the margins of the Awa and these will likely explain the magnitude of the sediment and nutrient load discharging to Lake Waikare. Overall, reduced sediment loads discharging from the Matahuru Awa will translate to reduced sediments stored in Lake Waikare.
Recommendations made: ▪ **A 12-month monitoring programme to examine water quality trends in the Matahuru tributaries in order to determine the magnitude of the sediment and nutrient loads discharging from the various sub-catchments into the awa and eventually into the lake;** ▪ Kaitiaki should be offered the fallen totara and kahikatea (*Dacrycarpus dacrydioides*) in the Awa; ▪ **Establish matsudana willows, wetland species, and taonga species at active streambank erosion sites**; ▪ Kaitiaki should undertake the work of fallen willow removal; ▪ **Erect fences in a configuration that will prevent stock access and protect plants; and** ▪ **Incentives should be provided to farmers to encourage them to install reticulated stock water systems by waiving water take consents and providing discounted solar-powered pumping systems, as the upper catchment is very remote.** Additionally, the report notes the priority focus for rehabilitation is hill country land in the Matahuru, to filter sediment from overland flow, conserve soil, and prevent further sediment entering the Matahuru Awa. **Riparian management should focus on the area between Lake Waikare and the junction of Matahuru Road and Hoult Road, following this, the second priority should be fencing the tributaries in sub-catchments that do not have headwaters in native forest**.
Information gaps: No information gaps were identified.

Hopkins A. 2016. Profiling suspended sediments in seven Matahuru Awa tributaries. Ngaa Muka Development.11 pp.
Water quality information: Suspended and dissolved substances play an important role in lake ecology. TSS are particles in the water column comprised of mineral and organic matter and are larger than 2 µm. Turbidity is a measure of water “cloudiness” and is determined by the amount of light that is scattered by the suspended material. Turbidity influences light penetration through the water column and, therefore, the growth of submerged aquatic plants. If a lake supports high levels of suspended substances, light may be attenuated to a level where it is insufficient for plant growth. In addition, phosphorus can bind to sediment particles and later be released into the lake water column under low oxygen conditions. Phytoplankton suspended in the water column is able to utilise the phosphorus in the water column, which can result in dense, toxic algal blooms. Moreover, high TSS can reduce fish spawning habitat, smother fish eggs and larvae, damage fish gills, reduce fish growth rates, and decrease fish resistance to disease. High TSS concentrations can also result in silting of streambeds, which may result in changes in the macroinvertebrate community assemblage and a loss of biodiversity.

The largest mean TSS concentration across seven tributaries of the Matahuru Stream was found in the Allen tributary, which also had a mean turbidity of 91.2 NTU. A tributary on the Crawford property had the second highest TSS concentration and a mean turbidity of 48.6 NTU. The Allen tributary has the largest catchment (1517 ha) and discharges 0.54 tonnes d^{-1} (0.35 kg ha^{-1} d^{-1}) of sediment to the Matahuru Awa. The Crawford and Evans tributaries have similar catchment areas (452 ha and 399 ha, respectively), and discharge a combined 0.08 t d^{-1} (0.09 kg ha^{-1} d^{-1}) of sediment to the Matahuru Awa. As expected, sub-catchments with large proportions of hill slope contribute the most to sediment loads. The Crawford, Evans, and Allen catchments together discharged a combined 46.1 t of sediment to the Matahuru Awa over the 50-day monitoring period.

The Allen sub-catchment has high erosion potential, sitting amongst hills with gradients between ten and 20 degrees. This erosion potential is reflected in the high mean TSS (109.9 g m^{-3}) recorded for the sub-catchment.

The mainstem of the Matahuru recorded a mean TSS concentration of 235.6 g m^{-3} and a mean turbidity of 193.6 NTU. The mean water temperature in the Matahuru Awa ranged between 11.1°C and 12.5°C across the monitoring sites. Mean dissolved solids ranged from 50 ppm to 87.5 ppm and mean electrical conductivity ranged from 91.2 µS to 130 µS across sampling sites.

Mean combined TSS discharging from the seven tributaries to the Matahuru Awa was 124.4 g m^{-3}. In comparison, the mean TSS concentration recorded at the bottom of the Matahuru catchment was 235.6 g m^{-3}. Therefore, it could be inferred that the sampled tributaries were responsible for contributing approximately 53% of the TSS concentration in the Matahuru Awa.

These results confirm that the Matahuru Awa is a significant source of sediment for Lake Waikare. This volume of sediment derived from the Matahuru Catchment is likely having significant negative impacts on the ecology of Lake Waikare by reducing light availability, increasing phosphorus availability, promoting noxious algal blooms, and degrading habitats suitable for native wildlife, such as fish and birds.

Recommendations:

All recommendations apply to further data collection, and this is included under the information gaps heading below.

Information gaps:

Future monitoring will be required to determine if point sources of sediment in the Matahuru sub-catchments can be located and managed to prevent sediment from entering the Matahuru Awa. This should involve examination and sampling of the Allen sub-catchment (as a priority), as well as the Crawford and Hickey catchments, to help determine whether there are point sources of sediment that contribute to the total sediment load of the Matahuru Awa.

Jenkins B, Vant B. 2007. Potential for reducing the nutrient loads from the catchments of shallow lakes in the Waikato region. Hamilton: Environment Waikato. DOI: https://www.waikatoregion.govt.nz/assets/WRC/WRC-2019/tr06-54.pdf. 29 pp.

Water quality information:

The modelled nitrogen load of Lake Waikare is 270 t $year^{-1}$, and 1.3 g m^{-2} $year^{-1}$. Under best practice land management practices, it is estimated that this load could be reduced by 7%. Under potential land management practices, it is estimated that this could be reduced by 38%.

The modelled phosphorus load of Lake Waikare is 21 t $year^{-1}$, or 0.1 g m^{-2} $year^{-1}$. Under best practice land management practices, it is estimated that this could be reduced by 11%. Under potential land management practices, this could be reduced by 35%.

The modelled sediment load of Lake Waikare is 1275 kt $year^{-1}$, or 36 kg m^{-2} $year^{-1}$.

Any efforts to reduce internal nutrient load will be less effective if the external nutrient load of the lake is not significantly reduced prior to treatment.
Recommendations: **Before a pilot study is carried out to reduce internal nutrient load, it is recommended that the external nutrient load be substantially reduced. A reduction of up to 50% may be required. It is also recommended that a thorough analysis of the feasibility, methods, and costs of reducing external nutrient load are examined and applied to the lake before employing internal nutrient load controls.**
Information gaps: No information gaps were identified.

Joynes SA. 2005. Lake Waikare: Rangiri spillway and northern shoreline stopbank hydraulic appraisal. Environment Waikato. 32 pp.
Water quality information: The report is a hydrological report and contains no water quality information.
Recommendations: Two options for improving the performance of the Rangiriri Spillway in order to better attenuate flows in the Waikato River were investigated: 1. Ensuring that the peak spillway discharge is 280 m^3/s instead of the modelled 230 m^3/s by lowering the spillway by 80 mm; or 2. Limiting flows in the river downstream of the spillway to 1560 m^3/s by lowering the spillway by 330 mm. Neither option would have a detrimental impact on the Northern Shoreline spillway and both options would result in the lake level rising more during flood events.
Information gaps: No information gaps were identified.

Keenan B. 2017. Whangamarino economic analysis. Waikato Regional Council. 4 pp.
This document provides no water quality information and does not offer recommendations nor identify knowledge gaps. The report is a brief analysis of economic data for the Whangamarino catchment. The key finding is that dairy cattle farming is the industry that contributes the most to Gross Regional Product (GRP) within the catchment. High producing exotic grassland also represents the highest proportion of land cover within the catchment. In addition, among the farm types present within the catchment, dairy cattle farming utilises the largest area of land in the catchment.

Lake M, Brijs J, Hicks BJ. 2008. Fish survey of the Whangamarino Wetland 2007/2008. Department of Conservation. DOI:

https://ftp.doc.govt.nz/public/folder/QnM3b1OEaU_bk3ahqEV8XA/outputs-2016-2017/049a-lake-2008.pdf. 37 pp.

Water quality information:

No water quality information is provided. Ecological (fish community) data was the focus of the report.

Recommendations:

1. An assessment of fish passage at the Whangamarino weir should be undertaken once the structure has been repaired. The assessment should focus on the ability of grey mullet, inanga (*Galaxias maculatus*), and smelt (*Retropinna retropinna*) to navigate the weir during peak migration periods.
2. Undertake an additional survey of the fish community in the Kopuera Stream catchment.
3. Undertake additional surveys of duck pond habitats in the Whangamarino, to assess any values that they may support.
4. A range of different sampling techniques should be used to compensate for different gear bias when surveying fish communities in wetlands.

Information gaps:

There were a number of habitats that were omitted from the sampling programme. For example, the Kopuera Stream, which flows into the Maramarua just upstream from the confluence with the Whangamarino River was not sampled. This system is known to be highly influenced by peat and may contain an unusual assemblage of species, including black mudfish. Permanent pool habitats created by duck pond development were also not assessed. These habitats are common in the Whangamarino and there is ongoing pressure to develop further areas of the wetland for waterfowl hunting. An understanding of which fish species use existing duck ponds would help assess the values that these habitats support in the Whangamarino.

In 1995, it was recommended that monitoring of fish passage over the Whangamarino Weir be undertaken during high water differentials, as well as a netting survey during summer to assess the effect of the weir on mullet. The authors noted that it appeared that these surveys were never conducted.

Lake Waikare Steering Group. 2007. Lake Waikare management options. Environment Waikato Internal Series 2007/12. Environment Waikato. 29 pp.

Water quality information:

The factors that affect Lake Waikare's water quality are:

- Sediment resuspension:

  Lake Waikare is very turbid and with a high loading of fine clay sediments. Research suggests that clay particles are unlikely to settle out of the water column by themselves.

  The large size of the lake means that it has a large wind fetch and the lake can be subject to prolonged windy periods. The wind stirring and wave energy, combined with the shallow water (maximum depth of 1.8 m) and fine sediments results in the constant re-suspension of bottom sediments.

- Lack of submerged plants

  Suspended sediment is considered the principal factor limiting submerged macrophyte re-establishment and the biological productivity as it restricts light penetration.

  The absence of submerged macrophytes means that there is no material within the lake to bind bottom sediments together, dissipate wave action, and aid in the prevention of sediment resuspension. The native seed bank in Lake Waikare is also very limited, which limits macrophyte recolonisation.

Pest fish, such as koi carp, catfish (*Ameiurus nebulosus*), and rudd (*Scardinius erythrophthalm*), also prevent or limit the development of submerged plants. Bottom-feeding pest fish also re-suspend sediments and can directly disturb plants, while pelagic rudd become herbivorous once they reach a certain size and feed directly on submerged plants.

