ECOLOGICAL IMPACTS OF THE FLOOD CONTROL SCHEME ON LAKE WAIKARE AND THE WHANGAMARINO WETLAND, AND POTENTIAL MITIGATION OPTIONS

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Ecological Impacts of the Flood Control Scheme on Lake Waikare and the Whangamarino Wetland, and Potential Mitigation Options

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Contract Report No. 2766

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EXECUTIVE SUMMARY

Whangamarino Wetland and Lake Waikare constitute the second largest bog and swamp complex in the North Island, and the largest lake in the lower Waikato basin. Whangamarino Wetland, is listed as a wetland of international significance under the Ramsar Convention for being an outstanding example of a wetland characteristic of its' region and for supporting significant populations of many threatened species. Lake Waikare contains high biodiversity values providing habitat for a range of indigenous fauna, including six threatened species.

Lake Waikare and Whangamarino Wetland are part of the Lower Waikato Flood Control Scheme, providing flood storage for the Waikato River. The Flood Control Scheme provides flood protection to approximately half of the Waikato River floodplain, resulting in substantial economic benefits. These include increased productivity of agricultural and horticultural land, and protection for private property and major communication and transportation networks.

A number of investigations have been undertaken since the implementation of the Flood Control Scheme, indicating that the scheme has had negative impacts on Lake Waikare and Whangamarino Wetland. Waikato Regional Council and the Department of Conservation have agreed that a review of the ecological impacts of the Flood Control Scheme was timely and have commissioned Wildland Consultants to undertake this review, and to provide recommendations for mitigating sediment inputs. A literature review was undertaken, and staff at Waikato Regional Council and Department of Conservation were interviewed to collect information on the ecological impacts of the Flood Control Scheme and to gather their ideas on potential mitigation options. Following on from these interviews, a workshop involving both agencies was held on 28 September 2011. The purpose of the workshop was to review and reach consensus on the ecological impacts of the Flood Control Scheme and to discuss mitigation options that had been put forward during the interviews.

The following ecological impacts were identified:

- A change in the hydrological regime of Lake Waikare, including a 1.13 m decrease in average water levels, a significant decrease in water level fluctuation, and very little variation in average seasonal water levels.
- Redirection of water movement between Lake Waikare, the Whangamarino Wetland, and the Waikato River. The direction of flow between Lake Waikare and the Waikato River has been reversed and the frequency and volume of water discharged from Lake Waikare into Whangamarino Wetland has been substantially increased, significantly altering its hydrology.
- An increase in the turbidity of water in Lake Waikare as a result of lower average lake levels.
- An increase in sedimentation in the Whangamarino Wetland, with rates varying between 16.8 mm/yr adjacent to the Pungarehu Stream and 2.5 mm/yr, about 275 m into the Whangamarino Wetland.

- An increase in the frequency and extent of flooding in the Whangamarino Wetland.
- Nutrient enrichment of the southern peat bog at Whangamarino Wetland.
- Erosion of the shoreline at Lake Waikare, particularly along the northern and eastern shorelines.
- Loss of wetland habitat at both Lake Waikare and Whangamarino Wetland, leading to an estimated 40 percent decline in wildlife.
- A greater risk of weed invasion.

There have been substantial changes within the lower Waikato River catchments since the Flood Control Scheme became operational in 1965. The intensification of land use (predominantly pastoral) presents a significant barrier to the mitigation of impacts. Sediment and nutrient loads to Lake Waikare and Whangamarino Wetland are substantial and have been increasing over time. For mitigation to have any real effect on the health of Lake Waikare or Whangamarino Wetland, catchment inputs will need to be addressed.

Introduced fish currently comprise 89 percent of the total sum of all fish present in the lower Waikato River between Ngaruawahia and Tuakau. The most abundant species, koi carp (*Cyprinus carpio*) is likely to be affecting water quality and the re-establishment of submerged macrophytes. Mitigation options that seek to improve water quality within Lake Waikare and Whangamarino Wetland without reducing introduced fish biomass are therefore likely to be less effective.

Mitigation options for Lake Waikare that were identified by the Lake Waikare Steering Group were re-evaluated. Two mitigation options were identified as having potential and were evaluated, along with another five options that arose out of staff interviews and the workshop. A broad scale evaluation system was developed which scored the following; effectiveness at reducing sediment loads, certainty of outcome, cost and other benefits. A checklist of other considerations was appended to the evaluation.

None of the mitigation options evaluated provide a single solution to reducing sediment inputs to Lake Waikare and Whangamarino Wetland. Any solution will need to include a combination of mitigation options, however all of the mitigation options evaluated had significant drawbacks. Further investigation, including filling critical gaps in knowledge may provide better certainty of outcomes and could identify further mitigation options.

Critical gaps in knowledge were identified. These include:

- Better quantification of sediment inputs and outputs. In particular, more data is needed on concentrations of suspended sediment in the Northern Outlet Canal, to more accurately determine the volume of sediment being discharged to the Whangamarino Wetland.
- Quantification of the extent of surface flooding within the Whangamarino Wetland at different water levels.
- A better understanding of the contribution introduced fish make to suspended sediment concentrations within Lake Waikare and the Whangamarino Wetland.

CONTENTS

Reviewed and approved for release by:

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Director/Principal Ecologist
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1. INTRODUCTION

Whangamarino Wetland and Lake Waikare constitute the second largest bog and swamp complex in the North Island, and the largest lake in the lower Waikato basin. Whangamarino Wetland, is listed as a wetland of international significance under the Ramsar Convention for being an outstanding example of a wetland characteristic of its' region and for supporting significant populations of many threatened species. Lake Waikare contains high biodiversity values providing habitat for a range of indigenous fauna, including six threatened species.

Lake Waikare and Whangamarino Wetland are part of the Lower Waikato Flood Control Scheme, providing flood storage for the Waikato River. Both ecosystems have become considerably degraded since implementation of the scheme due to a range of factors including poor water quality, modified hydrological regimes and invasion of pest plants and animals.

A number of investigations have been undertaken that indicate the Flood Control Scheme has had negative impacts on Lake Waikare and the Whangamarino Wetland. In response, mitigation options for Lake Waikare have been investigated and some management actions have been undertaken (Lake Waikare Steering Group 2007). Mitigation options for the Whangamarino Wetland have not been investigated to date, however between 2007 to 2010, $1.5 million was spent on understanding and addressing restoration issues within the wetland as part of the Department of Conservation Arawai Kākāriki Wetland Restoration Programme (Robertson and Suggate 2011). Some of this work has been focused on developing a better understanding of the effects of catchment activities on the wetland, including the effects of flood control discharges from Lake Waikare. Waikato Regional Council has also undertaken investigations of the effects of the Lake Waikare discharge to Whangamarino Wetland, as required by consent conditions for their discharge permit granted in 2002.

The Waikato Regional Council and the Department of Conservation agreed that a review of the impacts of the Flood Control Scheme was timely and commissioned Wildland Consultants to undertake this review and to outline recommendations for mitigating sediment inputs.

In particular the review was to address (but not be limited to):

- Sediment accumulation in the Whangamarino Wetland and Lake Waikare.
- Sediment and nutrient sources to the Lake and Wetland.
- Potential mitigation options for reducing sediment inputs to the Whangamarino Wetland and Lake Waikare.

In addition, critical gaps in knowledge and site-based limitations unrelated to the Flood Control Scheme that may prevent the uptake of mitigation options were to be identified.

This report describes the study area, the methods used to undertake the review, and the findings.

2. BACKGROUND

2.1 Lake Waikare

Lake Waikare is located approximately 30 km north of Hamilton and lies to the east of SH1, between Ohinewai and Te Kauwhata. It is the largest and oldest of the lakes in the Lower Waikato Valley, formed 17800 ± 200y BP (Viner, 1987). General characteristics of the lake and its' catchment are summarised in Table 1.

Table 1: Physical characteristics of Lake Waikare and its' catchment prior to the Lower Waikato Flood Control Scheme (1965) and at present.

	Prior to 1965		Present	
Area	44.5km^2	Barnes 2002	34.35 km^2	Reeves *et al.* 2002
Maximum Depth	~ 4.0 m	Reeves *et al.* 2002	1.8 m	Duncan 1997
Mean Depth	2.31 m	Barnes 2002	1.26 m	Reeves *et al.* 2002
Lake Volume	Unknown		43,146,000 m^3	Reeves *et al.* 2002
Mean annual lake level fluctuation	1.8 m	Environment Waikato, 1998.	0.35 m	
Trophic Status	Eutrophic*	Town 1982Barnes 2002	Hypertrophic	Hamilton *et al.* 2010
Catchment Size	< 210.55 km^2		210.55 km^2	Wildland Consultants 2011a
% Catchment in Native Vegetation Cover	Unknown		8.12	LCDB2
% Catchment in Pasture	Unknown		72.38	LCDB2
Wetland Vegetation	1700 ha	Cheyne1980	840 ha in 1980	Cheyne 1980

*Data is from 1982. No water quality measurements were undertaken prior to 1982.

The catchment is bounded by the Waikato River in the west and the Hapuakohe Range in the east (Figure 1). The Taupiri Range occurs to the south and a low ridge (Te Kauwhata-Waerenga Road) separates Lake Waikare from the Whangamarino Wetland to the north. Four small lakes occur to the west of Lake Waikare: Ohinewai (16 ha), Kopuera (52 ha), Rotokawau (22 ha) and Penewaka Lagoon (4 ha). All but Penewaka Lagoon are linked to Lake Waikare by drains.

Ownership of the lake bed and some marginal strips were recently transferred from Land Information New Zealand (LINZ) and Department of Conservation to Waikato-Tainui. Department of Conservation administers approximately 500 hectares of reserve around the lake edge, which include a large area of wetland on the western shoreline which extends and surrounds Lake Rotokawau (Figure 2). Waikato Regional Council own 95.91 ha of land in the vicinity of the Northern Outlet Canal which contains flood control assets including the canal, the Waikare control gate and associated stopbanks (Figure 2).

The Matahuru Stream is the main inflow to Lake Waikare, with headwaters in steep pastoral land with underlying greywacke rock and tephra. Soils in the headwaters are a mixture of Ultic and Recent soils with Gley and Granular soils common on the flats (Collier *et al.* 2010). Thirty-one percent of the catchment has severe erosion potential (River and Catchment Services Group 2011).

Data Acknowledgment

Catchments boundaries supplied by Waikato Regional Council.
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Figure 1. Lake Waikare / Whangamarino Wetland catchments

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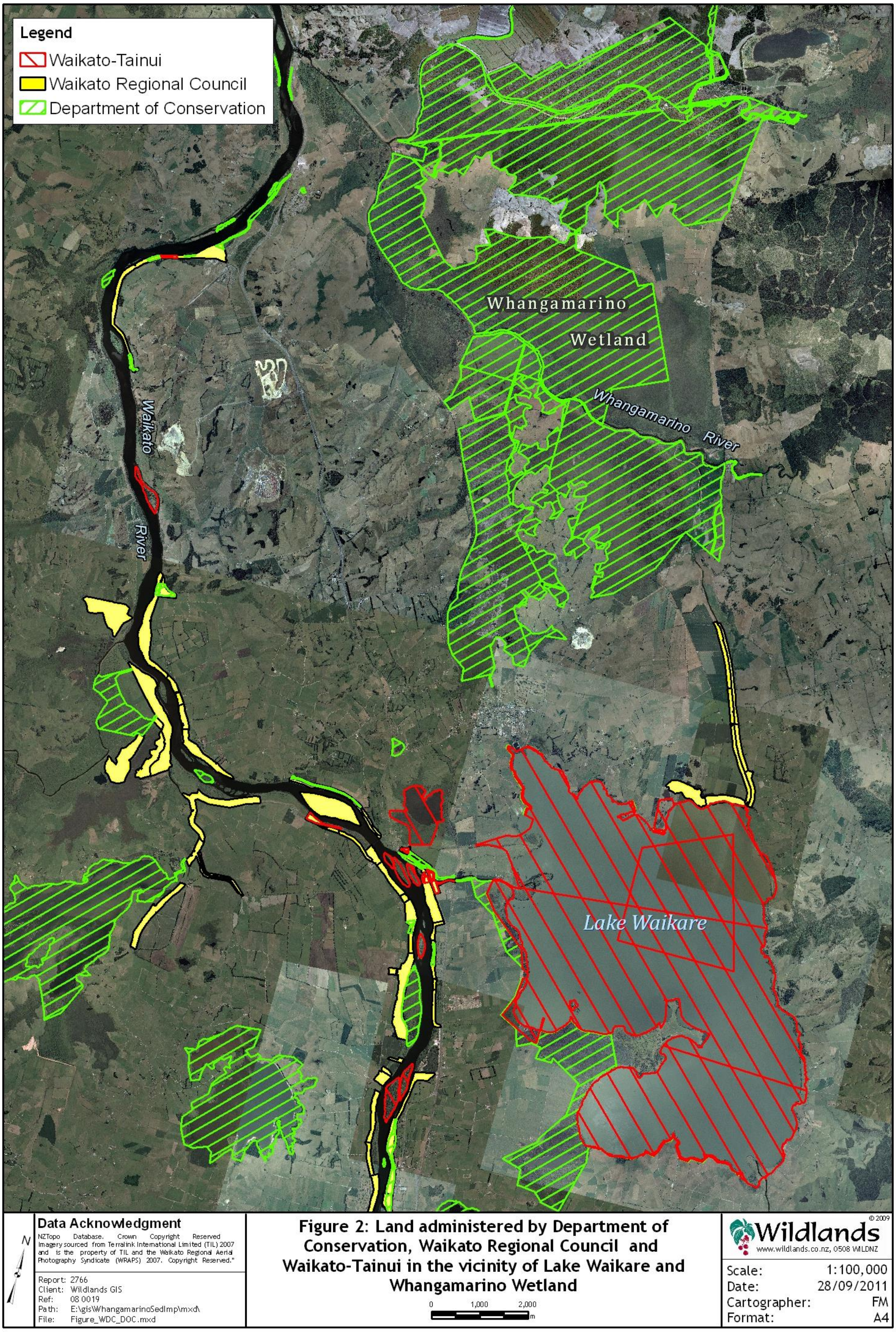


Figure 2: Land administered by Department of Conservation, Waikato Regional Council and Waikato-Tainui in the vicinity of Lake Waikare and Whangamarino Wetland

Historically (*c*.1840) the Lake Waikare catchment was most likely covered in secondary forest on the hills and freshwater wetland with enclaves of kahikatea (*Dacrycarpus dacrydioides*) forest on the flats. The forest would have been a mixture of bracken (*Pteridium esculentum*), fivefinger (*Pseudopanax arboreus*), kohuhu (*Pittosporum tenuifolium*), and other broadleaved species or manuka (*Leptospermum scoparium*) and/or kanuka (*Kunzea ericoides*). Over time there would have been a gradual transition to dominance by taller species such as rewarewa (*Knightia excelsa*), kamahi (*Weinmannia racemosa*), mangaeo (*Litsea calicaris*), rimu (*Dacrydium cupressinum*), and tanekaha (*Phyllocladus trichomanoides*) (Leathwick *et al.* 1995).