Sediment cores taken throughout the lake and tested for mercury concentrations found that there are unusually high concentrations of mercury around Sulphur Island in Lake Waikare (near the eastern shoreline). Mercury at such high levels could also inhibit the growth of plants within the lake.

- Sediment inputs

  Sediment runoff and stream bank erosion in the Matahuru Stream catchment provides the major source of sediment to the lake, contributing approximately 9,000 tonnes per year, over 75% of the lake's annual sediment load. The high degree of bank erosion combined with the high clay composition of the soils in the Matahuru Stream likely contribute to the high turbidity within the stream and, therefore, downstream effects on Lake Waikare.

- Nutrient inputs

  Lake Waikare has a hypertrophic nutrient status. Hypertrophic water bodies are super-saturated with plant nutrients (nitrogen and phosphorus) and have a high algal biomass, correspondingly low water clarity, and a strong tendency for algal blooms during summer.

  The main contributor of nutrients into Lake Waikare is the Matahuru Catchment, contributing an estimated 60% and 53% of the lake's total nitrogen and total phosphorus loads, respectively. Additionally, it is estimated that the Te Kauwhata sewage treatment plant contributes between 6-10% of the lake's total phosphorus loading and 1% of the total nitrogen loading.

- Wetland vegetation

  The loss of wetland vegetation from around Lake Waikare due to the conversion to pasture has exposed the lake to direct runoff from intensively used agricultural land on the lake margins.

Recommendations:

- **Riparian management**
  - Fence lake margins and create more wetland habitat

    Work with the landowners on the lake margin to undertake planting in order to create more wetland habitat and increase filtering of nutrient runoff from pastoral land. Fence the lake margin to exclude stock. Key species to plant include mānuka, karamu (*Coprosma robusta*), flax / harakeke (*Phormium tenax*), kahikatea (*Dacrycarpus dacrydioides*), cabbage tree (*Cordyline australis*), mingimingi (*Coprosma propinqua*), pūrei (*Carex secta*), *Machaerina teretifolia*, and kuawa (*Schoenoplectus tabernaemontani*).

    It is recommended that a margin survey be conducted to define the exact boundary of Lake Waikare to form the basis upon which riparian fencing can be implemented.
  - Reduce sediment inflows from Matahuru Stream

    Riparian management in the Matahuru catchment should be aimed at filtering sediment from overland flow. Care should be taken to not plant vegetation that will shade the banks. Therefore, the focus should be on fencing riparian margins to exclude cattle and form a low, vegetated buffer strip. The priority for vegetation management should be the section of the Matahuru Stream from the junction of Matahuru Road and Hoult Road to Lake Waikare. Other recommended actions are the fencing of tributaries, particularly in sub-catchments that do not have headwaters in native forest; and soil conservation on hill country land within the Matahuru catchment in order to reduce the potential for slips and further sediment entering the Matahuru Stream.

- Designating the lake to a new owner
  - It may be appropriate to consider alternative owners and designate the lake accordingly (the lake was owned by Land Information New Zealand (LINZ) at the time the report was published).
- Phase out the discharge of treated sewage from Te Kauwhata sewage treatment plant into Lake Waikare.
- Carry out a comprehensive cost-benefit analysis for different lake levels.

Information gaps:

The report identifies management options that require further research:

- Increasing water inflows from Te Onetea Stream

  Modelling to investigate the capacity of the existing culvert and a culvert twice the size. The effectiveness of an increase in flow through the culvert on suspended sediment levels in the lake should also be assessed. If modelling indicates that an increase in flows sufficient to significantly reduce turbidity is achievable, further investigations would then be required to determine whether this would cause more sediment to be flushed into the Whangamarino Wetland, which could have detrimental effects.
- Management of the western bays

  The re-establishment of submerged macrophytes could be trialled in the western bays of the lake. This should involve excluding pest fish from trial sites. Lake levels could also be manipulated within the permissible range to encourage more marginal wetland plant growth.
- Reducing the density of koi carp

  The relationship between water quality, the pest fish community, and vegetation in Lake Waikare is unknown. A research project could be funded that trials the control of koi carp through a large-scale netting operation in Lake Waikare.
- Flushing the lake

  It may be possible to flush a significant amount of sediment out of the lake moderately raising and lowering of the lake waters on a regular basis. This requires investigation into the lake depth required to eliminate sediment resuspension, the effects of lake flushing on suspended and deposited sediment levels in the Whangamarino Wetland, and the feasibility of altering the lake level regime.

Lawrence L, Ridley G. 2018a. Lake Waikare and Whangamarino wetland catchment management plan, Part 1. Waikato Regional Council. DOI: https://www.waikatoregion.govt.nz/assets/WRC/Council/Policy-and-Plans/CMP_Part_One_Catchment_Overview-WR.pdf. 123 pp.

Water quality information:

This Catchment Management Plan (CMP) provides broad background information on the Lake Waikare and Whangamarino Wetland catchment. It includes information on cultural perspectives, agricultural history, physical and ecological characteristics, socio-economic issues, and the legislative framework.

Section 6 provides an extensive summary of key catchment issues and opportunities, with many pertaining to water quality, water management, soil and land management, and biodiversity.

Key water quality information includes:

- Aquatic pests (i.e., koi carp) contribute to the resuspension of sediment.

- Sedimentation, turbidity, and resuspension affect the light climate of Lake Waikare and Whangamarino Wetland, which in turn reduces macrophyte growth.
- Urban growth contributes to increased stormwater and wastewater discharges, which can change the water quality in the receiving environment.
- Flooding events, potentially intensified due to flood protection schemes, can lead to 'black water' events. This is when floodwaters pick up excess carbon flowing over land. The carbon breaks down and leaches into water, turning it black. Bacteria break down the carbon, which consumes oxygen and leads to extremely low oxygen levels in water. Some sites in the catchment measured oxygen levels of 0% for over seven weeks after major flooding in 2017.
- The discharge of sediments, nutrients, and *Escherichia coli* has degraded water quality in Lake Waikare and the Whangamarino wetland. Annual CHLA, cyanobacteria, TN, and TP measurements revealed that these four parameters are below the national bottom line of the National Policy Statement for Freshwater Management (NPS-FM). A trend of rapid, sustained deterioration in water quality were also evident.
- Lake Waikare is a large, shallow lake, and thus prone the resuspension of sediments due to wind across a large fetch. Suspended sediments in turn reduce light within the water column.
- Lake Waikare has high algal levels which assign it a rating of D under the National Objectives Framework.

Recommendations:

- Development of a strategic pest plant management plan.
- Development of a strategic pest animal management plan.
- Review of integrated catchment management, river management, and land drainage activities to increase understanding of how the LWWFCS operates and how changes in the scheme can affect water levels in the lake and wetland.
- Develop pilot sites for demonstration, trial, and educational purposes within the catchment.
- Implement basic catchment management works, including fencing, soil conservation works, and planting/riparian planting programmes in areas identified as high risk or high priority. Implement progressively from the upper catchment to the lower catchment.
- Undertake an economic analysis of basic catchment management works (i.e., mānuka planting).
- **Investigate whether constructed wetlands are feasible treatment devices for sediment and nutrients**.
- **Develop a watercourse management framework for headwater streams to plan for progressive catchment works and address erosion, contaminants, and pest plant issues**.
- Consider land use options (particularly in the upper catchment) to ensure land use matches suitability. Alternative uses may be more suitable for unstable, erosion-prone areas.
- Identify high-priority areas for protection and/or enhancement.
- Consider offsite mitigation options.
- Focussed sub-catchment management: determine whether any lakes/wetlands/headwaters in the catchment have the potential to benefit from a focussed catchment management regime at a reduced scale. This could be linked with pilot site programmes.
- **Investigate contaminant inputs to all lacustrine and freshwater receiving environments**.

▪ Make use of parallel technical processes / projects / data (i.e., work undertaken by WRC's Science and Strategy Directorate, technical work in relation to the Northern Outlet Control Gate and the LWWFCS, and the Waikato and Waipā River Restoration Strategy). ▪ Review of the existing water takes within the catchment. ▪ Capitalise on the potential to showcase the Whangamarino Wetland to the tourism market, which could lead to additional funding sources/resources. ▪ Develop an understanding of the catchment's potential ecosystem services. ▪ Develop areas to facilitate improved access, connectivity to, and interaction with streams, lakes, and wetlands in the catchment. ▪ Identify key cultural sites for enhancement and protection. ▪ **Set measurable water quality (and other) targets**. ▪ Develop a catchment-specific 'On Farm Biosecurity' strategic plan alongside the Regional Pest Management Plan review. ▪ Engage with the Te Kauwhata Wastewater Treatment Consultation Group with regard to Lake Waikare information and environmental enhancement / restoration initiatives.
<u>Information gaps:</u> - Lack of data on the key issues affecting the upper catchment and inputs into Lake Waikare and the Whangamarino Wetland. - No measurable water quality targets have been set to guide management of the receiving environment.

Lawrence L, Ridley G. 2018b. Lake Waikare and Whangamarino wetland catchment management plan, Part 2. Waikato Regional Council. DOI: https://www.waikatoregion.govt.nz/assets/WRC/Council/Policy-and-Plans/FINAL-CMP-Part-Two-Implemenation-and-Action-Plan-20-September-2018.pdf. 34 pp.
<u>Water quality information:</u> This document builds on part one of the CMP, outlining specific actions and the key issues and opportunities they relate to, as well as the feasibility of each action. New water quality information is not introduced.
<u>Recommendations:</u> ▪ Investigate the merits of Lake Waikare as a water storage facility for irrigation and other water uses. ▪ Ongoing, lake monitoring for sediment and water quality. Catchment-wide monitoring is also recommended. ▪ Identify interventions to protect and restore Whangamarino Wetland. ▪ Investigate mānuka-dominated ecosystems to improve water quality. ▪ Biodiversity enhancement of the kahikatea remnants at Waerenga, Whangamarino Wetland, and Lake Rotokawau. ▪ Stream bank erosion protection and remediation in the Matahuru catchment hill country, Waerenga catchment hill country, and Northen Mangatangi. ▪ Pungarehu Canal Stabilisation. ▪ Implement a Lake Waikare Northern Foreshore wetland restoration project.
<u>Information gaps:</u>

No information gaps were identified.