Following World War II, a dramatic increase in forest clearance occurred within the catchment (Reeves *et al.* 2002). Current land use is a mix of beef, dry stock, dairying, sheep and some cropping (AGRIBASE data, reported in Jenkins and Vant 2007).

While the extent and hydrology of Lake Waikare has been significantly modified by the flood control scheme it still retains high biodiversity values and was ranked 39th out of 96 lakes in the Waikato Region for biodiversity management (Wildland Consultants 2011a). The large size of Lake Waikare ensures that it continues to provide valuable habitat for many indigenous species, including short-finned eel (*Anguilla australis*) and mysid shrimp (*Tenagomysis chiltoni*), and may be an important nursery habitat for banded kōkopu (*Galaxias fasciatus*) and giant kōkopu (*Galaxias argenteus*) (Hicks 2010). A number of threatened species are known to utilise the lake including long-finned eel (*Anguilla dieffenbachii*), white heron (*Ardea modesta*), NZ dabchick (*Poliocephalus rufopectus*), black shag (*Phalacrocorax carbo novaehollandiae*), and little black shag (*Phalacrocorax sulcirostris*). Black mudfish (*Neochanna diversus*) are likely to occur in the marginal wetlands contiguous with Lake Waikare and Lake Rotokawau.

2.2 Whangamarino Wetland

Whangamarino Wetland is located approximately 45 km north of Hamilton and lies to the east of SH1, between Te Kauwhata and Mercer. It is a large lowland freshwater wetland comprised of marsh, swamp, fen and bog. The wetland is contained within three shallow basins drained by the Maramarua and Whangamarino Rivers and the Reao Stream. Its large catchment (597 km^2, excluding the Lake Waikare catchment) extends in the north to the headwaters of the Mangatangi Dam in the Hunua Ranges (Figure 1). To the east it is bounded by the Maungaroa Fault and on the west by low hills adjacent to SH1.

The Waerenga sub-catchment provides the main inflows into the southern half of the wetland. The catchment has very similar geology and soils to the Matahuru catchment described above, although there are larger areas of Gley soils along the more extensive lowlands. Historical vegetation cover would have been the same as the Matahuru catchment (Leathwick *et al.* 1995). The current vegetation cover is mainly pastoral (90%) with some plantation forest on the northern hills (LCDB2). Thirty-six per cent of the catchment has severe erosion potential (River and Catchment Services Group and GHD Ltd 2011).

The wetland originally covered 10,300 ha however large areas have been drained and modified since World War II and, by 2008, 6,580 ha remained (Wildland Consultants

2011b). The Department of Conservation administers the majority of the remaining wetland (4,640 ha), with the balance owned by Fish and Game New Zealand (748 ha) and private landowners (1,192 ha) (Figure 2).

Whangamarino Wetland provides important habitat for a high diversity of indigenous plants and fauna, including ten threatened plant species (Wildland Consultants 2009). The wetland contains the largest populations in New Zealand of the threatened Australasian bittern (*Botaurus poiciloptilus*) (Robertson and Suggate 2011). It is also a significant site for other uncommon wetland birds including marsh crake (*Porzana pusilla affinis*), spotless crake (*Porzana tabuensis tabuensis*), North Island fernbird (*Bowdleria punctata vealeae*), and NZ dabchick and is a stronghold for the threatened black mudfish (*Neochanna diversus*) (Waugh 2007).

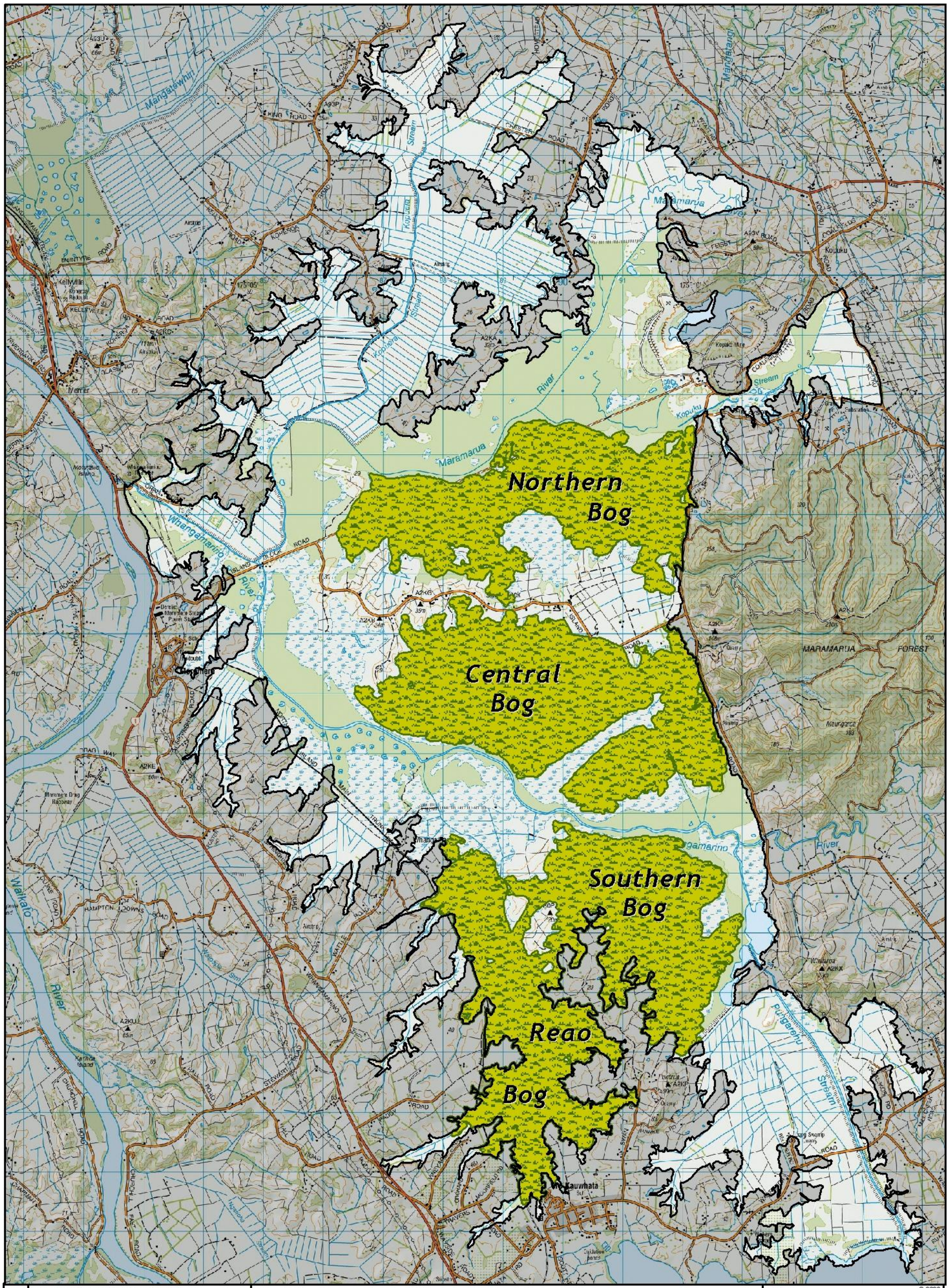
Whangamarino Wetland contains extensive areas of peat bog (Figure 3), a comparatively rare wetland type in New Zealand (Ausseil *et al*. 2008). Peat bogs derived from the remains of plants that have built up over hundreds of years, and their surfaces can be several meters higher than surrounding fen and swamp (Johnson and Gerbeaux 2004). Their main source of water is from rainfall and they are therefore dominated by plant species that are adapted to live in very low nutrient environments. This makes them particularly sensitive to nutrient inputs from surface water and groundwater.

The economic value or "ecosystem services" provided by Whangarmarino Wetland has been estimated by Kirkland (1988) to be $US9.9 million/year (2003 dollars). Ecosystem services provided by Whangamarino Wetland include floodwater mitigation, gamebird hunting, harvesting and fishing, which traditionally have included eels/tuna, flax/harakeke and whitebait/inanga, sightseeing and recreational opportunities, as well as carbon sequestration (Department of Conservation, 2007).

2.3 Lower Waikato Waipa Flood Control Scheme

The Lower Waikato Waipa Flood Control Scheme was initiated in 1958 following three large flood events in 1952, 1956, and 1958. The scheme was designed to provide flood protection and drainage improvements within the floodplains of lower Waikato and Waipa Rivers. The scheme consists of stop banks, pump stations, floodgates, and main river channel improvements. Construction commenced in 1961 and was completed in 1982, resulting in the protection of approximately half of the floodplain of the Waikato River (River and Catchment Services Group and GHD Ltd 2011).

The design of the Lower Waikato flood scheme was based on using the natural flood ponding areas provided by Lake Waikare and the Whangamarino Wetland to dampen peak flows in the Waikato River (River and Catchment Services Group and GHD Ltd 2011). It involved constructing a new outlet and canal (Northern Outlet Canal) with a control gate so lake levels could be permanently lowered and controlled to provide more flood storage within the lake (locations shown in Figure 1). Control gates were also installed on the Te Onetea Stream and the outlet of the Whangamarino River, to control the direction of water flows. The Rangiriri Stream was blocked off to prevent discharge to the Waikato River (Waikato Valley Authourity 1981).



Data Acknowledgment

Vegetation data from Paula Reeves (1994).
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Figure 3: The location and extent of bogs in Whangamarino Wetland in 1942

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A raised spillway was constructed at Rangiriri, to control the spilling of water from the Waikato River into Lake Waikare and along the northern foreshore of Lake Waikare to contain floodwaters. In significant flood events, water from the Waikato River flows over the Rangiriri spillway then overland into Lake Waikare and is eventually released through the Whangamarino River control gate once river levels in the Waikato River have subsided. These events are rare, the last occurring in 1998 (Brown 2010).

A review of the Flood Control Scheme was carried out in 1980 following a similar public participation process to that used for Crown water right applications. The purpose was to set limits on lake levels after taking into account the needs of different stakeholder groups (Hannah 1981). The result was a set of target water levels for different periods of the year which are shown below:

1 January-31 March	1 April-30 September	1 October-31 December
5.60 m	5.50 m	5.65 m

Under normal operating conditions (i.e. not under flood conditions) the target water levels are achieved by opening and closing the Waikare control gate. In practice it is not always possible to meet these targets as water levels are affected by other variables within the local catchments that there is no control over (e.g. evaporation, rainfall), (Mulholland in Barnes 2002). Keeping within target levels is also complicated by wind induced wave set-up which can affect lake levels by up to 200 mm (Rice Resources Ltd 1999a).

The Te Onetea and Whangamarino control gates also affect water levels in Lake Waikare. The Te Onetea control gate is opened when the water levels in the Waikato River at Rangiriri are higher than that of Lake Waikare and below RL 7.0 m (when water levels in the Waikato River go above 7.0 m the pressure on the gates prevents them from being closed). The control gates are closed when Lake Waikare water levels are lower than those in the Waikato River at Rangiriri, preventing outflow from the lake into the river (Mulholland in Barnes 2002). The opening and closing of the Waikare and Whangamarino control gates is automated although can be over-ridden when necessary (Mohammed Hassan, Waikato Regional Council *pers. comm.*). The Whangamarino control gate is only closed when water levels in the Waikato River are higher than water levels in the Whangamarino Wetland. On average this occurs twice a year for a period of up to three days at a time (Mulholland in Barnes 2002). A diagram of how the Flood Control Scheme currently operates has been created by Waikato Regional Council and is re-produced in Figure 4.

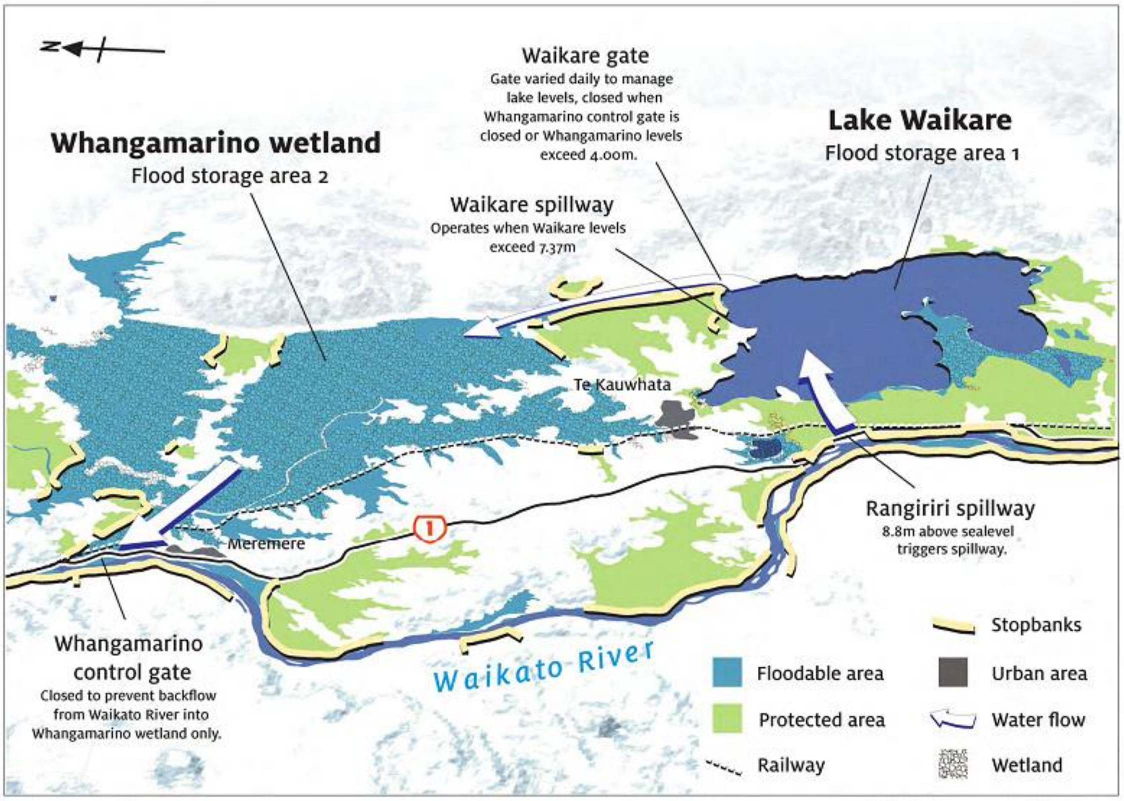

Figure 4: Summary of the Flood Control Scheme. Source: River and Catchment Services Group and GHD Ltd 2011.

Resource consents for continued operation of the Flood Control Scheme were granted to Waikato Regional Council in 1999, however these were appealed to the Environment Court. The appeals were settled in June 2002 and included an agreement requiring the Waikato Regional Council to fence 20 kilometers of the Matahuru Stream and to set up a stakeholder group to determine a programme of research and investigations into the cause of the lake's degradation and what could be done to improve the lake.

A stakeholder group, known as the Lake Waikare Steering Group, was formed, consisting of Fish and Game New Zealand, Ducks Unlimited Inc., Waikato District Council, Waikato Regional Council, Department of Conservation, and several adjoining landowners. They developed the following vision for the lake:

'To restore Lake Waikare to a healthy stable ecosystem supporting abundant plants and wildlife while providing a valuable flood storage role'.

The group met regularly until 2007 with their work culminating in a report on management options for the lake (Lake Waikare Steering Group 2007).

The consent formalised the target water levels for Lake Waikare set in 1981 and included principles for operating the major structures associated with the Flood Control Scheme. One of the principles is that water from Lake Waikare can only be discharged into Whangamarino Wetland when wetland water levels are below 4.0 m RL except '*Where the lake level is rising, and due to the nature of the event causing* *the rise (e.g. major flood), a decision is made to open the Waikare Gate regardless of the water level of the Whangamarino Swamp.'* (Rice Resourced Ltd 1999b).

A timeline of the events associated with the Flood Control Scheme is summarised in Table 2. It also includes other significant events that have affected the ecology of the lake (e.g. re-opening of the Te Onetea Stream and improvements to fish passage).

Table 2: Timeline of events associated with the Lower Waikato Waipa Flood Control Scheme, 1963-2003.

1963	Northern outlet canal completed
March 1965	Te Onetea Stream closed Rangiriri Stream closed
Aug 1965	Waikare control gates operational
1970	Whangamarino control gate operational
1981	Setting of target lake levels Rangiriri spillway raised to design levels
Early 1980's	Te Onetea Stream re-opened with a control gate
1984	Elver pass completed at Waikare control gate
2002	35 year discharge permit granted for operation of Waikare control gate Lake Waikare Steering Group formed
2003	Fish pass completed at Waikare control gate

3. REVIEW METHODS

3.1 Literature review

A review of information supplied by Waikato Regional Council and the Department of Conservation was undertaken, along with a review of scientific literature and other published material.

3.2 Analysis of monitoring data

Monitoring data associated with the Waikare control gate discharge permit was analysed using Microsoft Excel. Data included the following:

- Waikare control gate daily flows from 15 March 1988 - 31 July 2011.
- Lake Waikare water levels from 15 March 1988 - 31 July 2011.
- Suspended solids (direct sampling) from Northern Outlet Canal at Waerenga Road. Collected bi-monthly between August 2006 - July 2011 (some gaps in record).
- Suspended solids (direct sampling) from Matahuru Stream at Waiterimu Road. Collected bi-monthly between August 2006 - July 2011 (some gaps in record).

3.3 Interviews

Eleven staff from Department of Conservation and Waikato Regional Council were interviewed in August-September 2011. They included engineers (Guy Russell, Murray Mulholland), land management/environmental officers (Michelle Hodges, Therese Balvert), and a soil scientist (Reece Hill) from Waikato Regional Council. Programme managers (Lucy Roberts, Shannon Patterson), biodiversity rangers (Chris

Annandale, Kathryn Duggan, Kevin Hutchinson, Matthew Brady) and a wetland scientist (Hugh Robertson) were interviewed from the Department of Conservation. Many of the staff interviewed had long associations with Lake Waikare and/or Whangamarino Wetland, including one member who had visited the area for recreational purposes before the Flood Control Scheme began construction in 1965.

The purpose of the interviews was to collect information on the impacts of the Flood Control Scheme on Lake Waikare and/or Whangamarino Wetland and to discuss potential mitigation options.

Durations of interviews ranged from 20 minutes to 2 hours.

3.4 Workshop

A half-day workshop was held on 28 September 2011. The workshop was run by Wildland Consultants and was attended by 13 staff from the Department of Conservation and Waikato Regional Council. Many of the attendees had been involved in the interviews. The purpose of the workshop was to review and reach consensus on the impacts of the flood control scheme and to briefly review mitigation options that had been put forward during the interviews. In addition, both organisations presented their 'bottom lines' for acceptable mitigation options.

4. ECOLOGICAL IMPACTS OF THE FLOOD CONTROL SCHEME

In the following sections the impacts described are mostly adverse ecological effects, although it is acknowledged that there have been substantial economic benefits of the Flood Control Scheme which are described in full in the Lower Waikato Zone Management Plan (River Catchment Services Group and GHD Ltd 2011). These include the increased production of agricultural and horticultural land, avoidance of damage to private property and major communication networks, as well as the protection of parts of State Highway 1 and the North Island Main Trunk Railway from flooding. Economic benefits have been estimated at $30 million per year while the current costs of maintaining the scheme are $2 million per year (Speirs *et al.* 2010).

4.1 Change in Lake Waikare hydrological regime

The flood control scheme has had a significant impact on the hydrological regime of Lake Waikare (Table 3). Prior to the completion of flood control works at Lake Waikare in 1965, average lake levels were 1.05 m higher than the period up to 1980, and the gap has increased to 1.13 m in recent years.

Other notable changes to the hydrological regime include:

- A considerable reduction in the overall fluctuation range;
- Negligible variation in average seasonal water levels;
- Decrease in minimum water levels; and
- Decrease in maximum water levels.

Table 3: Summary of water level regime in Lake Waikare, before and after the Flood Control Scheme was completed in 1965, after the 1981 lake level setting hearing, and since resource consents were granted for the scheme in 2002. Water levels are based on Moturiki Datum. Source: Reeves *et al.* 2002; Waikato Regional Council.

	1958-1965	1965-1980	1981-2002	2002-2011
Maximum water level	8.38 m	6.12 m	5.65 m	6.02 m
Minimum water level	5.67 m	5.4 m	5.4 m	5.20 m
Average water level	6.67 m	5.62 m	5.6 m	5.55 m
Winter average (May to Oct)	6.84 m	5.66 m	5.5 m	5.54 m
Summer average (Nov to April)	6.47 m	5.59 m	5.65 m	5.56 m
Fluctuation range	2.71 m	0.72 m	0.25 m	0.82 m

As briefly discussed in Section 2.3, water levels are controlled and rarely fluctuate beyond 0.3 m from the target water level with almost no difference between seasonal average water levels. In the last 5 years, water levels have only exceeded the target limits twice (Figure 5). The first was during a drought in February 2008 where water levels fell to their lowest ever recorded (5.20 m) and the other occurrence was after an extended period of flooding in August 2008, when water levels reached 6.02 m (Figure 5).

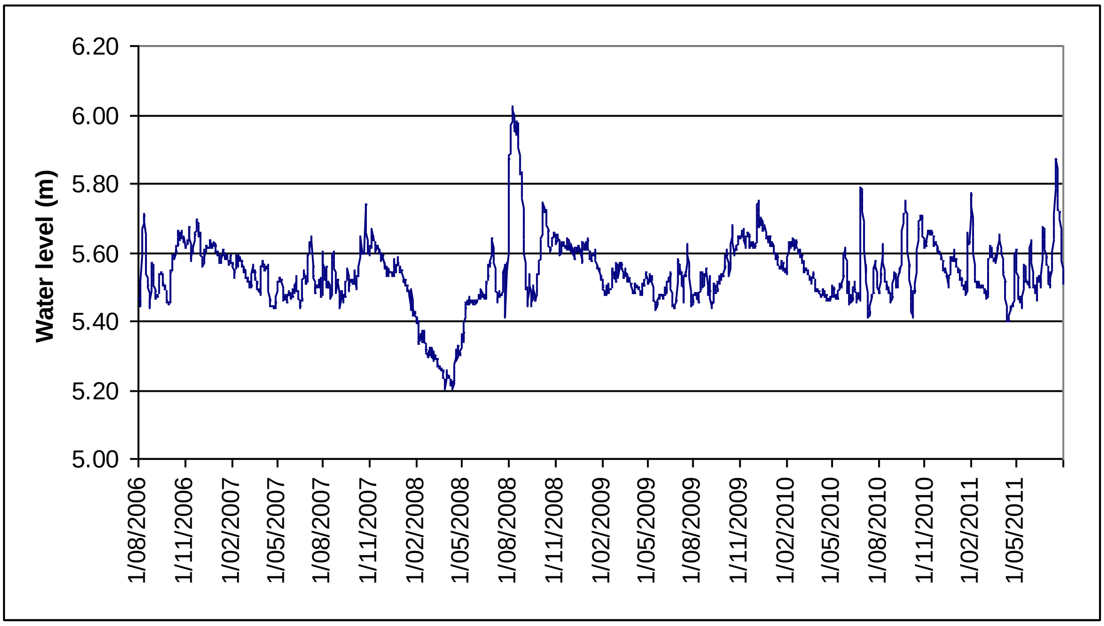

Figure 5: Lake Waikare daily water levels between 1 August 2006 and 31 July 2011. Water levels are based on Moturiki Datum. Source: Waikato Regional Council.

4.2 Redirection of water movement

The Flood Control Scheme had a direct impact on the direction of water movement between Lake Waikare, the Whangamarino Wetland, and the Waikato River, via a combination of control gate structures, the construction of the northern outlet canal and the lowering of Lake Waikare. Figure 6 illustrates the change in water movement before and after the construction of the Flood Control Scheme.

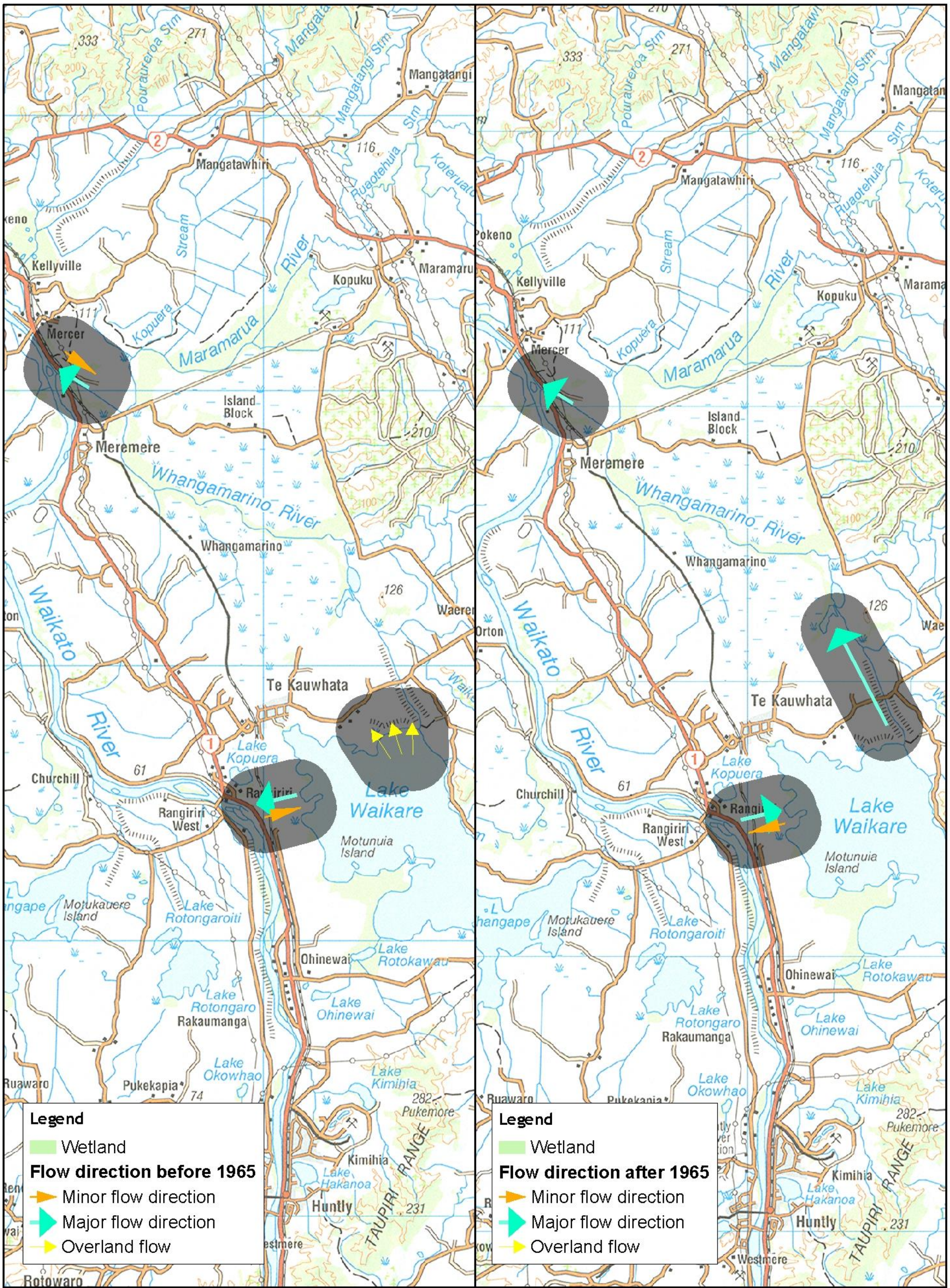

Figure 6: Comparison of the direction of water movement at Lake Waikare and Whangamarino Wetland, before and after the construction of the Flood Control Scheme

Data Acknowledgment

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Before the Flood Control Scheme, water from the Lake Waikare catchment flowed into the Waikato River via the Te Onetea Stream and the Rangiriri Stream under normal flow conditions. Under high flow conditions, water in the Waikato River would move into Lake Waikare via reverse flows through these streams. If water levels within the lake reached a certain point it would flow over a small ridge on the northern side of the lake and flow over the Te Kauwhata-Waerenga Road and into the Whangamarino Wetland. This occurred eleven times from 1950 to 1965 (Hannah 1981).

Following the lowering of Lake Waikare and the construction of the northern outlet canal, water from the Lake Waikare catchment now flows out of the lake via the northern outlet canal and into Whangamarino Wetland. Data collected since March 2011, shows that the highest volumes are discharged during the winter months and the lowest in February and March (Figure 7). The total annual volume of water discharged is 2-3 times the volume of Lake Waikare (43,146,000 m^3), and occasionally the entire volume of the lake has been discharged in a single month (Figure 7).