Lehmann MK, Hamilton DP, Muraoka K, Tempero GW, Collier KJ, Hicks BJ. 2017. Waikato Shallow Lakes Modelling. Hamilton, New Zealand: Environmental Research Institute. ISSN 2350-3432. 223 pp.
Water quality information: Suspended sediment in Lake Waikare is a major issue and contributes to the high rates of sedimentation in the Whangamarino Wetland. Early surveys (c. 1870s) suggest that Lake Waikare had native aquatic plants, but aerial photography suggests that lake water was turbid by the 1940s. The lake has gone beyond a trophic state 'tipping point' and experienced a regime shift. It is now classed as hypertrophic. TN, TP, and total CHLA levels place the lake within National Objectives Framework (NOF) Band D. This report reports the results of water quality modelling applied to four Waikato lakes, including Lake Waikare. The outcomes of the modelling applied to Lake Waikare are not included in the results or discussion. However, some of the modelling outputs have been presented in the methods section or have been appended to the report (Appendix C). The methods section provides a summary and analysis of water quality parameters for Lake Waikare, which were used as inputs to the modelling exercise. Summarised data includes: ▪ TP for Lake Waikare (1995-2015); ▪ TN for Lake Waikare (1985-2015); ▪ Total CHLA for Lake Waikare (1996-2015); ▪ Flow and suspended sediment records taken from the Myjers Bridge site on the Matahuru Stream (tributary of Lake Waikare) (2007-2016); Modelled annual discharge and nutrient loads from each sub-catchment contributing to Lake Waikare (2012-2016); and ▪ TSS concentrations at the Waiterimu Road and Myjers Bridge Matahuru Stream sampling sites; and ▪ Te Onetea Stream (tributary of Lake Waikare) flows (2013-2016). Appendix C includes a comparison between modelled parameters and measured parameters, including: ▪ Flows in Matahuru Stream at the Myjers Farm sampling site; ▪ DRP in the Matahuru Stream at the Waiterimu road site; ▪ Nitrate-N concentrations in the Matahuru Stream at the Waiterimu road site; and ▪ Ammonia-N in the Matahuru Stream at the Waiterimu Road site.
Recommendations: Clear recommendations were not provided, but key points that will direct management measures have been summarised below: ▪ **Annual nutrient budgets can be very useful for the derivation of restoration targets and evaluation of the relative importance of different nutrient sources;** ▪ **Controlling nitrogen is controversial due as reductions in nitrogen concentrations may cause the proliferation or blooms of nitrogen-fixing cyanobacteria. Therefore, a precautionary approach dictates that phosphorus reductions should be undertaken concomitantly with nitrogen reductions, ensuring that nitrogen to phosphorus ratios in catchment loads are not decreased through remediation actions.**

- **There are strong imperatives for managing pest fish species. These include the contribution of coarse fish to water column nutrients and sediments due to bioturbation and excretion. Therefore, controls on exotic fish must be a part of a targeted multi-stressor approach to restoration.**
- **Tangible outcomes for water quality will not be achieved if management actions are not sustained and are not of sufficient scale and magnitude, i.e., leading to a reduction in nutrient loads that is required to shift a lake's trophic status.**
- A demonstration lake is urgently required to provide an example of a successful change to a clear-water, macrophyte-dominated state. To achieve this, a geochemical engineering programme may be required, but this should be approached with care (cf. Lake Rotorua dosing).
- The implementation of each remediation measure should be conducted with innovation and planning in order to optimise its performance.

Information gaps:

A major gap is the paucity of measurements of nitrogen fixation across New Zealand lakes, both directly via isotopic and/or acetylene reduction techniques and indirectly from microscopic enumeration of heterocysts. This information is key given there is much emphasis on voluntary, planning, and policy mechanisms to reduce nitrogen loads, often with little attention given to phosphorus. Therefore, the role of nitrogen fixation in support of bloom-forming, nitrogen-fixing cyanobacteria, and in providing a source of 'new' nitrogen to lakes, should be part of dedicated core research. This research should include modelling exercises – and model scenarios for shallow lakes should build in the effects of climate change.

There are also major knowledge gaps with regard to fish. Future research should focus on coarse fish to improve the accuracy of modelling the effects of invasive fish on shallow Waikato lakes. This research should include:

1. Areal fish biomass estimates and size distributions;
2. Sediment resuspension rates for fish other than carp (e.g., goldfish, *Carassius auratus*);
3. Updated estimates of fish abundance and size distributions; and
4. The concentrations of nitrogen and phosphorus in bottom sediment pore water, as well as an understanding the volume of this pore water that is disturbed and released during invasive fish feeding.

Lockyer C. 2015a. Whangamarino water quality modelling and mapping using source catchments. Jacobs New Zealand Limited. DOI: https://ftp.doc.govt.nz/public/folder/QnM3b1OEaU_bk3ahqEV8XA/outputs-2016-2017/046a-lockyer-2015.pdf. 61 pp.

Water quality information:

A reduction in water clarity in Lake Waikare has been partly attributed to the lowering of the lake water level, which has increased the shear stress imposed on the lakebed by wind-wave orbital velocity, causing the resuspension of sand, silt, and clay within the water column during wind events. The dominant particle size within the lake water column is very fine sands, silts, and clays. These particle sizes are easily resuspended from the lakebed through wave action, however, sand and silt tend to settle within hours, while clay remains suspended for days. This has contributed to the continuous state of poor water clarity and high turbidity that is observed within the lake.

The report presents the results of nutrient and sediment modelling and mapping for the Whangamarino Wetland. The outputs of the model include:

▪ Loads of TP, TN, and TSS discharged to the Whangamarino Wetland from the Pungarehu, Whangamarino, and Maramarua outlets during large, medium, and small flood events; and ▪ Maps of high-risk sedimentation zones for large, medium, and small flood events. The model outputs revealed that in small and medium flood events, sand, silt, and clay transported by flood waters are likely to be deposited in the Whangamarino Wetland. In a large event, velocities are greater and, while silt is likely to drop out, most clay will be transported through the system. However, there are areas on the peripheries of the channels where water velocities and depths are lower, and there is risk of sediment being deposited at these locations during a large flood. While the model did not allow for a prediction of the distribution of nitrogen and phosphorus during flood events, it is expected that much of the nitrogen would be in soluble form and, therefore, would be distributed across the full extent of the modelled top water level. In contrast, much of the phosphorus load is likely to be bound to silt and clay and, therefore, the distribution of the phosphorus is expected to correspond to sediment deposition.
Recommendations: ▪ **Further water quality and flow monitoring to improve confidence in the sediment and nutrient estimates; and** ▪ **Further analysis to determine whether a relationship between wind and sediment concentration can be determined for the lake.**
Information gaps: There is limited water quality data (i.e., TN and TP) on outflows discharging from Lake Waikare through the control gates into Pungarehu Stream.

Lockyer C. 2015b. Whangamarino Wetland hydrology study. Jacobs New Zealand Limited. DOI: https://ftp.doc.govt.nz/public/folder/QnM3b1OEaU_bk3ahqEV8XA/outputs-2016-2017/047a-lockyer-2015.pdf. 56 pp.
Water quality information: No unique water quality information is provided in the report; however, it notes that the introduction of the Lower Waikato Waipa Flood Control Scheme and hydro dams along the Waikato River, together with land use changes and intensification in the wider catchment, have resulted in changes to water quality in Lake Waikare and the Whangamarino Wetland.
Recommendations: The report does not provide explicit recommendations, however, it notes that the frequency of peak water levels in the wetland can be reduced through management of the Lake Waikare flood gate. **Flood events and, therefore, peak water levels are responsible for depositing sediment and nutrients into the most sensitive areas of the wetland. Therefore, decreasing the frequency of these events would help to protect the wetland.** **The report also notes that preventing discharges into the Whangamarino Wetland from Lake Waikare when water levels exceed 4 m was identified as a management method in the Assessment of Environmental Effects for the 1998 application to dam and discharge from Lake Waikare. However, this measure was not implemented. The modelling analysis documented in the hydrology report, however, indicates that implementing this management method would benefit the wetland.**
Information gaps: Further research and improvements in data would improve the accuracy of model outputs. Opportunities for further data collection are summarised below. However, the report emphasises that priority should be placed on improving the calibration range and calibration to the spatial

extent. Similarly, running further scenarios for management purposes would inform an understanding of how the hydrological regime can be altered to enhance the wetland. Further research could include: ▪ Determination of the effects of climate change on flood events. ▪ WRC LiDAR data for an area of the Whangamarino Wetland (approximately 15 km^2) was corrupt. This area should be flown again and the data collected to improve understanding of the spatial extent of flooding through this area. ▪ LiDAR data for Lake Waikare area is also unavailable. ▪ An understanding of the impact of vegetation bulking and the interconnectedness of the terrain in the wetland would improve the estimates of the depth-area-volume relationship of the Whangamarino Wetland. ▪ Installation of a water level recorder in the Causeway catchment. ▪ Should another flood occur, further calibration of the upper flood levels would benefit future modelling and provide greater confidence in estimations of extreme floods. If a large flood event occurred, the spatial extent could be pegged or photographed, and used for calibration purposes. ▪ Rating curves from the three existing gauging stations should be reviewed and assessed for accuracy. ▪ An improved rating curve for the Whangamarino Weir would improve modelling. This would require more accurate measures of flow at this site.

Mead S. 2005. Possibilities study for the rehabilitation of Lake Waikare. Raglan, New Zealand: ASR. 12 pp.
<u>Water quality information:</u> Important characteristics of Lake Waikare identified in the report include: ▪ The lake's large wind fetch continually suspends fine sediments, which has resulted in the lake water being permanently turbid; ▪ Matahuru Stream is the source of 70% of the lake's sediment inputs; ▪ The light base (depth at which aquatic plants can survive) is currently only 0.3-0.6 m deep due to turbidity and suspended solids; and ▪ If the suspended solids could be removed, the light base in the lake could be increased to 1.1 m. The report identifies that a reduction in suspended solids (especially the smallest clay fractions that represent 40 – 70% of the suspended solids) will be the key factor in increasing the light base and successfully re-establishing aquatic vegetation.
<u>Recommendations:</u> An integrated approach will be required to achieve a lake habitat that supports dense beds of aquatic vegetation. Rehabilitation should use desktop studies prior to field application to further advance the potential mediation measures outlined below. Lake rehabilitation recommendations: 1. **Wave dampening** (i.e., by use of floating breakwaters, submerged mounds, and emergent structures), dredging to create sediment 'sinks' for suspended solids, deepening the lake, and/or promoting circulation. Any artificial structures used could potentially be constructed from sediment dredged/excavated from the lake; 2. **Re-establishment of macrophytes in order to stabilise sediments, assimilate nutrients, and re-establish water quality**. As this would occur under light limitation, appropriate

candidate species and methods for replanting would need to be used. Planting should occur following flocculation and after achieving improvements in water quality (i.e., light attenuation) by use engineering structures (e.g., baffling); and 3. **Use of physical/chemical treatments** (e.g., flocculation) to accelerate sediment settlement and reduce suspended sediment (SS) concentrations, possibly in conjunction with deepening of the lake to increase the likelihood of the suspended sediment settling. This will require a two-pronged approach to be successful: a. In-lake activities to restore the basin by increasing water depths (dredged holes or, possibly, larger areas of the bed); and b. Watershed restoration and catchment management (i.e., riparian planting, wetland creation, and wetland restoration). Other options to be considered: ▪ **Mitigation of the sewage discharge to the lake; and** ▪ **Construction of a wetland and/or structure to slow down the water velocity where the Matahuru Stream and other streams enter the lake to allow sediments to settle out of suspension.**
Information gaps: In order to determine the most effective method for re-establishing macrophytes within Lake Waikare, preliminary information needs to be collected, including: ▪ Long-term and current abiotic variables, especially redox potential; ▪ Information regarding how macrophytes are likely to respond to these abiotic variables; ▪ An experiment should be carried out over a six-week period to assess the growth of Egeria (*Egeria densa*) in relation to depth in order to provide baseline information on the potential for macrophyte growth under current conditions; ▪ An experiment should also be carried out that isolates several sites of 100 m^2. Planting of macrophytes should be carried out pre-determined areas within the 100 m^2 area. The subsequent growth and spread of macrophytes should then be temporally and spatially monitored. Monitoring of nutrient levels, light, and turbidity should also be undertaken over the course of the experiment; and ▪ An assessment of the catchment and soil characteristics, as well as current land use, to ascertain the sediment and nutrient sources that enter the lake (e.g., upstream streambank erosion and/or run-off from farmland).