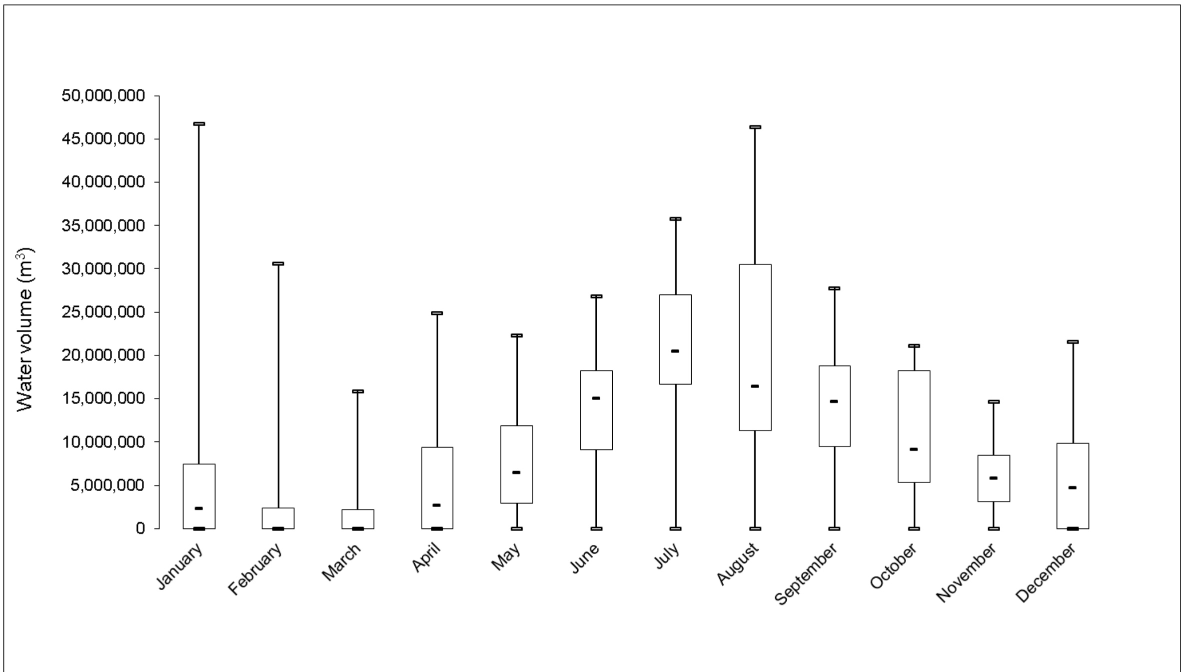

Figure 7: Lake Waikare total monthly outflows via northern outlet canal, 15 March 1988 and 31 July 2011. Source: Waikato Regional Council.

Under normal flow conditions, the Waikato River now flows into Lake Waikare via the Te Onetea Stream, a reverse of the historical direction. The control structure is occasionally closed when water levels are higher in Lake Waikare or when flow conditions are high in the Waikato River.

The other significant change since the Flood Control Scheme has been prevention of backflows of the Waikato River into the Whangamarino River following the installation of a control gate near the confluence of both rivers.

4.3 Increase in flooding extent and nutrient enrichment of bogs

While flooding around the margins of Lake Waikare has diminished significantly since the Flood Control Scheme, the change in flooding extent at Whangamarino Wetland as a consequence of the Flood Control Scheme is difficult to separate out from other factors. This is due to the following:

- Water level records only began in 1964 (Falls Road stage), just prior to the opening of the Waikare control gate (August 1965);
- Sand abstraction in the Waikato River at Mercer had a major effect on the hydrology of the wetland, lowering minimum water levels and decreasing the number of days the wetland was inundated (Department of Conservation 1991);
- Operation of the Whangamarino control gate has a major influence on water levels within the Whangamarino Wetland;
- A weir *c.*1,200 m upstream from the Whangamarino control gate raised minimum water levels in the Whangamarino Wetland from 2000;
- Land use changes in the catchment will have affected quantity and frequency of inflows over time;
- Detailed topographical information of Whangamarino Wetland and adjacent land was only recently commissioned and has not been available to date. The Department of Conservation is undertaking further hydrological modelling using LiDAR (airborne laser scanning) DEM (digital elevation model) for Whangamarino.

There is very little information on flows from Lake Waikare catchment into Whangamarino Wetland prior to 1965. Hannah (1981) reported that water discharged over the Te Kauwhata-Waerenga Road, 11 times between 1950-1965. This water would have presumably flowed into the large area of swamp next to the road and slowly filtered through into the Pungarehu Stream.

Post-1965, water from Lake Waikare has been channelled directly into the Pungarehu Stream and along the margin of the southern bog. Figure 8 shows the change in water levels at Falls Road when water is discharged from Lake Waikare into the Northern Outlet Canal. While the relationship is not directly causal because of inflows from the Waerenga catchment, it is evident that discharges from Lake Waikare affect water levels in Whangamarino Wetland. During periods of peak flows from Lake Waikare there is a particularly strong relationship between Waikare control gate outflows and water levels in Whangamarino Wetland (Figure 9).

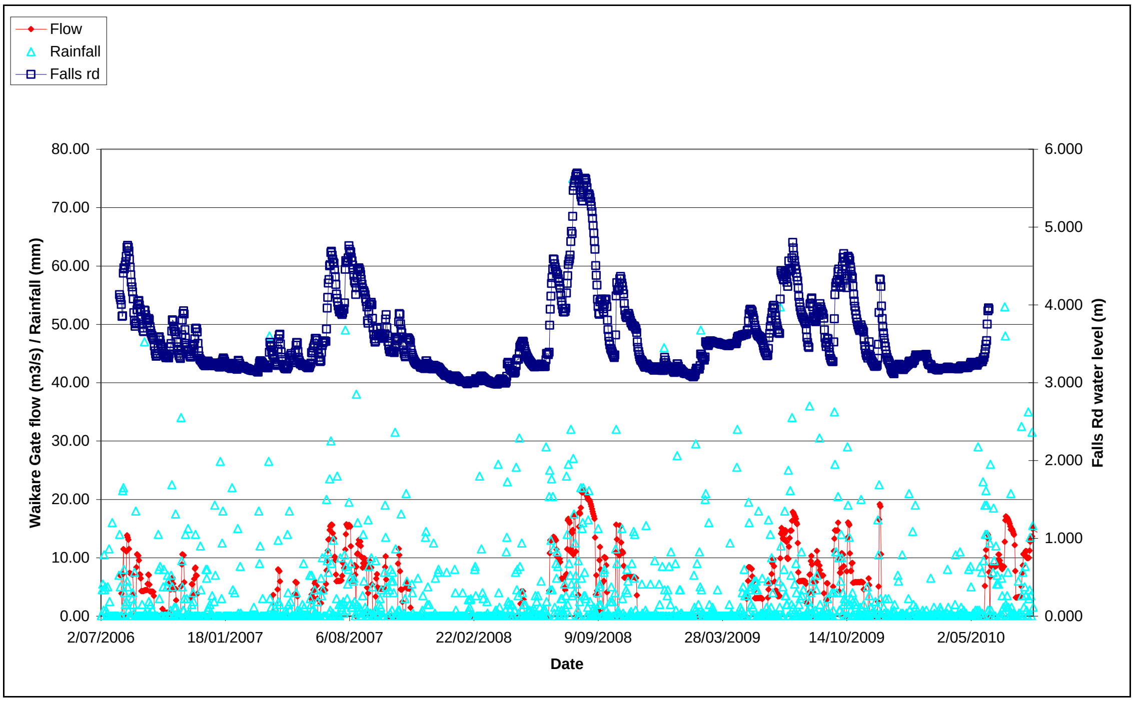

Figure 8: Daily flows from Lake Waikare vs daily water levels at Falls Road (Whangamarino Wetland) and rainfall (Mangatawhiri rainfall station). Source: Waikato Regional Council and NIWA CliFlo.

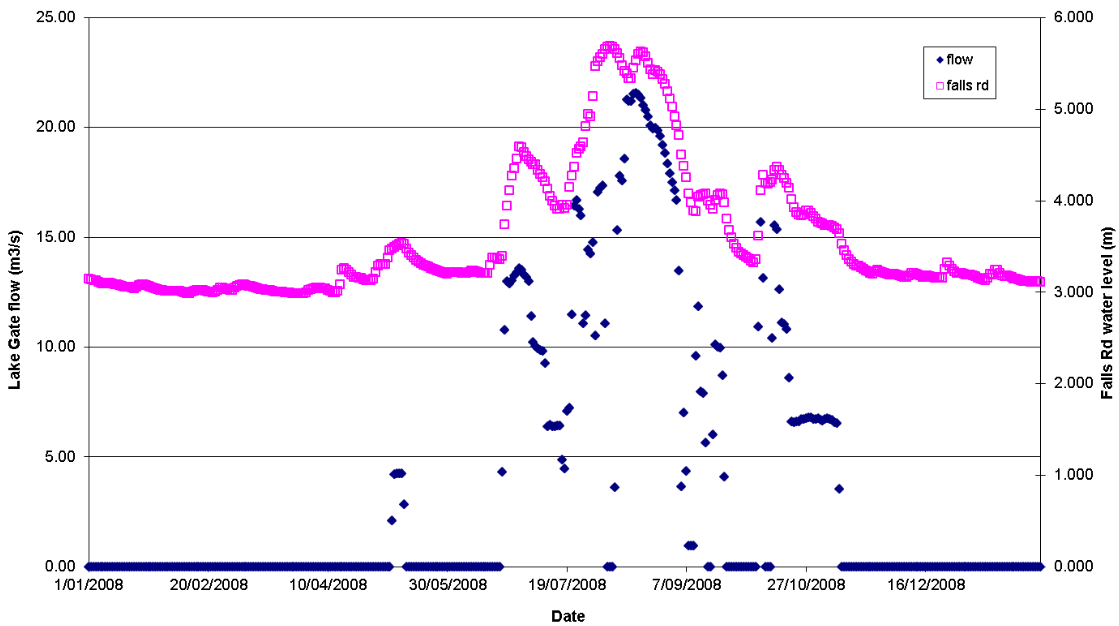

Figure 9: Daily flows from Lake Waikare vs daily water levels at Falls Road (Whangamarino Wetland) during a flood event in August 2008. Source: Waikato Regional Council.

During periods of peak discharge from Lake Waikare, water levels at Falls Road frequently exceed 4.0 m ASL however when the gates at Lake Waikare are closed water levels at Falls Road rarely exceed 4.0 m ASL even when rainfall has been very high (Figure 8). When water levels are at 3.7 m ASL at Falls Rd, water is confined to the low lying areas next to the main waterways (i.e. marsh and swamps) (Department of Conservation 1991), however when water levels exceed 3.7 m ASL then floodwaters begin to penetrate into the extensive areas of fens and bogs within the Whangamarino Wetland (Figure 10).

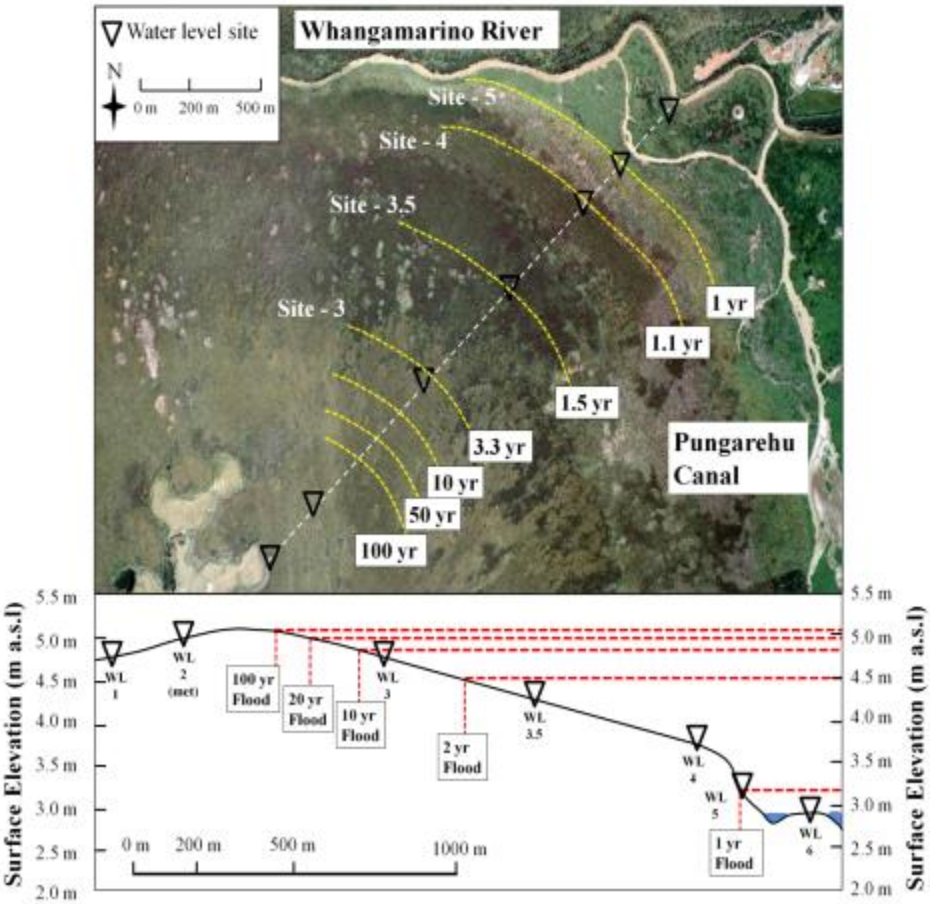

Figure 10: Aerial image of a cross section of the southern bog at Whangamarino Wetland with predicated flood inundation return periods (years) under current conditions. The dashed yellow line at Site 3 corresponds to the invasion of manuka and grey willow into the bog. Reproduced with permission from Blyth (2011).

Floodwaters entering the Whangamarino Wetland have high concentrations of suspended sediments and nutrients (Gibbs 2009; Blyth 2011). The impacts of sedimentation are discussed in section 4.5. Nutrient enrichment of wetlands frequently results in changes to vegetation composition and structure (Sorrell 2010). An analysis of vegetation change in the Whangamarino Wetland between 1963 and 1977 by Reeves (1994) found that there was a rapid decline in the vegetation type ‘sedges and wirerush’ that characterises the bogs (from 3394 ha to 2055 ha). The ‘sedges and rushes’ vegetation type was displaced by vegetation dominated by manuka (*Leptospermum scoparium*) and grey willow (*Salix cinerea*), the latter a serious threat to the indigenous botanical values of the Whangamarino Wetland. The largest changes in vegetation composition have occurred on the Southern Bog (Figure 11) and the Reao Bog (Reeves 1994; Wildland Consultants 2011b) and appear to be ongoing.

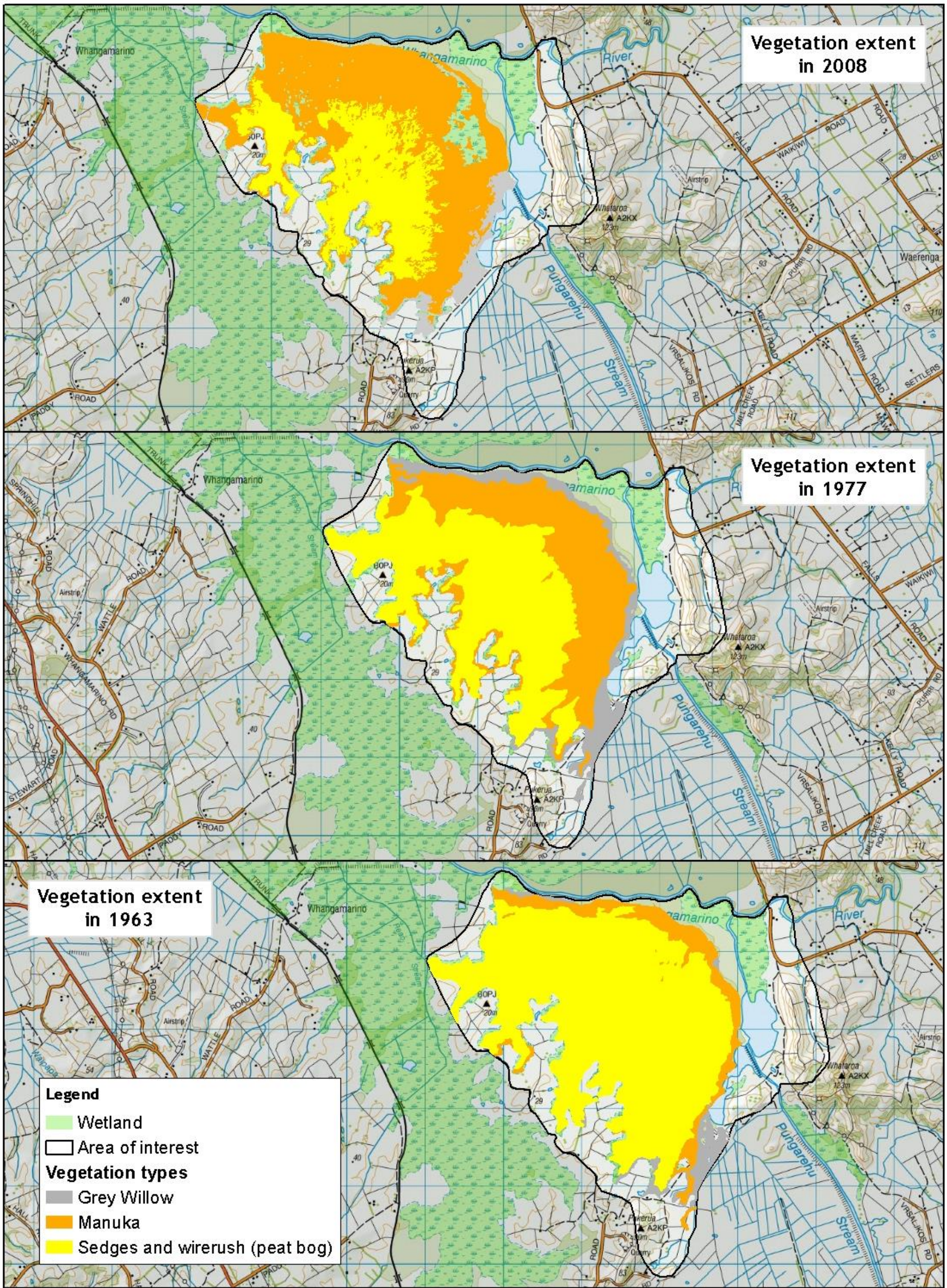

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Figure 11: Change in the extent of grey willow, manuka and sedges and wirerush in the southern bog between 1963, 1977 and 2008

0 1,000 2,000 m

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Reeves (1994), Shearer (1997) and Shearer and Clarkson (1998) attributed the changes to the vegetation composition and structure of peat bogs to a decline in minimum water levels at Whangamarino Wetland since the mid-1960's, however subsequent eco-hydrological investigations by Blyth (2011) strongly indicate that flood inundation and associated nutrient enrichment is most likely the major cause. A flood return period of 3.3 years was found by Blyth (2011) to delimit the extent of manuka encroachment into the Southern Bog (Figure 10).

4.4 Increase in turbidity

Prior to the Flood Control Scheme, Lake Waikare turbidity was lower according to anecdotal reports by historical lake users who remember a 'clear' lake with the bottom visible, submerged vegetation and sandy beaches on the northern and eastern shores (Reeves *et al.* 2002).

The decrease in average lake levels as a result of the Flood Control Scheme has affected turbidity by causing increased sediment re-suspension of lake bed sediments (clay, silt and fine sand) by small wind-waves. Winds are mostly from the south-west, with generally more wind in the afternoon (Reeves *et al.* 2002) and the coarser grain sizes are found in exposed, shallow areas including the north-east corner next to the Waikare control gate (Stephens and Ovenden 2002). These wind-waves generate orbital velocity currents (shear stress) at the lake bed 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 lake bed, and therefore increased the amount of sediment lifted into the water column. Numerical modelling results by Reeves *et al.* (2002) 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%. (N.B. these values are based on modelled mean wave climate.) Field measurements by McLea (1986) support these results, with highest suspended solids (SS) results in the summer, when lake levels were lower.

Experiments on lake bed sediments show that the 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 will remain in suspension for days (Reeves *et al.* 2002). The effect of grain size turbidity will be discussed in more detail in Section 5.2 (barriers to mitigation).

Figure 12 shows suspended solid (SS) data collected by Waikato Regional Council between 1996-2011 from two sites within Lake Waikare and Matahuru Stream. SS at the lake sites were high (between 50-600 mg/L with a maximum of >900 mg/L on one occasion). They generally had a similar magnitude, suggesting the lake is well mixed, but did not show a regular seasonal pattern. Water samples collected around the lake over the period 1982-1997 also had a wide range of SS (10.5-341 mg/L, with a mean of 117 mg/L, n=59) (Duncan 1997), suggesting that lake SS has followed this pattern for some time.

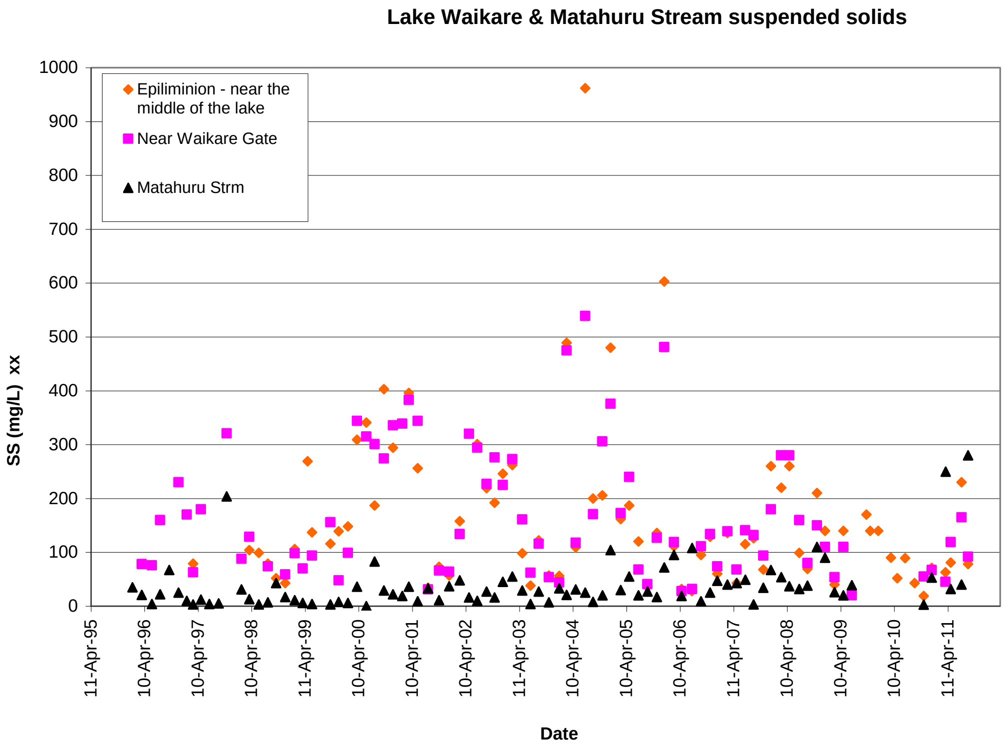


Figure 12: Suspended solid (SS) data collected from two sites within Lake Waikare and Matahuru Stream between 1996-2011. Source: Waikato Regional Council.

Matahuru Stream SS were generally much lower (usually <100 mg/L) than the lake SS, indicating most of the lake SS is due to lake bed resuspension by wind-waves. A combination of six weeks of no rain and calm weather resulted in low SS lake results (33-66 mg/L, mean 42 mg/L) being measured in February 1994 (Reeves *et al.* 2002).

Figure 13 is a simple conceptual model of the interaction between lake level (as a result of the Flood Protection Scheme), waves, catchment input, SS, and the amount of light that can penetrate the water column. Arrows indicate whether the effect of each factor is high or low. Low lake levels cause higher wave orbital velocities and when this is combined with high catchment sediment input, maximum SS levels are likely, resulting in low light levels. Conversely, an increase in lake level would reduce wave orbital velocities, and, combined with lowered catchment sediment inputs, SS levels would reduce, improving lake light levels.

Lake Level	Wave Orbital Velocities	Catchment Sediment Input	Suspended Soilds	Light
↓	↑	↓	↑	↓
↓	↑	↑	↑	↓
↑	↓	↓	↓	↑
↑	↓	↑	↓	↑

Figure 13: Interaction between lake water level (as a result of the Flood Protection Scheme), waves, catchment input, SS, and the amount of light available for plants in Lake Waikare. Arrows indicate the magnitude of each effect (e.g. low or high).

4.5 Increase in sedimentation

Sediment deposition in Lake Waikare as a result of the Flood Control Scheme can only be estimated due to insufficient data. A sediment budget estimate for Lake Waikare is given below based on estimates of sediment inputs (Matahuru Stream, Te Onetea Stream, and Rangiriri Spillway) and sediment outputs (Waikare control gate). However, infrequent (*c.*2 monthly) suspended solids (SS) data for Waikare control gate make it difficult to quantify sediment output.

Sediment inputs from Waikato River via Te Onetea Stream are low *c.*300 t/year due to the low SS of Waikato River (20 mg/L mean, 120 mg/L in flood) and low water flows (Duncan 1997). Overflows from Rangiriri Spillway into the lake are infrequent (last occurrence was in 1998) and Rangiriri sediment inputs have therefore been considered to be negligible, as in previous studies. Sediment inputs to the lake from the Matahuru catchment are approximately 9,000-12,000 tons/year according to Waikato Regional Council monitoring data from 2006 to 2011.

Sediment output from the Waikare control gate was calculated from water flow and SS data. Waikato Regional Council has collected daily water flow data for Waikare control gate since 1998. Figure 14 shows that the gate is usually closed for most of the summer and open for the rest of the year, with variable daily flow rates and maximum flood flows of 12-22 m^3/s in the winter.

SS data near Waikare control gate have been monitored at *c.*2 month intervals since 2006, with some gaps in the dataset (Figure 14). Lake SS is highly variable depending on sediment resuspension due to wind-waves, therefore frequent data are needed to calculate an accurate sediment yield. Due to a lack of frequent SS data, sediment outputs from Lake Waikare have low certainty. Using the available flow and SS data, sediment yield for Waikare control gate was estimated at 4,964-32,592 t/year. SS levels in the Pungarehu Stream are similar to SS levels in Lake Waikare, even in the summer months when the Waikare control gate is shut. This is likely due to a small amount of water passing into the Northern Outlet Canal via the fish pass.

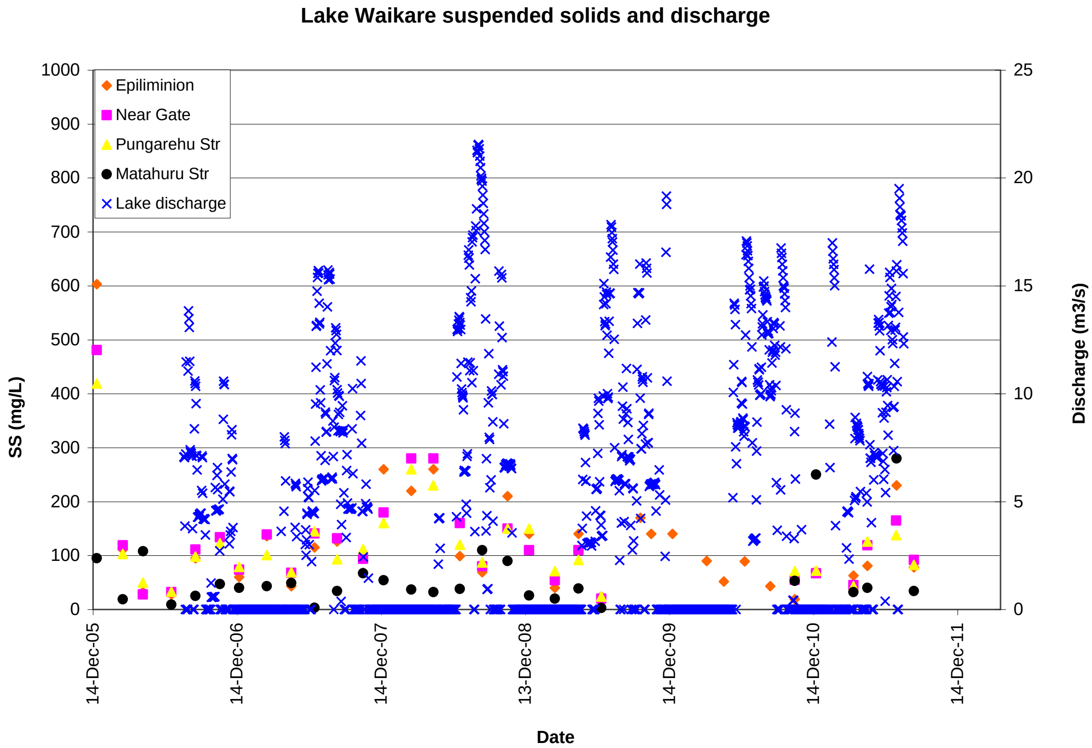


Figure 14: Waikare control gate flow data and suspended solid (SS) data from Matahuru Stream, Pungarehu Canal, and two sites within Lake Waikare, 2006-2011. Source: Waikato Regional Council.

There is insufficient data to determine whether sediment deposition is occurring on the bed of Lake Waikare. However, sediment transport in Lake Waikare has changed since the Flood Control Scheme began due to increased sediment resuspension resulting from lower lake water levels and the high degree of flushing of the lake (2-3 times the lake volume passes though the Waikare control gate). Any sediment in suspension would be flushed though the Waikare control gate into the Whangamarino Wetland. As a result of this, it is likely the Flood Control Scheme has resulted in more sediment passing though the lake and into the wetland. Duncan (1997) estimated sediment inputs and outputs to the lake were either approximately equal or slightly negative resulting in some erosion of lake bed sediment by *c.*0.08 mm/yr, however there was a great deal of uncertainty in these calculations. Sediment accumulation rate cores of the lake bed at several sites would provide useful information about sediment deposition in the lake.

Since completion of the Flood Control Scheme there have been changes in the sediment regime in the Whangamarino Wetland, including an increase in the proportion of sediment arriving from Lake Waikare compared to the Whangamarino River (Waerenga) catchment (Gibbs 2009). Sedimentation rates near the Northern Outlet Canal and the Whangamarino River have also increased (Reeve *et al.* 2010) and changes to soil characteristics indicating increased sedimentation (e.g. mineral content, bulk density, moisture content, soil colour, mud content, and grain size) have occurred (Reeve *et al.* 2010; Blyth 2011).