Mulholland W. 1991. Whangamarino Wetland hydrological issues associated with water level management. Waikato Regional Council. Waikato Regional Council Technical Report 1991/24. 30 pp.
Water quality information: The report is a hydrological report, and no water quality information was provided. However, there were several maps (Figures 6-8) that show areas of the Whangamarino Wetland flooded by silted Lake Waikare waters for floods of different severities.
Recommendations: No recommendations were made. However, the report concludes that the installation of a water control structure to maintain minimum wetland water levels would not significantly impact flood control and drainage interests for land bordering the wetland.
Information gaps:

Further information is required to elucidate more definite timing of the origin and development of the Whangamarino Wetland. The maximum peat depth needs to be confirmed and dated.

Patterson S. 2008. Whangamarino weir resource consent 890227: Consent compliance report. Department of Conservation. 10 pp.
<u>Water quality information:</u> No water quality information is provided in this report. It documents monitoring overseen by DOC, which includes habitat monitoring, fauna monitoring, and vegetation monitoring.
<u>Recommendations:</u> ▪ Monitor whether grey willow is spreading into the peat bogs proper using colour aerial photography every five years; ▪ Carry out willow control in the southern peat bog using aerial spot spraying using a glyphosate-based herbicide; ▪ Monitor willow control areas; ▪ Eradicate willow from the core area of the Reao Arm peat bog; ▪ Eradicate a small patch of reed sweet grass in the mineralised areas of the Reao; ▪ Continue monitoring plots that were established in 1999; ▪ Carry out annual surveillance for new plant pest incursions; ▪ Monitor the population of the threatened plant, stout water milfoil (*Myriophyllum robustum*), every five years; ▪ Eliminate deer from the reserve; and ▪ Search for populations of stout water milfoil and *Cyclosorus interruptus*.
<u>Information gaps:</u> No information gaps were identified.

Reeve G, Gibbs M, Swales A. 2010. Recent sedimentation in the Whangamarino Wetland Hamilton: National Institute of Water and Atmospheric Research. DOI: https://ftp.doc.govt.nz/public/folder/QnM3b1OEaU_bk3ahqEV8XA/outputs-2016-2017/036a-reeve-2010.pdf. 44 pp.
<u>Water quality information:</u> The Whangamarino Wetland has been affected by sediment runoff from erosion and large inputs of N and P from farmland. Low water clarity in Lake Waikare resulting from elevated suspended sediment concentrations has also substantially reduced light penetration (i.e., euphotic depth). Prior to the commissioning of the Pungarehu Canal, flood water inundation of the wetland was derived from the Whangamarino River. However, since the canal became operational, the additional sediment from Lake Waikare has been mixed and deposited with the sediment from the Whangamarino River during subsequent flood events. Under extreme flood conditions (i.e., when the canal control gate is open), most of the surface sediments deposited in the Whangamarino Wetland are derived from Lake Waikare. During these flood events, discharge exceeds bank-full conditions and silt-laden floodwaters overtop the canal bank and flow into the wetland, where they are deposited.

The influence of the Pungarehu Canal and the sedimentation pattern in the Whangamarino Wetland are consistent with levee-type deposition, with maximum SAR occurring close to the canal and reducing with distance and elevation from the sediment source. In other words, SAR decreases with distance from the Pungarehu Canal (i.e., 16.8 mm/yr in the canal itself, compared to 2.5 mm/yr at the upper boundary of the wetland adjacent to mānuka scrub). This occurs due to: (1) the hydraulic effects of vegetation, which reduce current speeds, favouring settling and trapping of fine suspended sediments; and (2) a reduced period of inundation by canal waters with increasing wetland surface elevation. A change in sediment soil type from highly organic peat to one dominated by inorganic clays occurred at some time in the past, and the most likely causes of such a change would be the commissioning of the Pungarehu Canal in 1965 and the concomitant release of clay sediment from Lake Waikare into the wetland. The sampling results suggest the SAR was 2.2 mm/yr prior to the commissioning of the Pungarehu canal, and 7.9 mm/yr post-commissioning, with a rapid increase in SAR from the 1980s. The construction of the canal created a conduit for highly-turbid, sediment-laden water to enter the Whangamarino Wetland. This silt-laden water from Lake Waikare is delivered to the wetland by over-bank flows during flood events. The time lag likely occurred because floods need to be large enough to inundate the core sites and, therefore, sediment deposition would have occurred intermittently after the construction of the canal. Differences in SAR estimates were also detected between the 1995 and 2010 sampling rounds, and this is related to an actual increase in sediment loads received by the Whangamarino Wetland due to catchment disturbance as a result of human activities. Without the weir in Whangamarino River, lower water levels between flood events would confine over-bank sediment deposition to zones closest to the open water channel. However, with the weir operating, sustained, artificially-high water levels allow sediment to spread across a wider area of the wetland. The heavier clay sediments likely settle in the slow-moving water close to the inflow, while the lighter sediments, with a higher organic composition, can disperse laterally over a greater range. The sediment mixing between the Whangamarino River and Pungarehu Canal sources also changed after the artificial water level change in 1994, which allowed greater sedimentation closer to the Pungarehu Canal source. There is a mānuka signal indicating that, prior to the commissioning of the Pungarehu Canal, the channel margins of the wetland supported a mānuka scrub community. However, since the commissioning of the Pungarehu Canal, the mānuka scrub plant has retreated a distance of at least 123 m, as the additional sediment from the canal has buried it.
<u>Recommendations:</u> No recommendations were made.
<u>Information gaps:</u> No information gaps were identified

Reeves P. 1994. 50 years of vegetation change in the Whangamarino Wetland [Masters]. University of Auckland. DOI: https://auckland.primo.exlibrisgroup.com/permalink/64UAUCK_INST/13vfdcn/alma99264794611502091. 162 pp.
<u>Water quality information:</u> Water quality records are sparse for the Whangamarino Wetland and its tributaries. However, records show that in 1981, the Whangamarino and Maramarua Rivers had high concentrations of all nutrients (nitrate and ammonia) measured, indicating that the water had a eutrophic status. At this

time, excessive growth of macrophytes, high turbidity, and occasional thin phytoplankton surface scums were also observed.

The water in Lake Waikare is discharged into the Whangamarino Wetland via a channel linking it to the Pungarehu Stream. Therefore, Lake Waikare waters have a major effect on the water quality of the wetland. Collapse of the lake's extensive macrophyte beds in 1977-78, the shallowness of the lake, and high exposure to wind has made it very silty but well oxygenated. Very high suspended solid loadings and very high total phosphorus concentrations have been recorded at the Lake Waikare outlet. However, faecal coliform densities were low despite the Te Kauwhata township discharging sewage into the lake.

In 1986 sampling recorded high colour, high suspended solid concentrations, low dissolved oxygen and low pH all year round at the Whangamarino River's outlet to the Waikato River.

There are at least 11 catchment streams that drain into the wetland. A review in 1989 revealed that the majority theses tributaries exhibited poor quality indicators, with high levels of nitrate and ammoniacal nitrogen, high turbidity, and often excessive weed growth. Streams that originated higher up in the catchment generally had moderately high water quality, but this degenerated once- the streams reached the lower pastoral land.

In 1991 it was found that the Whangamarino River at its outlet to the Waikato River experienced frequent anoxic conditions and had high turbidity and suspended solids all year round (although this became worse after flood events). In addition, levels of faecal coliform bacteria were moderate to high, iron concentrations were high, and nutrient levels were also high, particularly for total phosphorus, organic nitrogen, and nitrate.

Poor water quality in the Whangamarino Wetland can be attributed to discharges from land use activities within the catchment, particularly dairy and piggery discharges. These diffuse discharges, as well as general catchment soil loss and stream bank erosion, contribute to poor water quality. Other significant discharges are:

1. The opencast coalmine, which discharges treated stormwater runoff (with acceptable levels of boron but high levels of suspended solids) into the Kopuku Stream;
2. A winery discharges into a tributary of the wetland. The discharge contains nutrients and suspended solids and has a high biochemical oxygen demand; and
3. The Meremere Power Station (now closed) once discharged ash pond liquor, which was high in alkalinity due to boron, to the Whangamarino River.

Altogether, Lake Waikare waters and agricultural discharges have the most influence on water quality in the Whangamarino Wetland.

<u>Recommendations:</u>

Active conservation management is required to retain remaining botanical values. Management of wetlands can be improved by taking into account biodiversity and the important processes performed at ecotones. Careful consideration of the different types of biodiversity within a wetland can help to clarify the level where efforts should be concentrated.

The thesis recommends a number management options to address the most significant impacts on the wetland vegetation:

1. Raising minimum water levels

   This has already been undertaken by DOC and a weir now prevents water levels falling below 3.4 m at the ropeway water level recorder.

   Further manipulation of the weir to allow water to fluctuate naturally in seasonally dry periods would mitigate the loss of the 'essential dynamic nature' of a floodplain, while ensuring water levels are high the rest of the year.