Prior to the Flood Control Scheme, sediment from Lake Waikare would only have discharged into the Whangamarino Wetland every 1-2 years when lake levels rose above the ridge at the northern end of the lake (Section 4.1.2) and spilled into the wetland across a wide area. As lake levels were much higher, there would have been less sediment in suspension and it is likely that a large proportion 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, partly 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. The Waikare control gate is usually closed during flood peaks, containing water and sediment in the lake until wetland water levels have reduced. However, when the Waikare control gate was open during a flood, a high sediment yield (700 t/day) was recorded by Gibbs (2009) in the Northern Outlet Canal. Flows near the gate are fast enough to prevent sediment deposition, but at the far end of the canal, flows are slower and a small amount of sediment deposition has occurred (Duncan 1997; Lamb 2011).

When Whangamarino River water levels are low (<3.2 m at Falls Rd), sediment-laden water remains within stream channels, passing through the wetland and into the Waikato River with little sedimentation of the stream beds and no sedimentation of the wetland (Duncan 1997). When the Waikato River is in flood the Whangamarino control gate is closed, causing flood waters from the Whangamarino River (Waerenga) catchment to be trapped and to backflow into the wetland. The higher Whangamarino River water levels cause surface flooding and sediment-laden water enters the wetland, especially near the streams. As water enters the wetland it slows down due to the hydraulic effects of vegetation which reduces current speeds, favouring settling and trapping of fine suspended sediments (Reeve *et al.* 2010).

Sedimentation Accumulation Rate (SAR) cores taken along a transect near Falls Road by Reeve *et al.* (2010) used radio-isotope measurements to show sedimentation rates in the wetland have increased since the Northern Outlet Canal was built. The highest sedimentation rates occurred adjacent to the canal (16.8 mm/year), reducing to lower rates (2.5 mm/yr) approximately 275 m into the wetland. Deeper in the cores, the SAR was lower, showing sediment deposition was slower in the past. Sediment colour, increased mud content, and lower grain size also indicated that more sediment has arrived from Lake Waikare since the Flood Control Scheme began.

Compound Specific Isotope (CSI) cores taken along another transect near Falls Road by Gibbs (2009) used stable isotope forensic techniques to determine the catchment source of sediment being deposited in a low lying portion of the wetland. Results showed an increase in the proportion of sediment from Lake Waikare since the Northern Outlet Canal was built, especially next to the canal and near the surface of the core (most recently deposited). Older sediments found deeper in the core (before the canal was built) had less Lake Waikare sediment, and contained more Whangamarino catchment sediments from the steep hill country at the headwaters of the Whangamarino River and lowland alluvial plains next to Waerenga Stream (a tributary of Whangamarino River).

Soil samples taken along a transect by Blyth (2011) showed a change in soil character, indicating increased sedimentation in samples closer to the Whangamarino River, including higher mineral content, higher bulk density, and lower moisture.

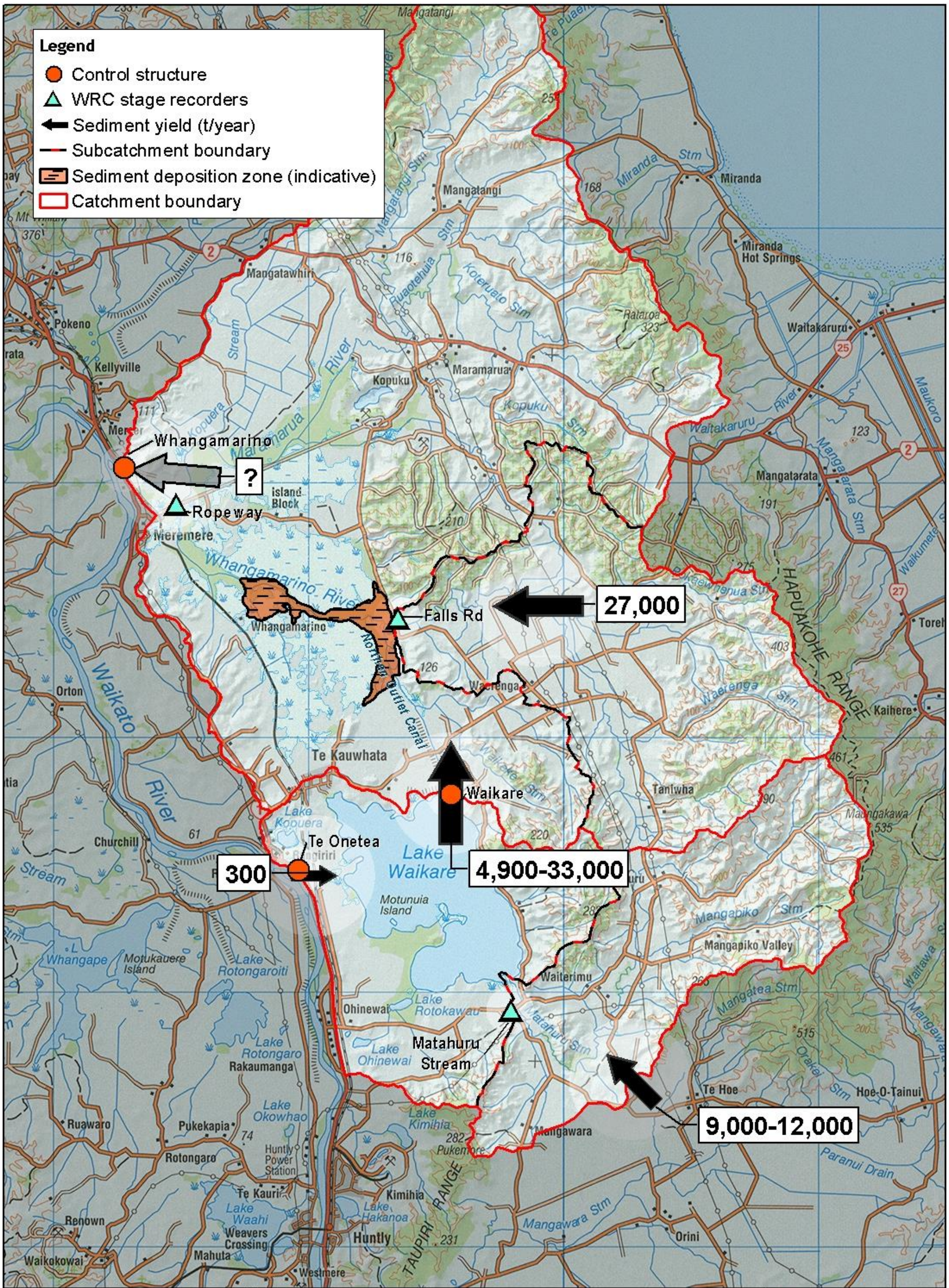
Calculating a sediment budget for the Whangamarino Wetland using sediment inputs (Lake Waikare and Whangamarino River) and outputs (Whangamarino control gate) is difficult due to a lack of SS and flow data. Lake Waikare sediment inputs were summarised earlier in this section and were estimated between 4,964-32,592 t/year. Whangamarino River sediment inputs were estimated by Duncan (1997) at *c.*27,000 t/year but there are uncertainties associated with several components of this calculation. Sediment output though the Whangamarino control gate cannot be calculated because flows during floods are complicated by river backflow when then gate is closed and there is no regular SS data collection at the Whangamarino control gate. Duncan (1997) estimated sediment inputs and outputs for the wetland, calculating deposition of *c.*0.48 mm/y averaged across 77 km^2 of the wetland, however there is high uncertainty associated with several components of this calculation. Nevertheless there is sufficient evidence to indicate the Flood Control Scheme has altered the sediment regime of Whangamarino Wetland with most of the sediment from Lake Waikare likely to be deposited in the zone shown in Figure 15.

Estimated sediment inputs and outputs for Lake Waikare and the Whangamarino Wetland described in the sections above are shown on a map of the area in Figure 15. There is some uncertainty associated with each sediment input/output calculation and these are described in Table 4, along with the input/output method or source.

Table 4: Sediment input and output source and calculation method.

Input/Output	Flow Data Calculated From	Suspended Solids Data Calculated From	Sediment Yield Confidence	Source
Matahuru Stream	Water level measured periodically.	SS monitoring at Myjers Farm.	High	Waikato Regional Council monitoring data.
Te Onetea gated culvert	Water level estimates.	SS data from Rangiriri.	Medium	Duncan 1997.
Waikare control gate	Water level measured daily.	Two-monthly SS monitoring near Waikare control gate.	Medium	Waikato Regional Council monitoring data.
Whangamarino River	Water level estimates.	SS data from Whangamarino River.	Low/Medium	Duncan 1997.
Whangamarino control gate	Uncertain.	Relationship between SS and flow uncertain.	Very low	No sediment yield given.

A summary of factors likely to be contributing to sedimentation in Whangamarino Wetland under varying rainfall conditions are summarised in a simple conceptual diagram in Figure 16, where arrows indicate how much weight each factor carries (e.g. high or low).



Data Acknowledgment
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Figure 15. Estimated sediment inputs and outputs for Lake Waikare and Whangamarino Wetland

0 5 10 km

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Rainfall in Catchment	Lake Waikare				Whangamarino River					Wetland Flooding & Sedimentation			
	Flow	Suspended Solids	Waikare Gate Open	Sediment Yield	Flow	Suspended Solids	Sediment Yield	Whanga. Gate Open	Backflow	Suspended Solids	Nil (water in stream bed)	Near stream bank	Surface Flooding
low	↓	↓	✓	↓	↓	↓	↓	✓	✗	↓	✓		
	↓	↑	✓	↑	↓	↑	↑	✓	✗	↑	✓		
medium	↑	↑	✓	**↑**	↑	↑	**↑**	✓	✗	**↑**		✓	
	↑	↓	✓	↓	↑	↓	↓	✓	✗	↓		✓	
high	nil	↑	✗	✗	**↑**	↑	**↑**	✗	✓	**↑**			✓
	nil	↓	✗	✗	**↑**	↓	↓	✗	✓	↓			✓

Figure 16: Conceptual model of wetland flooding and sedimentation under varying Lake Waikare and Whangamarino flows and suspended solids, as a result of rainfall. Colour of arrows indicate the relative influence of each factor carries (e.g. ↑= low, **↑**=high).

Sediment yield from Lake Waikare to Whangamarino Wetland depends on Waikare control gate flow, lake SS, and the Waikare control gate being open, with greatest yield when flow and SS 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 SS, with greatest yield when flow and SS are both high. However, 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.

Wetland sedimentation is therefore dependent on the magnitude of SS (from Lake Waikare and/or Whangamarino River) and the extent of wetland flooding. When flows are low there is no flooding and the sediment-laden water remains in the streams until it exits the wetland via the Waikato River. When flows are higher the sediment laden water overtops stream banks and sediment deposits on stream banks nearby. When flows are very high and surface flooding occurs, sediment laden water will travel further into the wetland where the vegetation will eventually slow the water and the sediment will deposit out.

Increased sediment load and changes to the hydrology since the initiation of the Flood Control Scheme have affected the ability of the lake-wetland ecosystem to process and eject water and sediment, both historically and in the present day. Resulting high lake turbidity levels and increased sediment deposition in the wetland will have affected the abundance and health of aquatic organisms. Studies elsewhere have shown that turbidity and sedimentation have profound and cascading effects on the ecology of freshwater ecosystems (Henley *et al.* 2000). Effects can include a reduction in food availability, environmental quality and habitat leading to decreases in plant, zooplankton, insect and fish abundance. At Whangamarino Wetland, the altered hydrology, deposition of sediments and elevated nutrient loading is also related to shifts in the composition and structure of wetland vegetation and other indicators symptomatic of degraded wetland ecosystems (Blyth 2011).

4.6 Shoreline erosion

Erosion along wave-exposed tracts of the Lake Waikare shoreline is another indirect effect of the change of lake level due to the Flood Control Scheme that may affect both lake turbidity and sedimentation. When a lake level is lowered, the shoreline takes time to adjust to the new water level. Over time, the old lake bed is eroded by wind-waves and sediment is redistributed between the nearshore (shallow water where waves break) and new beaches until the new, stable, shoreline is formed. However, at Lake Waikare, the lake level is constantly changing as part of the Flood Control Scheme, which may delay or even prevent the shoreline from adjusting fully. This may cause ongoing shoreline erosion on the windward side of the lake, adding sediment to the lake. However, the proportion of sediment contributed by shoreline erosion is unknown.

4.7 Loss of wetland habitat and quality

There has been substantial loss of wetland habitat since implementation of the Flood Control Scheme. In many cases this was an intended outcome. Stopbanking, subsidised as part of the Flood Control Scheme, resulted in large areas of wetland being converted to pasture or horticulture, particularly at the Whangamarino Wetland (Figure 17).

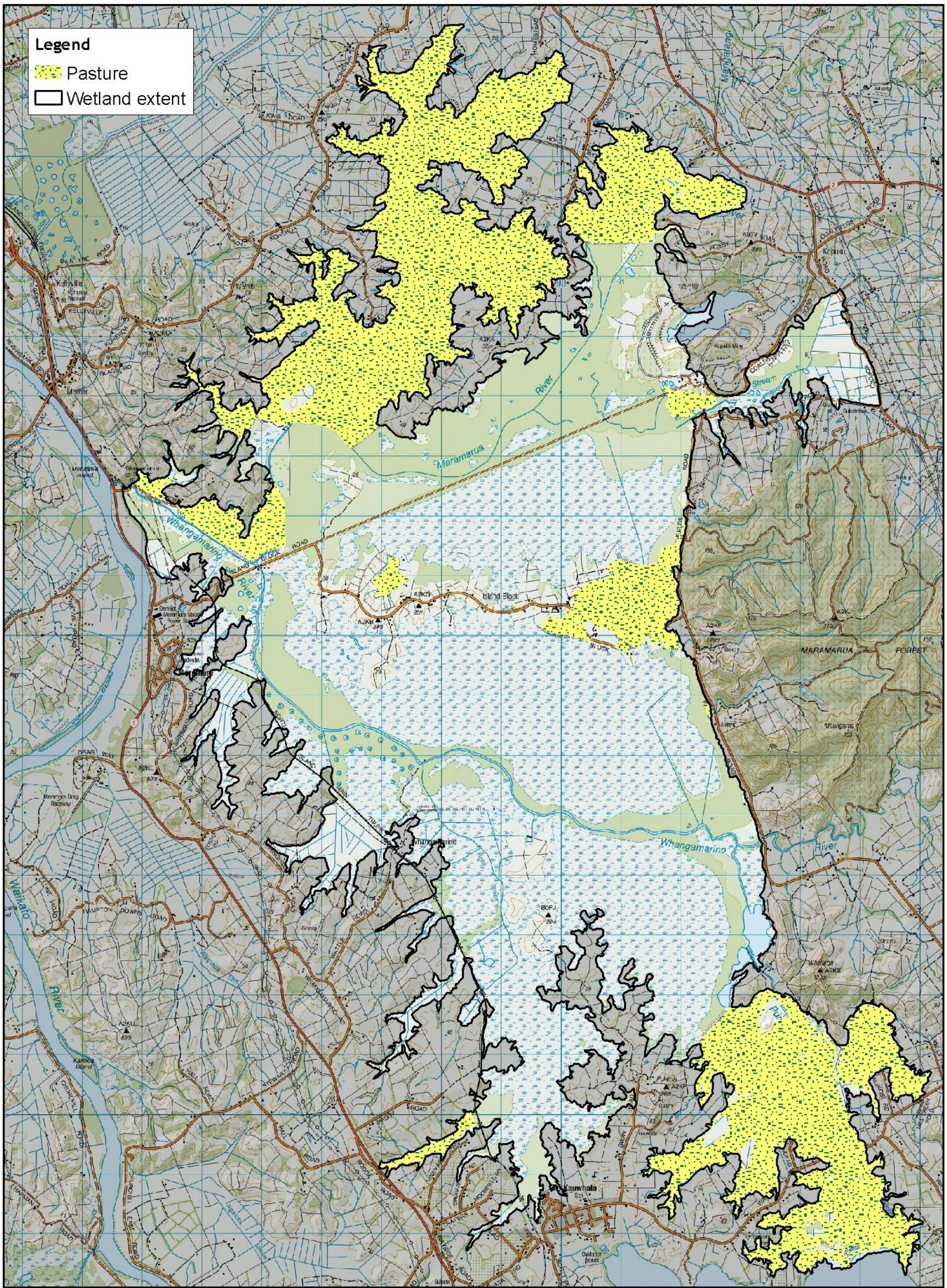

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Figure 17: Parts of the Whangamarino Wetland that were stopbanked and converted to pasture as a result of the Flood Control Scheme

0 2.5 5 km

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At Lake Waikare, the loss of wetland habitat was more a consequence of the change in the hydrological regime. Lowering the average lake level and restricting lake level fluctuations was estimated to have reduced the wetland area from 1,700 ha to 840 ha (Cheyne in Davenport 1980). The quality of the wetland also declined due to an extensive and rapid invasion by crack willow (*Salix fragilis*) and grey willow (*Salix cinerea*) after 1965 (McLea 1986).