2. Selective willow control

   Willow control should be carried out in areas identified as being of high priority, namely the remaining '*Carex* sedgeland' areas, the semi-mineralised zones, and peat bog margins. Selective thinning of willow would prevent populations of species such as Gaudichaud's sedge (*Carex gaudichaudiana*), marsh clubrush (*Bobloschoenus fluviatilis*), and jointed

baumea (*Machaerina articulata*) becoming locally extinct in areas of the wetland. However, in areas where botanical values are low due to the dominance of introduced species under willow, no control of willow should be carried out. Instead, acceptance of willows as a permanent feature in parts of the Whangamarino Wetland should be fostered. 3. Fire Controlled burning of peat bogs to maintain a mosaic of young and old growth would provide habitat for the early native successional species. 4. Establishment of a swamp beside the Lake Waikare outlet A swamp of emergent macrophytes at the outlet of Lake Waikare would reduce the sediment load that is otherwise directly deposited in the Whangamarino Wetland. 5. Fertiliser budgeting Active promotion of fertiliser budgeting in the immediate catchment may help to curb mānuka invasion of the peat bogs, particularly in the southern peat bog, which has a long farmland to wetland border.
<u>Information gaps:</u> The implications of raising minimum water levels in the Whangamarino Wetland on botanical elements are unclear. Another big unknown is the effect of koi carp on herbaceous vegetation in the mineralised swamps. In addition, it is unknown how the population size of koi carp will be affected by increased habitat availability due to raised water levels. The effects of how holding the water levels above normal fluctuations on native species are also unknown. The thesis provides recommendations for further research: 1. An investigation into rehabilitating the native *Carex* dominated communities. A study that aimed to rehabilitate *Carex* swards on DOC land would ensure complete protection of these threatened communities. 2. Piezometers installed along the transect lines in this study, and monitored over a reasonable length of time, would promote a better understanding of the mechanisms driving the vegetation communities in the swamp areas. 3. Determine nutrient levels in water and plants in the semi-mineralised and peat bog areas to better equate land use activities with vegetation changes.

Reeves P, Craggs R, Stephens S, de Winton M, Davies-Colley R. 2002. Environmental changes at Lake Waikare, North Waikato, wave climate, water quality and 'biology'. Hamilton: National Institute of Water and Atmospheric Research. NIWA Client Report: EVW02235. 75 pp.
<u>Water quality information:</u> The report provides a brief history of changes in the water quality of Lake Waikare: In the 1870s, Lake Waikare had appreciably clearer water than it does under present day conditions. Aerial photography suggests that, by the 1940s, the lake had developed high turbidity, most likely due to land clearance within the lake catchment and consequent increases in sediment and nutrient loading in the lake. The turbidity reduced whenever the Waikato River flooded into the lake. This indicates that the majority of the turbidity entering the lake was sourced from the Matahuru Stream, which is still the situation today. It is uncertain when the lake became permanently turbid. Some remember the lake being visually ‘clear’ with a visible bed in the mid-1960s, at the time of the construction of the flood control works. However, shortly after this, the lake was reported as being ‘highly turbid’ and it is likely that the lowering of lake levels did have an effect on the water quality of the lake, particularly turbidity. Turbidity around the lake shoreline, particularly in areas where submerged vegetation existed,

remained low until at least 1966. However, aerial photographs taken on 4 November 1977 show that the areas of shoreline that had been comparatively clear had also become turbid. In the mid-1980s, the lake had developed a mud-brown colouration due to very high total suspended sediment (TSS) concentrations (median 120 g m^{-3}, range 10.7 – 500).

Present-day TSS levels (median 110 g m^{-3}) and turbidity (median 105 NTU) remain high. Consistency of turbidity readings between different sampling sites suggests that the lake is generally well mixed, although variation may occur during sediment-entraining windstorms. When wind-induced wave action increases appreciably, lake turbidity levels can change very quickly.

The highest TSS values were recorded during summer sampling, when lake levels were relatively low.

Chlorophyll *a* is comparatively high (median 28 mg m^{-3}) – consistent with eutrophic – bordering on hypertrophic status. However, chlorophyll *a* does not correlate closely with turbidity, indicating that algae are not a major contributor to lake turbidity and their contribution is masked by high levels of inorganic clay and silt. However, turbidity and TSS are well-correlated, consistent with lake turbidity (light scattering) being largely attributable to fine-grained inorganic sediment. Despite this, even without the inorganic sediment (clay) there is considerable light attenuation by the high algal biomass and high aquatic humus content of the lake water. Therefore, even if all the turbidity-causing inorganic sediment was removed from the lake water, the maximum depth of submerged vegetation growth would still be limited to ~1.1 m, owing to light attenuation by high concentrations of algae and dissolved humic matter that reflect high nutrient loading and swamp/bog drainage from the catchment.

There are two main populations of particles present in Lake Waikare: comparatively coarse particles of silt or, more likely, flocculated aggregates of smaller particles, and (much smaller) particles of fine clay. The coarse particles settled out within a few hours, while after some of the fine clay particles still remained in suspension after four days, and the water was still noticeably turbid. This settling behaviour suggest that much of the suspended material is very fine-grained.

Median TN and TP concentrations in the lake are 1.1 g m^{-3} and 0.18 g m^{-3} respectively, consistent with a highly eutrophic status.

The flood control works in 1965 appear to have affected the wave climate, water quality, and biology of the lake. Wave modelling shows that the near-bed wave-orbital velocities would have substantially increased (between 40-80%) with a one metre decrease in the average depth of the lake. This would have increased the amount of wave-induced sediment resuspension – and hence turbidity – within the water column. The other significant consequence of the flood control scheme was controlling water levels within a small range, thus preventing the lake being flushed with Waikato River water during high flows, which periodically provided dilution, provided an outlet for some of the lake's sediment load, and reduced turbidity.

Wave modelling showed that raising the lake level by 1 m would cause a 40-80% reduction in the mean wave-orbital-velocities at the lakebed, which translates into a decrease in the mean suspended-sediment reference concentration of 95-99.99%. This indicates a very significant drop in wave-induced suspended sediment concentrations if the lake were to be raised by 1 m. It is not possible to quantify how this would affect turbidity in the lake, as it is possible that the very fine clay particles, which are strongly light attenuating, will still not settle out of the water column.

<u>Recommendations:</u>

The report doesn't provide recommendations, but discusses management options:

- Biomanipulation

  If substantial impacts by fish on submerged plants are confirmed, one management option is to manipulate fish composition and abundance in the lake – 'biomanipulation'. Fish can be intensively netted, poisoned (e.g., rotenone), or prevented from returning to the lake from spawning/feeding grounds. Generally, a substantial modification of fish stocks is required, with removal of 75% of the population commonly advocated, or total biomass reduction to <150 kg fish ha^{-1}. In Lake Waikare, declining catch rates of koi carp were reported following an intensive netting programme, suggesting that biomanipulation could be a valid option. There may be a requirement for a sustained fishing effort, especially if conduits for re-entry of fish from the Waikato River and the Whangamarino system cannot be screened off. However, there have been observations that koi congregate at spawning grounds within the Whangamarino system, which may facilitate their removal or isolation from the lake (e.g. by screening off re-entry).

- **Matahuru Stream catchment**

  Riparian management in the catchment should be aimed at filtering sediment in overland flows. Fencing off grassed buffer strips of between 5-15 m should be sufficient. More precise buffer widths for individual streams can be calculated using a formula. Re-vegetation of riparian margins of small pasture streams can lead to channel widening, which can temporarily increase sediment yields. Therefore, more rapid reductions in sediment input can be achieved by maintaining grassed riparian margins, rather than planting with shrubs and trees.

  However, considering the degree of erosion of the Matahuru Stream, it would be worthwhile trying to stabilise its banks where the stream is wide enough (>7-8m to prevent full shading of the stream banks. Planting trees and shrubs with vigorous growth and extensive rooting systems (e.g., non-invasive willows and poplars, *Populus spp.*) at sufficient densities (approximately ten metre intervals) to stabilise bank erosion is a possibility.

  In addition, fencing off existing totara (*Podocarpus totara var. totara*) along streambanks and underplanting with other native species should help stabilise banks.

  The Matahuru Stream from the junction of Matahuru Road and Hoult Road to Lake Waikare, and tributaries in sub-catchments that do not have their headwaters in native forest, are considered priorities for riparian management.

- **Lake Waikare riparian management**

  Trees that can withstand strong wave action (e.g., non-invasive willows, or native trees and shrubs such as flax, cabbage trees, and kahikatea should be planted on actively eroding shorelines and fenced for protection.

  The priority areas are along the northern shore (particularly properties 10, 11, 12, 15, 16, and the unplanted section of 19), and along the eastern shore (particularly properties 23 – 30, 37 – 43, and 45).

- **Capture of catchment turbidity in wetlands**

  A natural wetland occurs adjacent to the 500-600 m of the Matahuru Stream immediately upstream of the lake. It has been suggested that the Matahuru Stream could be re-directed into the wetland to settle out suspended sediments and reduce turbidity loading in the lake. To reduce the amount of sediment entering the wetland, a sediment retention pond could be constructed upstream of the wetland to settle out a coarse fraction of the sediment load.

- **Increasing the inflow from the Te Onetea Stream**

  It has been suggested that increasing the inflow of the Te Onetea Stream may help reduce turbidity in the lake. However, a significant increase in the present flow of water through the Te Onetea Stream would be required to substantially reduce the average HRT of the lake and significantly reduce lake water turbidity.

- Wave baffles

  Wave baffles could be installed to protect inshore areas. The western shore would be the best area to undertake such protection works, and wave barriers should be placed approximately 100 m from shore. This would probably be the best method for achieving a zone of lakebed which is protected from waves below the wave base, but that is sufficiently supplied with light for growth above the light base.

- **Consolidation of lake sediments**

A possible method for reducing suspended sediment is to drop the water level down to expose large areas of the lakebed. These areas would then be left to dry out and consolidate before re-flooding. A dried sediment sample from Lake Waikare remained consolidated after several days of submersion in lake water, suggesting that this could be a possible method for reducing the entrainment of sediment into the lake water column. ▪ **Mussel bio-filtration** Phytoplankton control by filter feeding mussels is a possibility. However, unless a large increase in mussel numbers occurs in Lake Waikare in the future, biofiltration will not provide a means of controlling phytoplankton abundance. ▪ Fish exclusion cages An option for reducing fish impacts on plant establishment is to cage off areas of suitable lake margins from fish access. This could be incorporated with wave baffles as above. Fish exclusion cages need to have good hydraulic exchange with the open lake and should exclude large fish (e.g. mesh size 20-50 mm). Once constructed, fish need to be removed by intensive netting and the exclosures may need to be initially seeded with plant material. Cages should be sited at shallow areas ≤0.7 m, where light is sufficient for plant growth and wind/wave exposure is minimal. The report also provides an effectiveness assessment and risk analysis for each management option. As there are no low risk / highly effective management options for restoring light climate in the lake, the report has provided alternate mitigation options: ▪ Enhancement of the remaining swamp areas on the western margin of the lake, particularly the margins of properties 1, 3, 69-71. Enhancement would include fencing out stock, controlling weeds such as crack and grey willow. ▪ Returning to a more natural fluctuation regime, with a minimum water level of at least 5.4 m in summer, and a maximum winter level of 6.1 m. ▪ Lake edge fencing and planting to enhance habitat for birds and fish. This should focus on low-lying areas around the lake that are periodically wet. ▪ Riparian planting in the Matahuru Stream catchment (details above). ▪ Restoration of submerged vegetation in either one of the smaller lakes nearby (Lake Kopuera or Lake Ohinewai), where there is a greater chance of restoration success.
Information gaps: It is not known whether raising the lake level would reduce suspended sediment concentrations enough to a level where turbidity doesn't prevent light penetration. This is because it is possible that turbidity is caused by a very tiny fraction of the lakebed sediment, which would still not settle out of the water column with a decrease in wave orbital velocities. The only way to determine this would be to deploy a wave-gauge with optical backscatter and turbidity sensors at a number of locations within the lake. In conjunction with sediment samples, it would then be possible to adjust the suspended sediment formula for the sediment specific to Lake Waikare. There is no published information on fish species biomass in Lake Waikare (e.g. kg fish species ha^{-1}). This information is required before any speculation can be made on fish impacts on submerged plants. Alternatively, structures to exclude fish from shallow areas where plant establishment is possible (e.g. a wave baffled western shoreline) would identify if fish are an additional barrier to plant establishment.