Loss of wetland habitat undoubtedly lead to a decline in the diversity and abundance of indigenous plants and fauna. Detailed wildlife surveys began in 1981 so, while decline in populations for most species cannot be accurately quantified, the Wildlife Service estimated a 40% loss in wildlife as a result of the Flood Control Scheme (Harris 1983). There are some records of population numbers for black shag (*Phalacrocorax carbo novaehollandiae*), and mallard (*Anas platyrhynchos platyrhynchos*) at Lake Waikare before and after 1965. Black shag declined by 85% (Falla and Stockell 1945; Cheyne in Davenport 1980) while mallard populations were unaffected (Adams 1965 in Kingett and Associates 1987; Greenwood 1997).

Detailed ecological investigations at Lake Waikare in 1983-1984 found a depauparate littoral and benthic fauna, which was attributed to the loss of wetland habitat associated with the Flood Control Scheme (McLea 1985).

4.8 Weed invasion from the Waikato River

The Waikato River system upstream of the Te Onetea Stream contains a number of aquatic and wetland weeds that are not present in the Whangamarino and Lake Waikare catchments. The change in direction of water movement through Lake Waikare and the Whangamarino Wetland, as a result of the Flood Control Scheme, has provided a pathway for these weeds. The most serious of these are alligator weed (*Alternanthera philoxeroides*) and yellow flag (*Iris pseudacorus*).

A weed surveillance programme has been in place since 2009, to help prevent the spread of these weeds into Lake Waikare and Whangamarino Wetland (Champion and Bodmin 2009). Small populations of both species have been found within Lake Waikare and the Whangamarino Wetland since late 2009 and considerable resources have been expended to control them by both Department of Conservation and Waikato Regional Council.

Potential habitat for yellow flag within the Whangamarino Wetland has been estimated at 273 ha (Wildland Consultants 2011c). Once established, yellow flag develops a thick rhizome mat that can suppress germination of other plant seedlings and also elevate local topography by trapping sediment and creating a drier habitat (Thomas 1980). This can allow it to spread into previously unsuitable habitat and also enable other species to invade, altering successional trajectories (Thomas 1980).

Alligator weed occupies similar habitat to yellow flag and both species have been found together along the banks of the Waikato River (Philip Mabin, West Waikato Weeds, pers. comm). Alligator weed can also form floating mats and therefore has the potential to occupy much larger areas of habitat within the Whangamarino Wetland than yellow flag.

5. BARRIERS TO MITIGATION

5.1 Sediment input

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 (Duncan 1997; Reeves *et al.* 2002; Stephens and Ovenden 2003). The remaining sub-catchments around the lake contribute *c.*13% of the annual sediment load and Te Onetea Stream provides the remaining 11% (Lake Waikare Steering Group 2007).

Matahuru River SS 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 (96.8% of the range of flow had been measured) (Kotze *et al.* 2008).

Despite catchment management efforts (including stream fencing) by Waikato Regional Council, aerial photograph catchment surveys show the proportion of unstable land in the catchment increased from 37% to 52% between 2002-2007 (Thompson and Hicks 2011).

Sediment input from the Waerenga Catchment into the Whangamarino Wetland is substantial (260 mg/L) during floods (Blyth 2011) and sediment loads may be up to 27,000 t/year (Duncan 1997).

The degree to which sediment inputs from Lake Waikare and Whangamarino River is deposited in the wetland depends on the extent of wetland flooding, as described in Section 4.2.2 and shown in Figure 14.

5.2 Lake turbidity

Turbidity is a strong barrier to mitigation of Lake Waikare water clarity due to a larger number of easily resuspended clay particles. Lake bed and 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 (Stephens and Ovenden 2003).

Clay makes up only a very small percentage (*c.*2%) of the sample volume (and therefore makes only a small contribution to sedimentation in the lake) 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 for only short periods. But the clay can remain in suspension for many days (Stephens and Ovenden 2003), meaning that it will be repeatedly resuspended by wind-waves, causing a large component of the high lake turbidity.

Stephens *et al.* (2004) investigated the possibility of lake level draw-down to consolidate lake bed sediments in order to improve lake water clarity. However, small scale experiments found that, upon rewetting, the same fine clay particles would almost immediately be resuspended by wind waves and water clarity would not be improved.

5.3 Water quality

Mitigation options that seek to improve the light climate within Lake Waikare to allow submerged vegetation to re-establish are likely to be hampered by poor water quality within the lake. Reeves *et al.* (2002) found that even if all turbidity causing sediment was removed from lake water, the maximum depth of growth would still be limited to *c.*1.1 m due to light attenuation from high algal biomass and concentrations of aquatic humic matter.

Water quality at Lake Waikare is summarised in Table 5. The lake remains in a hypertrophic state although there has been an improvement in some water quality variables in recent years. Suspended solids concentrations have decreased along with phosphorus, which is strongly associated with sediments. Turbidity has also decreased, as would be expected with declining suspended solids. This is most likely the result of sediments stored in the lake bed being depleted as suspended solid concentrations in the Matahuru Stream have not decreased over this period (Section 4.2.1). Nitrogen and chlorophyll a (algae) are increasing, most likely as a result of intensification of farming practices which is occurring throughout the Waikato Region (Jenkins and Vant 2007).

Table 5: Average turbidity, total nitrogen, total phosphorus, chlorophyll a and suspended solids in Lake Waikare. Data from Waikato Regional Council.

	1998-2002	2003-2007	2008-2011
Total nitrogen (mg/m^3)	1580	2371	2830
Total phosphorus (mg/m^3)	339	283	182
Chlorophyll a (mg/m^3)	67	105	124
Suspended solids (g/m^3)	183	189.8	112.2
Turbidity (NTU)	184	160.5	76.7

5.4 Introduced fish

The biomass of introduced fish in the Waikato River between Ngaruawahia and Tuakau has been estimated at 89% of the total sum of all fish present (Hicks *et al.* 2010). Of the introduced fish, koi carp (*Cyprinus carpio*) accounted for the greatest biomass (82.6%), followed by goldfish (*Carassius auratus*) (5.8%), rudd (*Scardinius erythrophthalmus*) (0.8%) and brown bullhead catfish (*Ameiurus nebulosus)* (0.7%). Similar proportions were found within the Whangamarino Wetland (Lake *et al.* 2008) and a similar scenario is likely to exist within Lake Waikare where 1.5 tonnes of koi carp were captured in a trial koi carp trap over 2.5 days (www.waikatoregion.govt.nz, accessed 16/9/2011).

Many introduced fish are benthic feeders (e.g. koi carp, goldfish, and catfish) and have been found to affect water quality (including turbidity) in controlled experiments overseas (Hicks *et al.* 2010; Blair 2008). It is not known to what degree introduced fish affect water quality in New Zealand but their sheer abundance is concerning and it seems likely that they are having a detrimental effect on turbidity within shallow lakes and wetlands within the Lower Waikato River system. Mitigation options that seek to reduce turbidity within Lake Waikare and Whangamarino Wetland without reducing introduced fish biomass are therefore likely to be less effective.

5.5 Alternative flood storage

During the interviews and workshop, Department of Conservation staff raised the issue that the limited ability of the Flood Control Scheme to divert water discharges from Lake Waikare to anywhere else, was a major barrier to mitigating impacts of the Flood Control Scheme on Whangamarino Wetland.

6. MITIGATION OPTIONS

There are a range of potential mitigation options for reducing sediment inputs to Lake Waikare and Whangamarino Wetland. Previous investigations have focused only on reducing inputs to Lake Waikare and are reviewed in section 6.1. The most feasible and potentially effective of these are considered further in section 6.3. The remainder of this section describes potential mitigation options for reducing sediment inputs to Whangamarino Wetland.

6.1 Previous investigations

The Lake Waikare Steering Group investigated a range of potential mitigation options for restoring the health of Lake Waikare (summarised in Table 6). Options can be divided into three groups (from least feasible to most promising):

1. Mitigation options that were considered not feasible because they would be very difficult to implement, prohibitively expensive and/or have a high level of uncertainty regarding the outcome. (Shaded red in Table 6).

2. Mitigation options that would have little effect. (Shaded orange in Table 6).

3. Mitigation options that had at least a moderate chance of success although their effectiveness requires further investigation. (Shaded green in Table 6).

There is no one mitigation option that is likely to restore the health of Lake Waikare. A combination of options targeting both catchment inputs and the current store of sediment and nutrients within the lake will be required.

Table 6: Mitigation options investigated by Lake Waikare Steering Group (2007). A question mark indicates that further investigation is needed. See Section 6.1 for explanation of colour shading.

Mitigation Options	Progress to Date	Likelihood of Success	Effectiveness if Successful
Restoration of Lake Surrounds			
Enhance surrounding wetlands: Restore hydrological regime, undertake planting if necessary.	Penewaka Lagoon has been bunded and planted to enhance habitat.	Moderate-High	Low[1]
Terrestrial planting on lake margins to reduce erosion: Approach landowners to fence and plant the lake shore.	15.3 km of lake margin fenced and planted with 2,100 indigenous and exotic plants.[2]	Low-Moderate	Low
Establish aquatic emergent plants on lake margins: Propagate and transfer suitable plants to lake.	-	Moderate	Low
Reduce Inputs to Lake Waikare			
Divert Matahuru Stream through a natural wetland that occurs next to Lake Waikare.	-	Low	Low
Divert Matahuru Stream to the Waikato River bypassing Lake Waikare.	-	Not considered a feasible option.	-
Flush the lake using Waikato River water via Te Onetea Stream or Ohinewai.	-	Not considered a feasible option.	-
Redirect Te Kauwhata wastewater discharge away from Lake Waikare.	15 year consent for discharge recently granted	Low-Moderate	Low
Constructed wetlands on major drains.	?	Moderate-High	Low
Reduce Sediment/Nutrients Within Lake Waikare			
Lake level draw down, could include vegetating lake following drawdown.	Research on effectiveness undertaken (Stephens *et al.* 2004). Indicated very unlikely to be successful.	Not considered a feasible option.	-
Flocculate sediments in Lake Waikare.	Advice sought. Likely to be very costly with only temporary improvement.	Not considered a feasible option.	-
Dredge sediment from the Lake Waikare.	None.	Not considered a feasible option.	-
Alter hydrological regime of Lake Waikare to increase fluctuation range.	None.	Moderate-High	?
Wave barriers to reduce wave energy.	Research proposal developed (ASR Ltd 2005).	Moderate	?
Island creation to reduce wave energy.	None.	Low	Low

Mitigation Options	Progress to Date	Likelihood of Success	Effectiveness if Successful
Pest fish control.	Koi carp cage trap trialled. Permanent trap at Waikare control gate being implemented.	Low?	Low
Bio-filtration by freshwater mussels (*Echyridella menziesi*).	None at Lake Waikare. Research on farming freshwater mussels in very early stages.	Currently not considered a feasible option	Low

[1] Enhancing wetland habitats is likely to have significant benefits for wildlife, however will have little impact on improving water quality within Lake Waikare.
[2] Source: Therese Balvert, Waikato Regional Council.

6.2 Catchment management

Both the Matahuru and Waerenga catchments contribute substantial sediment loads to Lake Waikare and Whangamarino Wetland (Section 4.2.2). Attenuating sediment loads from these catchments will be necessary to achieve sustainable outcomes over time. A range of attenuation tools are used, both in New Zealand and overseas, to reduce sediment loads to waterways. These are summarised in Table 7 and their applicability to Matahuru and Waerenga catchments are assessed.

Over 30% of each catchment comprises land with severe erosion potential. The least suitable land for pastoral use occurs in the very steep hills of the Matahuru catchment (NZLRI data, http://ourenvironment.scinfo.org.nz/ourenvironment, accessed 25/10/2011). Retirement from pasture and/or reforestation of these areas could result in a significant reduction in downstream sediment loads. Waikato Regional Council has made available incentives for soil conservation in the Matahuru catchment (35% of the cost of soil conservation works is eligible for funding) however, there has been little interest from landowners in accessing these funds. Between 2002 and 2007 farmland with planted soil conservation cover decreased from 15% to 10% (Thompson and Hicks 2011).

Livestock exclusion is considered highly appropriate in both catchments in tandem with grass filter and/or planted buffers. In the Matahuru catchment 29.6 km of Waikato Regional Council assisted fencing has been carried out since 2002, mostly along the lower reaches of the Matahuru Stream and 4,211 plants have been planted in fenced off areas (Therese Balvert, Waikato Regional Council, pers. comm.). Despite these actions sediment loads have increased over this period (Grant *et al*. 2010). While there can be time delays before the benefits of mitigation may be observed, it is probable that livestock exclusion needs to be more widely practiced throughout the catchment, particularly along smaller tributaries in the upper catchment (Reece Hill, Waikato Regional Council, pers. comm.).