Reeves P, Hancock N. 2012. Ecological impacts of the flood control scheme on Lake Waikare and the Whangamarino Wetland, and potential mitigation options. Wildlands. DOI: https://www.waikatoregion.govt.nz/assets/WRC/Council/Policy-and-Plans/HR/S32/D/3154305.pdf. 60 pp.

Water quality information:

Prior to the Flood Control Scheme, anecdotal reports by historical lake users recall a 'clear' lake with a visible bottom, submerged vegetation, and sandy beaches on the northern and eastern shores. However, the decrease in average lake levels due to the Scheme has increased turbidity in Lake Waikare by increasing sediment re-suspension of lake bed sediments (clay, silt, and find sand) by small wind-waves. These wind-waves generate orbital velocity currents (shear stress) at the lakebed, which resuspend sediment into the water column. Because wave orbital velocities decrease almost exponentially with depth, lowering the lake by 1 m would have significantly increased the amount of shear stress at the lakebed, and, therefore, increased the amount of sediment lifted into the water column. Numerical modelling results suggest that the lowered lake level could have increased orbital velocities by 40-80%, translating into an increase in the mean suspended sediment reference concentration of 95-99%.

Field measurements support these results. TSS in the lake is high and has a wide range (between 50-600 mg/L with a maximum of >900 mg/L on one occasion), with highest TSS results in the summer, when lake levels are lower. Samples generally had a similar magnitude, suggesting the lake is well mixed.

Further to this, experiments on lakebed sediments show that clay, silt, and fine sand readily resuspends into the water column on windy days. The silt and fine sand settle out in a matter of hours, but the clay remains in suspension for days.

Matahuru Stream TSS are generally much lower (usually <100 mg/L) than lake TSS, indicating most of the lake TSS are a result of lake bed resuspension by wind-waves. For example, six weeks of no rain and calm weather resulted in low TSS lake results (33-66 mg/L, mean 42 mg/L) being measured in February 1994.

Sediment inputs to the lake from the Matahuru catchment are approximately 9,000-12,000 tons/year. Matahuru Stream TSS was recorded at *c.* 102 mg/L and had one of the highest sediment yields for the monitored Waikato catchments with a sediment yield of *c.*12 kt/year. High sediment runoff from the Matahuru catchment is continually introducing sediment into Lake Waikare where it may accumulate within the lake or be resuspended and flushed into Whangamarino Wetland via the Northern Outlet Canal. The Matahuru catchment has been well documented as the main source of sediment inputs into Lake Waikare, contributing *c.*76% of the sediment inputs. The remaining sub-catchments around the lake contribute *c.*13% of the annual sediment load and Te Onetea Stream provides the remaining 11%.

Sediment inputs from the Waikato River via Te Onetea Stream are low *c.* 300 t/year, due to the low TSS of the Waikato River (20 mg/L mean, 120 mg/L in flood) and low inflow volumes. Overflows from the Rangiriri Spillway into the lake are infrequent, and Rangiriri sediment inputs are therefore considered to be negligible.

Sediment transport in Lake Waikare has also changed since the Flood Control Scheme began due to the increased flushing of the lake (two to three times the lake volume passes through the Waikare control gate). Prior to the Flood Control Scheme, sediment from Lake Waikare would only have discharged into the Whangamarino Wetland every one to two years, when lake levels rose above the ridge at the northern end of the lake and spilled into the wetland across a wide area. There also would have been less sediment in suspension when levels were high enough to spill into the wetland, and it is likely that a large proportion of sediment was retained within the extensive area of wetland that previously existed between Lake Waikare and the Pungarehu Stream. This wide expanse of vegetated wetland area would have slowed water speeds and trapped sediment, partially protecting the rest of the wetland from flooding and sedimentation.

Under the current operation of the Flood Control Scheme, the Northern Outlet Canal acts as a narrow conduit for suspended sediment to be flushed from Lake Waikare into the Whangamarino Wetland when the Waikare control gate is open. Therefore, it is likely the Flood Control Scheme has resulted in more sediment passing through the lake and into the wetland, with floodwaters entering the Whangamarino Wetland from Lake Waikare having especially high concentrations of nutrients and TSS. One measurement taken when the Waikare control gate was open during a flood revealed a sediment yield of 700 t/day in the Northern Outlet Canal.

Sediment yield for the Waikare control gate and inputs to the Whangamarino Wetland from the lake were estimated at 4,964-32,592 t/year. TSS levels in the Pungarehu Stream are similar to TSS levels in Lake Waikare and Whangamarino River sediment inputs have been estimated at *c.* 27,000 t/year. In addition, there has been an increase in the proportion of sediment arriving from Lake Waikare in relation to that from the Whangamarino River (Waerenga) catchment. Sediment yield from Lake Waikare to Whangamarino Wetland depends on Waikare control gate flow, lake TSS, and the Waikare control gate being open, with greatest yield when flow and TSS are both high, and no sediment yield when the Gate is closed (usually the case during large floods). Likewise, sediment yield from Whangamarino River into the wetland depends on Whangamarino River flow and TSS, with greatest yield when flow and TSS are both high. In this case, when the Whangamarino gate is closed (during floods), sediment yield to the wetland remains high due to backflow of the Whangamarino River. Sediment input from the Waerenga Catchment into the Whangamarino Wetland is substantial (260 mg/L) during floods, and sediment loads may be up to 27,000 t/year. High Whangamarino River water levels cause surface flooding and sediment-laden water enters the wetland, especially near the streams. When Whangamarino River water levels are low (<3.2 m at Falls Road), sediment-laden water remains within stream-channels, passing through the wetland and into the Waikato River. Erosion along wave-exposed tracts of the Lake Waikare shoreline is another indirect effect of the change of lake level that may affect both lake turbidity and sedimentation. The lake level is constantly changing due to the Flood Control Scheme, which may cause ongoing shoreline erosion on the windward side of the lake, increasing sediment inputs. Turbidity is a strong barrier to mitigation of Lake Waikare water clarity due to a larger number of easily resuspended clay particles. Water sample results show that there are two populations of grain size in Lake Waikare, with a large number (but small volume) of fine clay particles and a small number (but large volume) of silt and very fine sand particles. Clay makes up only a very small percentage (*c.*2%) of the sample volume but it makes up the majority of the sample by number (meaning there are lots of clay particles to be resuspended by wind waves). These clay particles have optical properties (due to their size, shape, and colour) that cause poor water clarity and therefore increase turbidity. The silt and very fine sand resuspend easily but settle out again in a matter of hours, contributing to lake turbidity only for short periods. However, the clay can remain in suspension for many days, meaning that it will be repeatedly resuspended by wind-waves, contributing to high lake turbidity. Overall, lake water quality is poor, such that even if all the turbidity-causing sediment was removed from lake water, algal biomass would still be high, as would concentration of aquatic humic matter. The lake remains in a hypertrophic state, although there has been an improvement in some water quality variables in recent years. TSS concentrations have decreased, as has phosphorus, which is strongly associated with sediments. Turbidity has also decreased, as would be expected with a decline in TSS. However, nitrogen and chlorophyll *a* are increasing, most likely due to the intensification of farming practices, which is occurring through the Waikato region.
<u>Recommendations:</u> The report provides a broad scale evaluation of mitigation options, which is summarised in Table 8 of the report. These mitigation options are: ▪ **Catchment management – targeted farm-scale actions:** Retirement and/or reforestation of the least suitable land for pastoral use in the very steep hills of the Matahuru catchment could result in a significant reduction in downstream sediment loads. Livestock exclusion is also considered highly appropriate in both the Matahuru and Waerenga catchments, in tandem with grass filter and/or planted buffers. Livestock exclusion needs to be more widely practiced throughout the Matahuru catchment in particular, especially along smaller tributaries in the upper catchment. ▪ **Catchment management – constructed wetlands at bottom of catchment:**

Constructed wetlands or the fencing of natural wetland seeps can result in substantial reductions in sediment loads. Wetlands also provide other significant benefits, including potential reductions in nutrient loads (up to 80% of nitrogen and particulate phosphorus) and flood attenuation, an important issue for the Waerenga catchment, as this would also help to reduce flood peaks in the Whangamarino Wetland. Wetlands need to cover between 1-2.5% of the catchment (either as a collection of small wetlands or a large wetland at the bottom of the catchment) to achieve significant reductions in sediment loads.

- Increased lake levels / fluctuations in range in Lake Waikare;
- Wave barriers in Lake Waikare:

  A 15 m wide floating tyre breakwater would greatly reduce wave action in its lee under most conditions. However, further modelling is required to calculate the effects on circulation and identify optimum locations.
- **Constructed wetland between Lake Waikare and Whangamarino Wetland:**

  Construction of a treatment wetland between Lake Waikare and Whangamarino Wetland has the potential to significantly reduce sediment as well as nutrient loads. However, calculating the size and likely performance of a wetland to capture sediment exiting the Waikare control gate requires detailed modelling.
- **Confine Waikare control gate outflows by stop-banking/bunding and/or reducing peak flows/duration of peak flow events from Lake Waikare.**

None of the mitigation options evaluated provide a single solution to reducing sediment inputs to Lake Waikare and the Whangamarino Wetland. Any solution would require a combination of mitigation options. **Principally, for mitigation to have any real effect on the health of Lake Waikare or the Whangamarino Wetland, inputs from the Matahuru and Waerenga catchments need to be addressed as well as the current store of sediment and nutrients within the lake**.

The report also recommends that a comprehensive cost-benefit analysis of a range of water level scenarios for Lake Waikare be undertaken.

It is also noted that options that seek to improve water quality within Lake Waikare and the Whangamarino Wetland without reducing introduced fish biomass are likely to be less effective.

Information gaps:

Critical knowledge gaps were identified:

- There is a need for better quantification of sediment inputs and outputs. In particular, more data is needed on TSS in the Northern Outlet Canal, to more accurately determine the volume being discharged to the Whangamarino Wetland.
- The extent of surface flooding within the Whangamarino Wetland at different water levels should be quantified.
- There is a need for a better understanding of the contribution introduced fish make to suspended sediment levels within Lake Waikare and the Whangamarino Wetland.

Additional information that would be useful includes:

- Sediment accumulation rate cores of the lakebed at several sites;
- TSS and flow data for Whangamarino Wetland;
- The proportion of sediment contributed by shoreline erosion; and
- An understanding of where the sediment is coming from in the Matahuru Stream catchment.

Rice Resources Ltd. 1999a. Lake Waikare Flood Protection Scheme Consents Application.: Environment Waikato. Document # 656663. 101 pp.
This document comprises a resource consent application for the ongoing operation of the Lake Waikare flood protection scheme. No water quality information is provided and no knowledge gaps are identified. Any recommendations are in the form of draft conditions.

Rice Resources Ltd. 1999b. Lower Waikato Flood Control Scheme Lake Waikare system structures mitigation/management plan. Environment Waikato. Document # 656668. 40 pp.
Water quality information: The report includes no water quality information.
Recommendations: The report does not provide recommendations, but details a list of environmental issues and their associated action plans, which include the following proposed actions: ▪ **Determine a joint approach with other agencies and parties to Transit NZ with respect to gaining an increased culvert size when State Highway 1 is realigned through the Te Onetea zone;** ▪ Undertake a monitoring programme of riverbed changes in Te Onetea Stream and Waikato River every ten years; ▪ **Catchments feeding the lake should be assessed for sediment sources and likely contributions to the lake's sediment inputs;** ▪ **Promotion of the 'Streamcare' concept with Matahuru Stream landowners by the Asset Management Group of Environment Waikato;** ▪ **Stabilisation of the lakebed at the lake margins with plantings;** ▪ Establishment of lake boundaries as part of lake margin management to identify any actual/potential effects on landowners with regard to lake margin plantings; ▪ Assessment of any peat slumping in the area as a prelude to consideration of progressive slumping due that may have occurred due to lakes lower levels; ▪ **Keep the lake levels higher to test any associated reduction on wind stir effects and sediment re-suspension;** ▪ Undertake a cost benefit analysis of lake level increases; ▪ Koi carp control; ▪ **Establish a regular monitoring programme for basic and key parameters of the lake water. Monitoring should occur at set frequencies and on key dates;** ▪ Identification of sediment settlement sites along the Waikare Canal. The Asset Management Group of Environment Waikato should establish a sediment clean out programme that includes clean out times and triggers.
Information gaps: No information gaps identified.

Shearer JC, Clarkson BR. 1998. Whangamarino Wetland: Effects of lowered river levels on peat and vegetation. International Peat Journal. 8:52-65. DOI: https://doi.org/10.1672/0277-5212(2004)024[0133:VAPCIT]2.0.CO;2.
Water quality information: pH of peat water in the Whangamarino Wetland was, on average, 0.43 units higher than that of the surficial peat. However, both measurements of pH varied together. The pH of water varied between 3.7 and 5.4 with all but 5 of the 50 measurements falling between 4 and 5.
Recommendations: No explicit recommendations were made, but the authors note that restoration and maintenance of river levels, fire protection, removal of agricultural nutrient inputs, and grey willow control are required to sustain the peat bog ecosystem.
Information gaps: No information gaps were identified.

Sledger RF. 1981. Management decisions with regard to multiple use of resources. The Waters of the Waikato; University of Waikato. ISBN 0-9597571-5-5. 15 pp.
Water quality information: No water quality information was provided in this paper. This paper describes the balancing of differing stakeholder interests in the management of Lake Waikare as part of the Lower Waikato-Waipa flood control scheme.
Recommendations: The report provides no recommendations but documents the management decisions of the Waikato Valley Authority with regard to the operation of the scheme structures associated with Lake Waikare. These decisions were: 1. Management of control levels for Lake Waikare would be as follows: April 1st to September 30th, 5.5 m Moturiki Datum October 1st to December 31st, 5.65 m Moturiki Datum January 1st to March 31st, 5.6 m Moturiki Datum 2. Te Onetea Stream gate would be made operational and any further work to facilitate free flows would be undertaken. 3. The management of control levels would be undertaken by the operation of the Northern Outlet gate and the Te Onetea Stream gate.
Information gaps: There is little information on the condition of the Whangamarino Wetland prior to the flood control scheme being implemented.

Stephens S, de Winton M, Sukias J, Ovenden R, Taumoepeau A, Cooke J. 2004. Rehabilitation of Lake Waikare: Experimental investigations of the potential benefits of water level drawdown Hamilton: Environment Waikato. DOI: https://www.waikatoregion.govt.nz/assets/WRC/WRC-2019/TR04-25.pdf. 50 pp.
Water quality information:

Lake Waikare historically contained healthy aquatic plant populations but visual clarity in the lake had decreased by the 1940s, coincident with land clearance, and the complete collapse of submerged vegetation occurred in 1977/1978. Shallow lakes that have lost macrophyte communities usually exhibit frequent periods of resuspension, high turbidity, and low light penetration – conditions that are all typical of Lake Waikare today, which is now hyper-eutrophic and incapable of supporting submerged vegetation.

Light penetration is linearly related to turbidity in Lake Waikare, i.e., the light climate would improve if turbidity reduced. Furthermore, turbidity is linearly related to suspended sediment concentrations in Lake Waikare with a 1:1 ratio, i.e., reducing suspended sediment concentrations would reduce turbidity and improve the light climate. Fine-grained, clay-sized organic sediments presently dominate the high turbidity and light attenuation in the lake, with notable increases in turbidity observed when waves are actively stirring the lakebed. The lake remains turbid even after prolonged periods of calm weather.

The authors conducted experiments which involved drying lake sediments and then rewetting them and subjecting them to artificial currents. Turbidity and sediment concentration both increased with current speed. Some experimental troughs were vegetated while others weren't, and it was noted that turbidities remained comparatively low in the vegetated troughs compared with the unvegetated troughs.

One trough was dry for four months before being re-wetted. The first resuspension experiment in this trough showed considerable improvement with regard to lower resuspension rates and turbidity, especially when compared with a trough that had been kept dry for two months. However, after being inundated for two months and then re-stirred, the four-months-dry trough exhibited resuspension and turbidities similar to the two-months-dry trough, indicating that the benefits of desiccation had been lost.

For most experimental treatments, volatile (organic) suspended sediment concentrations formed high proportions (mostly >50%) of the total suspended sediment concentrations at the start of resuspension tests, and most likely consisted of algae or floating plant matter in the water column. However, although there was some additional resuspension of organic material during the resuspension experiments, percent organic matter generally dropped to less than 15%, showing that it was mostly the inorganic sediments that were being resuspended.

The analyses indicated that some aggregation of particles occurred when the sediments were dried, but this did not greatly alter the grainsize distributions. Median grainsizes by particle volume were classified as fine sand for all suspended sediment samples, but a high proportion of clay-sized particles were also found during resuspension, and median grainsizes by particle number were classified as clay.

The nutrient results show some evidence of nutrient release from sediments following rewetting, but in minor quantities compared to levels occurring naturally in the lake (background lake TN and TP levels in Lake Waikare water are 1100 and 180 mg m^{-3} respectively). Therefore, any nutrient release from lakebed sediments into the water column following drawdown and rewetting of Lake Waikare is unlikely to be important given the high nutrient levels already found in the lake.

The resuspension experiments showed that suspended sediment concentrations were linearly related to turbidity, as expected. Turbidity is an index of visual clarity, but it was also linearly related to light penetration, or light climate in Lake Waikare. The turbidity to suspended solids ratio drops during active resuspension events, as more sand particles are resuspended (which are largely optically irrelevant). Despite this, in the trough experiments, there remained a high proportion of clay-sized particles in resuspension after currents were applied. These clay particles are highly light attenuating and contribute disproportionately to restricting light penetration. Turbidities measured during trough resuspension were similar to those found in the lake, suggesting that despite the initial increased erosion resistance resulting from desiccation, resuspension of light-attenuating particles would still occur in the lake when energetic wave stirring occurred if desiccation of littoral zones was trialled.

The presence of planted macrophytes clearly reduced resuspension in the troughs, supporting abundant evidence from other studies that aquatic macrophytes reduce sediment resuspension and thus maintain water clarity.
Recommendations: Achieving an improvement in the light climate that was sufficient to establish plants would require the following actions to be in place: ▪ A reduced wave climate, which could be practically achieved by a reduction in fetches through lake draw down. This would need to be maintained until plants had established sufficiently to provide their own wave-dampening action, then water level would need to be gradually raised at a rate that allowed the plant canopy height to adjust. Therefore, the flood control scheme could not operate during this sensitive period. Reinstatement of water levels following drawdown would need to be linked to field observations and would probably need to occur over a period longer than six months. ▪ Some consideration should be applied to methods of removal or control of pest fish before attempting rehabilitation. ▪ **Possible nutrient reduction in the lake and inflowing waters**. ▪ Some active planting would most likely be required for rehabilitation.
Information gaps**:** Although drawdown provides an opportunity to initiate plant growth in the lakebed sediments, the fate of this vegetation upon refilling the lake remains uncertain. Unknowns include the quality of light penetration during re-wetting, and the relationship between disturbance by coarse fish and wave action. Therefore, wave baffles could be used to study the relationship between the wave environment and the establishment and persistence of plants. The impact of pest fish on vegetation and methods of controlling pest fish could also be assessed.