Constructed wetlands or the fencing of natural wetland seeps can result in substantial reductions in sediment loads. 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. However, wetlands are less effective in reducing fine and dispersible clays (McKergow *et al*. 2007) and therefore rate only as ‘moderately applicable’ within the Matahuru and Waerenga catchments. Nevertheless, wetlands also provide other significant benefits that would facilitate restoration of Lake Waikare and Whangamarino Wetland including the potential reduction of nutrient loads (up to 80% of nitrogen and particulate phosphorus, McKergow *et al*. 2007) and provide flood attenuation, an important issue for the Waerenga catchment as it would help to reduce flood peaks in the Whangamarino Wetland.

Table 7: Sediment reduction tools and their applicability to Matahuru and Waerenga catchments. (Adapted from McKergow *et al.* 2007). Rankings are H=high, M=moderate, L=low.

Mitigation Option	Description	Applicability to Matahuru Catchment	Applicability to Waerenga Catchment	Effectiveness/ Sediment Reduction	Other Benefits (b) or Drawbacks (d)
Farm Management					
Farm design to reduce connectivity with waterways	Placement of troughs, gates and tracks to reduce connectivity with waterways.	H	M	L-M	b: Reduce N, P, faecal microbes.
Pasture retirement and/or reforestation	Retire and/or reforest land with severe erosion potential.	H	M	H	b: Reduce N, P, faecal microbes, improved aquatic habitat, biodiversity values, landscape aesthetics. d: Potential weed management issues.
Riparian Management					
Livestock exclusion	Exclude livestock from margins of streams, drains, stock water races, lakes, wetlands (usually by fencing).	H	H	30-90%	b: Reduce N, P, faecal microbes. d: Potential weed management issues.
Grass filter strip	Managed band of dense grass. Fenced and may be lightly grazed with sheep to reduce biomass.	H	H	20-40%	b: Reduce N, P, faecal microbes. d: Potential weed management issues.
Riparian buffer	Managed band of shrubs/trees along stream bank.	M	M	L-M	b: Reduce N, P, improved aquatic habitat, biodiversity values, landscape aesthetics. d: Requires active vegetation management.
Drainage Manipulation					
Vegetated or partially vegetated drains	Vegetated surface drains with wetland plants and water tolerant grasses.	L	M	M	b: Reduce N, P, improves biodiversity and seasonal aquatic habitat. d: May alter drain hydraulics.
Sediment Traps, Dams and Ponds					
Sediment trap	Excavation in bed of a watercourse designed to settle and trap coarse sediment (sand and gravels).	L	M	Up to 90% of fine sand	b: Reduce P. d: May alter drain hydraulics.
Dams and ponds	Watercourse dammed or area excavated slowing water flow and allowing sediment to settle.	M	M	M-H	b: Reduce P, faecal microbes, flood attenuation. d: May have negative impacts on downstream flows, water quality impacting aquatic life.

Mitigation Option	Description	Applicability to Matahuru Catchment	Applicability to Waerenga Catchment	Effectiveness/ Sediment Reduction	Other Benefits (b) or Drawbacks (d)
Wetlands					
Natural seepage wetland	Seeps flowing via wetlands at edge of streams.	H	M	60%	b: Reduce N, flood attenuation, improves biodiversity and aquatic habitat. d: Potential weed management issues.
Floodplain wetlands	Stream flood flows intercepted by riverine wetlands, meanders, oxbows etc.	L	L	L-M	As above.
Constructed wetlands	Artificial wetland created on key flow path.	M	M	60-80%	As above.

Large areas of the Waerenga catchment and the sub-catchments to the west of Lake Waikare consist of flat land with drain networks. It is not known how these are currently managed and whether they could be more effectively managed to reduce sediment entering Lake Waikare and Whangamarino Wetland.

The continuing increase in suspended solid concentrations within the Matahuru Stream despite livestock exclusion indicates the need to better understand where sediment is coming from. This would enable better targeting of appropriate sediment mitigation practices which may find greater acceptance and uptake with landowners. A new tool that that guides farmers, land management officers or farm advisers in selecting the most appropriate sediment mitigation tools based on the identification of major flow paths is currently in development (McKergow and Tanner 2011).

6.3 Reduce re-suspension of sediments in Lake Waikare

6.3.1 Increase lake levels/fluctuation range

This option was considered by the Lake Waikare Steering Group and would involve raising average lake levels and increasing the fluctuation range. It was one of the most promising options evaluated although impacts on adjoining landowners are potentially significant (Table 6). It could significantly reduce sediment outputs from the lake by reducing re-suspension of lake bed sediments and thereby reducing the amount of sediment reaching the Whangamarino Wetland. An increase in fluctuation range that mimicked natural seasonal patterns (i.e. lower in summer, higher in winter) would also facilitate wetland restoration on the margins of the lake.

The group recommended that a comprehensive cost-benefit analysis of a range of water level scenarios be undertaken. This has not been done to date but remains a worthwhile next step if this option was to be pursued.

Potential Issues

- Resource consent would be required and is likely to be a contentious and costly process.
- Compensation of adjoining landowners may be required or stopbanking may be necessary to contain lake water.
- White total sediment volume would be reduced it s unlikely to significantly reduce lake turbidity because the latter is caused by very fine particles that make up less than 1% of sediment volume.
- Could potentially slow down the flushing of nutrients stored within the lake.

6.3.2 Wave barriers

Wave barriers were considered by the Lake Waikare Steering Group as a method for reducing wave energy in localised areas within Lake Waikare to enable the re-establishment of submerged macrophytes. It is possible that macrophytes might spread beyond breakwaters if sufficient populations could be established having a greater effect on reducing suspended sediment. A research proposal that considered wave barriers as a mitigation option was put together by ASR Ltd (2005). They briefly investigated the use of floating breakwaters as a wave barrier device as these work well in lakes of the size of Lake Waikare, are relatively easy to construct and can be removed if required. Using wave statistics known for Lake Waikare they calculated that a 15 m wide floating tyre breakwater would greatly reduce wave action in its lee under most conditions. Further modelling would be required to calculate the effects on circulation and to identify optimum locations.

There are other options for constructing wave barriers (e.g. submerged mounds, emergent structures) and a range of scenarios that could be modelled to determine what might be most effective at reducing suspended sediments within the lake or at critical locations such as the Waikare control gate and the Matahuru Stream inflow.

Potential Issues

- Introduced fish and algal blooms that occur as a result of a reduction in water mixing may prevent establishment of macrophytes.
- Plant inoccula would be needed to establish submerged vegetation as seed bank is unlikely to be sufficient (Reeves *et al.* 2002).
- Will not significantly improve lake turbidity in the short term and certainty of outcome requires further investigation.

6.4 Prevent sedimentation within Whangamarino Wetland

Between 2008 and 2010, 57,000 m^3 of sediment was estimated to have been deposited in the Whangamarino Wetland adjacent to Pungarehu Stream (Lamb 2011). Options for the removal and disposal of this quantity of sediment are likely to be limited with removal operations likely to generate negative impacts on vegetation and wildlife within this area of the wetland. Options that prevent sedimentation occurring within the Whangamarino Wetland are therefore preferable and would provide a better long term outcome. Several options for preventing sedimentation that were raised during interviews and the workshop for this project, are described below.

6.4.1 Constructed wetland

One of the most frequently suggested options for preventing sedimentation in the Whangamarino Wetland was the construction of a treatment wetland between Lake Waikare and Whangamarino Wetland. As discussed in section 6.2, constructed wetlands have the potential to significantly reduce sediment as well as nutrient loads. However, their performance is affected by the settling velocity of sediment particles, with fine and dispersable clays being difficult to retain. Flow volumes and flow pathways, which affect settling rates, can both be optimised by wetland design and also the operation of the Waikare control gate. Calculating the size and likely performance of a wetland to capture sediment exiting the Waikare control gate requires detailed modeling. Applying the 1 - 2.5% of the catchment ‘rule’ (section 6.2) provides a very rough estimate of wetland size required. As the Lake Waikare catchment is 176 km^2 (subtracting the lake), the optimum wetland size would be 176-440 ha. This is a substantial area to construct and there are no comparable constructed wetland projects of this size within New Zealand. A similar type of wetland was constructed recently at Lake Okaro (Rotorua) but was only 2.3 ha in size at an estimated cost of $520,000 (Environment Bay of Plenty 2006).

Potential Issues

- There is very limited public land between Lake Waikare and Whangamarino Wetland and therefore land would need to be purchased to accommodate the area required.
- Stopbanks currently extend along large parts of the Northern Outlet Canal and these are likely to need moving.

6.4.2 Confine discharge from Lake Waikare

One of the mitigation options put forward by staff at Waikato Regional Council was to try and confine water discharged from Lake Waikare. The aim would be to contain discharges to the main waterway channels within the Whangamarino Wetland or to limit the extent of inundation to less sensitive wetland types. Containing discharges to main waterway channels would require keeping water levels below 3.4 m at the Falls Rd stage. This would not be possible without stopbanking waterways. To protect bogs from being regularly inundated with floodwaters would require keeping water levels below 4 m at the Falls Rd stage or bunding the margins of the southern and central bogs.

Potential Issues

- Likely to increase water levels within Lake Waikare as water will need to be retained for longer following a flood event.
- Reduce the ability of the Flood Control Scheme to respond to flood events.
- Stopbanking will reduce inundation of adjacent wetland in the area altering plant and animal communities and affecting recreational values (e.g. hunting).
- Bunding will negatively affect the hydrology of the wetland by creating abrupt hydrological changes and altering plant communities. Bunds are often also pathways for weeds.

6.4.3 Reduce peak discharges from Lake Waikare

Department of Conservation staff proposed reducing peak flow rates and/or reducing the duration of peak flows as a mitigation option for limiting the extent of flood inundation to less sensitive wetland types. This has some similarities with other proposed mitigation options (i.e. 6.3.1 & 6.4.2) as it is likely to involve temporarily raising water levels in Lake Waikare beyond the target limits until water levels in Whangamarino Wetland are low enough that water discharged from Lake Waikare will not adversely affect the more sensitive wetland types.

Potential Issues

- Likely to increase water levels within Lake Waikare as water will need to be retained for longer following a flood event.

- Reduce the ability of the Flood Control Scheme to respond to flood events.

- Resource consent may be required and is likely to be a contentious and costly process.

- Compensation of adjoining landowners may be required or stopbanking may be necessary to contain lake water.

7. EVALUATION OF MITIGATION OPTIONS

A broad scale evaluation system was developed to compare mitigation options for the purpose of selecting which options should be considered further (Table 8). All options require further investigation to provide more certainty over their likely effectiveness and certainty of outcome. Table 8 should not be used to determine which mitigation options to adopt. Criteria were divided into ‘evaluation criteria’ and ‘other considerations’. A scoring system was developed for the evaluation criteria which are described below:

- *Effectiveness.* Mitigation options were scored on how well they were likely to reduce sediment inputs to Lake Waikare (0-3) and Whangamarino Wetland (0-3) and whether they would reduce sediment re-suspension within Lake Waikare (0-3).

- *Certainty of outcome.* This criterion was scored according to three key factors.

    1. Number of barriers to success (e.g. introduced fish, poor water quality improvements, lack of adequate plant innocula, required water levels in Whangamarino Wetland) which was scored from zero to three, the fewer barriers the higher the score.

    2. Action requires numerous landowners to adopt mitigation practices, which was scored as either zero (yes) or two (no).

    3. Confidence in the science. This was an expert judgement based on the current state of knowledge and the complexity involved. This was scored from zero to three.

- *Costs.* These were estimated based on cost estimates for different mitigation options presented in McKergow *et al.* (2007) and Hudson *et al.* (2008). Costs were scored in the following way: three = <$1 million, two = $1-10 million, one = $10 to $50 million, zero = >$50 million. A weighting of two was applied to this criterion.

- *Other benefits.* This criterion was scored according to whether the mitigation option was likely to result in improvements in the ecological health of Lake Waikare and Whangamarino Wetland. Three types of benefits were scored:

1. Improvement in biodiversity values, scored from zero to two.

2. Improvement in water quality, scored from zero to two.

3. Whether the mitigation option would attenuate flood peaks, scored as either zero (yes) or one (no).

Other considerations included factors that may prevent the adoption of a mitigation option regardless of its evaluation score. These are described below:

- *Acceptable to the Department of Conservation.* At the workshop held in September both the Department of Conservation and Waikato Regional Council outlined their 'bottom lines' for acceptable mitigation options. Waikato Regional Council was prepared to consider all mitigation options at this stage. Department of Conservation did not want to consider any options that would further compromise the hydrology and water quality of the Whangamarino Wetland. They were, however, prepared to consider use of the conservation estate for mitigation purposes.

- *Does not impact the Flood Control Scheme.* Some of the mitigation options will affect the operation of the Flood Control Scheme with likely effects on landowners.

- *Will not require action on private land.* Some mitigation options will require action on private land. Actions include the adoption of sediment attenuation practices or could involve the purchase of land. The willingness of landowners to participate will affect the success and timing of outcomes.

Table 8: Broad scale evaluation of mitigation options. See the remainder of section seven for an explanation of the scoring system.

Mitigation Option	Evaluation Criteria					Other Considerations		
	Effectiveness (0-9)	Certainty of Outcome (0-8)	Cost (0-6)	Other Benefits (0-5)	Total (0-28)	Acceptable to DOC	Does not Impact Flood Control Scheme	Will not Require Action on Private Land
Catchment management - targeted farm-scale actions.	5	2	4*	4	15	✓	✓	X
Catchment management - constructed wetlands at bottom of catchment.	5	2	0	4	11	✓	✓	X
Increase lake levels/fluctuation range in Lake Waikare.	3*	3	4	3*	11	✓	X	?
Wave barriers in Lake Waikare.	2*	3	4	2	11	✓	✓	✓
Constructed wetland between Lake Waikare and Whangamarino Wetland.	3*	7	0	4	14	✓	?	X
Confine Waikare control gate outflows by stopbanking/ bunding.	2*	5	4	2	13	X	?	?
Reduce peak flows/duration of peak flow events from Lake Waikare.	2	6	4	2	14	✓	X	?

* Low confidence in score.

None of the mitigation options evaluated in Table 8 provide a single solution to reducing sediment inputs to Lake Waikare and Whangamarino Wetland. Any solution will include a combination of mitigation options however all of the mitigation options evaluated had significant drawbacks. For example the mitigation option that scored highest, 'catchment management – targeted farm-scale actions' scored only a '2' for certainty of outcome and would require a much greater level of engagement by landowners than in the past. Further investigation, including filling critical gaps in knowledge (section 8) may provide better certainty of outcomes and could identify further mitigation options.

8. CRITICAL GAPS IN KNOWLEDGE

The following have been identified as critical gaps in knowledge that need to be addressed to improve evaluation of mitigation options:

- Better quantification of sediment and nutrient inputs and outputs. In particular, more data is needed on concentrations of suspended sediment in the Northern Outlet Canal, to more accurately determine the volume of sediment being discharged to different regions of the Whangamarino Wetland.
- The quantification of the extent of surface flooding within the Whangamarino Wetland at different water levels, and how these are influenced by the operation of the Lake Waikare control gate.
- The contribution that introduced fish make to suspended sediment levels within Lake Waikare and the Whangamarino Wetland.

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