Stephens S, Ovenden R. 2003. Sediment resuspension and light attenuation in Lake Waikare: phase 1 - lakebed sediments. National Institute of Water and Atmospheric Research. NIWA Client Report: HAM2003-128. 21 pp.
Water quality information: A grain size analysis showed that turbidity was caused by clay particles of about 1 μm in diameter. These particles take approximately 20 days to fall through the water column. Therefore, all of the clay particles found in Lake Waikare are unlikely to ever settle out of the water column by themselves. Turbidity in the lake will temporarily increase when waves lift coarser sediment up into the water column, but these sink relatively fast, leaving suspended fine clay particles. The sediment analyses suggest that predicting temporary turbidity changes is perhaps not so important as finding a way to remove the small volume of very fine sediments from the water column.
Recommendations**:** **Methods for removing fine sediment fraction from the water column should be explored. Possible ways of removing fine sediments from the water column are:** **1. Consolidate them by drying out the lake and lakebed, in the hope that they become bound together and do not re-enter the water column on re-wetting;** **2. Introduce plants to trap and bind the sediments;** **3. Put a flocculent such as alum into the water column**. **Appling flocculent is a temporary measure and the light climate won't support plant growth, therefore, lakebed drying is the primary option. Then, if consolidation occurs and the light**

climate improves plants may re-establish and increase sediment binding. A flocculent could also be added at this stage to aid the process. **Exposure to the air and subsequent consolidation (desiccation) of lakebed sediments has been successful as part of water clarity rehabilitation projects overseas, and is a preferred option for exploration in Lake Waikare.** An experiment is recommended that will determine whether desiccation would be successful in removing suspended clay particles from the water column in Lake Waikare. The method involves the creation of four mini lakes, by placing fine lakebed sediment and lake water into four concrete troughs. The troughs would be settled, drained, and consolidated over the summer period, and relevant tests conducted on the sediments. Sediment samples would be collected and tested for density, organic carbon, sulphates, and aluminium. After re-wetting, water samples would be tested for phosphorus, nitrogen, and pH.
Information gaps: No information gaps were identified, however, recommendations for experimental research were made, as detailed above.

Te Onetea Stream, Lake Waikare and Whangamarino River Flood Control Structures. 1999. Environment Waikato. Hamilton. #770706 p. 145.
Water quality information: This document compiles documents with relation to a hearing on a resource consent for the flood control structures associated with Te Onetea Stream, Lake Waikare, and the Whangamarino River. The documents include the section 42a report, submissions, and minutes from a pre-hearing meeting. No new information is provided, however, key themes include: The flood control structures associated with Te Onetea Stream, Lake Waikare, and the Whangamarino River have had, and could potentially continue to have, a significant adverse effect on the quality of water and habitat in Lake Waikare. The water quality in Lake Waikare has seriously declined since 1965 and the lake, which once clear, is now turbid with suspended sediment. Increases in silt and green algae were also observed. The lowering of the lake levels, combined with the collapse of rooted macrophyte populations, resulted in an increase in sediment re-suspension and a reduction in water clarity in Lake Waikare. This high sediment load may also be preventing the re-establishment of macrophytes in the lake. If macrophytes were able to re-establish, they could aid in stabilisation of the lake bed and a reduction in sediment re-suspension. Additionally, reducing sediment inputs from the Matahuru Stream may provide significant mitigation for the adverse effects of re-suspended sediment in Lake Waikare and Whangamarino Wetland. The management and quality of water flowing into Whangamarino is important for its health and viability. The Whangamarino Wetland receives water with high suspended sediment loads from Lake Waikare. The document also suggests that the flood protection infrastructure has resulted in a reduction in the water quality of the Whangamarino River. The Te Onetea gate provides water quality values by introducing relatively clean, fresh water to Lake Waikare from the Waikato River. Waikato River water has a suspended solids concentration of 20 mg/l normal circumstances. This is substantially lower than concentrations in the lake (average of 117 mg/l). It was noted that, at the time the document was prepared (1999), Lake Waikare was classed as “contact recreation” under the WRC water quality classification system. Submitters raised concerns about the constant movement of water through the fish pass, as it was suggested that it may impact suspended sediment concentrations.
Recommendations**:**

The document does not include a list of recommendations but relevant requests from the submitters have been compiled below:

- **Multiple parties requested a comprehensive management plan towards the restoration of water quality in Lake Waikare and the management of the effects of the water regime on the Whangamarino Wetland. The plan should be prepared in consultation with all affected parties**.
- **It was requested that the throughput of water from the Waikato River, through Lake Waikare, and into the Whangamarino Wetland be maximised. A key part of this is the maximisation of the volume of higher-quality water passing from the Waikato River through Te Onetea Stream into Lake Waikare. It was suggested that this could be achieved by widening the Te Onetea control gate.**
- **A sediment trap at the discharge from Lake Waikare to the outlet canal may be effective.**
- **Generally speaking, a reduction in the deposition of silt in Lake Waikare and the Whangamarino Wetland was raised as a key outcome sought. The Matahuru Stream discharges nutrients and silt into Lake Waikare and it was suggested that the water quality of the Matahuru Stream be improved to remedy this. Submitters requested a comprehensive Streamcare package be compiled for the Matahuru and Mangapiko Streams and their tributaries, as well as any other significant sources of sediment for the lake, in order to improve their water quality.**
- **It was requested that the water levels in Lake Waikare be partially restored to minimise sediment resuspension and offset 800 acres of original wetland around the lake margins, which was lost due to water level control. In particular, it was requested that a higher winter water level should be allowed for. This could be achieved by controlling the rate of water discharged through the Lake Waikare control gate. As part of this, it was recommended that a comprehensive study be initiated to establish the minimum level that Lake Waikare should be set at in order to minimise silt resuspension.**
- It was recommended that the lake be designated a Wildlife Management Reserve and that crown land around the lake edge be reserved for wetland development. It was requested that the margins be fenced to exclude stock, promote the re-establishment of plants in order to reduce sediment resuspension, and restore habitat.
- It was requested that any applications for new abstraction consents or activities that would cause fluctuations in the lake level beyond its set minimum would be declined.
- It was recommended that a comprehensive study be initiated to determine the most appropriate water regime for the flow of water into the Whangamarino Wetland. Based on this, management plan should also be developed to maintain the Whangamarino Wetland's hydrological and habitat functions.
- It was requested that a Water Conservation Order be sought for the flow into the Whangamarino, including flow via the Te Onetea Stream.
- **It was also requested that a comprehensive study and monitoring programme be conducted to measure the effects of the flood control structures, with particular regard to reduced water levels and the re-suspension of sediment.**
- Submitters requested that only a short duration of consent be approved.

<u>Information gaps</u>**:**

No key information gaps were identified, however, requests for further research/monitoring were made, including:

- A comprehensive study that will determine the most appropriate water regime for the flow of water into the Whangamarino Wetland.
- A comprehensive study and monitoring programme to measure the effects of the flood control structures, with particular regard to reduced water levels and the re-suspension of sediment.

Thompson AB. 2011. Soil stability and disturbance in the Matahuru Catchment. Waikato Regional Council. DOI: https://www.waikatoregion.govt.nz/assets/WRC/WRC-2019/2011-08.pdf. 24 pp.
Water quality information: No water quality information is contained within this report. The report compares the extent of erosion processes and soil conservation measures in the Matahuru catchment in 2002 and 2007. Key findings were that farmland had decreased significantly across the catchment, while farmland with residual conservation cover had increased significantly. Bare soil caused by natural processes had also decreased across the catchment, and these decreases were only statistically significant for farmland. Decreases in the extent of planted soil conservation measures were also measurable, but minor in scale, and not significant for any land use aside from farmland.
Recommendations: No recommendations were made.
Information gaps No information gaps were identified.

Watts C. 2009. The invertebrate fauna of Whangamarino Wetland, Waikato. Lincoln: Landcare Research. Landcare Research Contract Report: 0809/121. 47 pp.
Water quality information: The report is not a water quality report, but a review of entomological data for the Whangamarino wetland.
Recommendations: ▪ The results presented in the report summarise the invertebrate fauna from a small area that comprised only a few vegetation types. Future research should, therefore, focus on the composition of the invertebrate communities inhabiting other vegetation types within Whangamarino, such as areas dominated by reedlands, rushlands, and shrublands. ▪ This study supported the decision to remove and control willows from significant wetland sites, such as Whangamarino. Future research should also focus on a year-round study of the insect community in deciduous willow-dominated vegetation compared with native, evergreen wetlands and decipher impacts on higher trophic interactions. In addition, research should monitor the rates and patterns of invertebrate population recovery after willow removal and after restoration of native wetland vegetation. ▪ Opportunities to monitor changes in the invertebrate fauna as a result of the impacts of introduced mammal species should be undertaken and should focus on rates and patterns of invertebrate community composition change following introduced mammal control. ▪ Monitoring of unique species, such as '*Batrachedra*' sp. and *Paracephaleus* species should be a priority of the management and restoration of Whangamarino. ▪ The report noted that additional entomological studies were required to gather information regarding the composition, abundance and distribution of invertebrates at Whangamarino. A simple survey method using modified malaise traps could be setup at Whangamarino to monitor these populations overtime. ▪ The use of the modified malaise trap technique was recommended for future research programmes.
Information gaps:

There is a general paucity of data on New Zealand wetland invertebrate taxonomy and limited geographic spread of sampling. Because many invertebrates in New Zealand are 'new' species and await formal description, numerous taxa sampled in this study could only be identified to family or genus level. In addition, a lack of specialist knowledge means that only a few taxonomists are familiar enough with the fauna to be able to identify specimens.
Therefore, the report noted that, generally speaking, additional entomological studies are required to obtain information regarding the composition, abundance, and distribution of invertebrates at Whangamarino. Additionally, the results presented in the report summarise the invertebrate fauna collected from a small area and restricted to only a few vegetation types that were relatively dry and only periodically flooded. The composition of the invertebrate communities inhabiting other native vegetation types (e.g., *Carex* sedgelands, *Eleocharis* reedlands, and mānuka shrublands) remains unknown. Future research should focus on these habitats.
The report highlighted that the density of introduced mammals at Whangamarino is unknown, as is the impact of these species on the invertebrate fauna.
At the time the report was prepared, the effect of manipulating the hydrological regime on the invertebrate community at Whangamarino remained unknown and required further investigation.
It is unknown how widespread unique species (i.e., *Batrachedra* and *Paracephaleus* sp.) are, or at what density they occur compared to host plant density. It was noted that further research was required to determine whether these taxa could possibly be used as indicator species.

Waugh J. 2007. Report on the Whangamarino Wetland and its role in flood storage on the lower Waikato River. Department of Conservation. A 122 3063. 8 pp.
<u>Water quality information:</u> No water quality information was provided in this report. Rather, it is an assessment of the significance and value of the flood control functions of Lake Waikare and the Whangamarino Wetland.
<u>Recommendations:</u> The author recommended clarifying how the flood storage areas are designated and/or protected.
<u>Information gaps:</u> It was unclear whether the flood storage areas around Lake Waikare and the Whangamarino Wetland are adequately protected.

Sincerely,

SLR Consulting New Zealand

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Technical Director, Environmental Services

5.0 Feedback

At SLR, we are committed to delivering professional quality service to our clients. We are constantly looking for ways to improve the quality of our deliverables and our service to our clients. Client feedback is a valuable tool in helping us prioritise services and resources according to our client needs.

To achieve this, your feedback on the team's performance, deliverables and service are valuable and SLR welcome all feedback via https://www.slrconsulting.com/en/feedback. We recognise the value of your time and we will make a $10 donation to our Charity Partner - Lifeline, for every completed form.

Appendix A Reference List

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SLR Project No.: 15088

7 May 2024

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