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Lake Mangahia Management Recommendations for Lake Level, Marginal Vegetation and Nutrient Removal

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Note: This report was originally published in July 2008 as Technical Report 2008/35. This new edition corrects a minor data error which appeared in Table 3 and Table 4 (pg 37). As a result of correcting this data a small change was required to be made to associated text on pages 40-41. These changes make no difference to the conclusions or recommendations in the report, but in the interests of data accuracy we are re-releasing this publication.

Lake Mangahia management recommendations for lake level, marginal vegetation and nutrient removal

NIWA Client Report: HAM2008-044
April 2008

NIWA Project: EVW08219

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Executive Summary

Environment Waikato engaged NIWA to carry out the following activities at Lake Mangahia: review the summer minimum water level, describe current vegetation including priorities for weed control, delimit aerial spray exclusion zones and set backs for fencing, recommend species and locations for planting, and present options for nutrient removal from inflow water, after reviewing water quality data. Subsequently NIWA was asked to provide indicative information on the use of an infiltration filter system at Lake Mangahia similar to the one proposed for Lake Serpentine.

A site visit was conducted on 11 February 2008 with landowners, NIWA staff and Environment Waikato staff to view the marginal vegetation, farm drains and discuss current management of the lake environs. NIWA staff made an additional site visit on 26 February 2008 and undertook a bathymetric survey using sonar equipment and a vegetation survey of the lake margins. Five transects were established from the lake edge to the fenceline with species presence, height and % cover recorded.

Based on historic and recently recorded lake depths, the water level of Lake Mangahia appears to be lower than it was before the early 1990's. The current lake depth set by the weir is estimated at 1.8 m, 0.5 m less than the surveyed depth of 2.3 m recorded in 1979 (Irwin, 1982) during a dry year. Therefore, an increase in weir outlet height of 0.5 m to 37.3 m a.s.l. (Moturiki Datum) is recommended. Re-measurement of water levels in relation to the bench mark used by Irwin would provide greater certainty to the conclusions based on historical data.

Six different vegetation types and 68 plant species were recorded from the margins of Lake Mangahia. Of note was the extent of peat influenced native vegetation that included parasol fern (*Gleichenia microphylla*), and regenerating kahikatea (*Dacrycarpus dacrydioides*) which contribute to the ecological values of the site. Extensive clearance of manuka (*Leptospermum scoparium*) and encroachment by grey willow (*Salix cineria*) is evident from comparisons of historic and current aerial photographs, whilst comparisons between the current survey and a previous survey in 1993 also showed a reduction in the shoreline occupation of bamboo spike sedge (*Eleocharis sphacelata*) and flax (*Phormium tenax*) / pukio (*Carex secta*).

Pest plants recorded during the survey were prioritised for control with high risk species including grey willow, royal fern (*Osmunda regalis*), japanese honeysuckle (*Lonicera japonica*), arum lily (*Zantedeschia aethiopica* cv. green goddess) and Chinese privet (*Ligustrum sinense*). Guidance on treatment options was provided for high and medium priority species.

Four aerial spray exclusion zones were identified for willow control operations which incorporate areas of open willow canopy where spray penetration would kill non-target native plants in the understorey, areas with high value kahikatea vegetation and vegetation features the land owners wish

to preserve. Recommended follow-up monitoring to assess the outcome of the spray operation is outlined.

Recommended setback distances for fencing were identified based on the surveyed wetland vegetation patterns within the current grazed paddocks. Enhancement plantings of suitable species were suggested at priority sites including the wetland area at the north end of the lake, newly fenced pasture margins and the Waipa District Council reserve.

Analysis of available lake water quality data using the Trophic Level Index (TLI) method indicate an increasing trophic status (nutrient enriched) to a current status of hyper-eutrophic. However more data collected at least seasonally are recommended to confirm recent trends. A combination of a significant increasing trend in P concentrations and the low N:P ratios suggest inputs of both N and P nutrients to the lake should be minimised where possible.

Nutrient remediation options were considered and include the construction of an infiltration filter system to intercept and treat drainage water entering the lake from the extensive north-eastern catchment. The addition of a wood chip area of 0.13 ha in size would target nitrogen removal by denitrification. An estimated size for the complete infiltration filter system to treat the drainage inflow is approximately 0.83 ha. It is anticipated that the system could remove at least 80% nitrogen, 60-80% phosphorus, reduce suspended sediments and reduce *E. coli* from the main drain into the lake. Indicative costs for construction of the complete infiltration filter system, on commercial rates as if done by a contractor, are estimated at $200,000. Measurements of drainage nutrient inflows are recommended to confirm the assumptions made in the assessment.

1. Introduction

Lake Mangahia survives as a good example of a dystrophic (peat-stained) lake with associated peat influenced vegetation whilst many others throughout New Zealand have been lost or are very degraded. Although Lake Mangahia has been degraded, it was regarded by previous investigators as one of the least modified lakes in the Waipa District, second only to Lake Maratoto (Chapman & Boubee, 1977; Thompson & Champion, 1993) and had the highest ecological ranking of peat lakes in the Waipa District (Thompson & Greenwood, 1997). Chapman & Boubee (1977) recommended that at least one of the peat lakes in Waipa County be set aside for preservation as a scientific reserve in recognition of the distinctive biological and physical characteristics that peat lakes have.

Lake Mangahia is located south-west of Hamilton City, on Rukuhia Road, in the Waipa District of the Waikato Region. Lake Mangahia occupies an area of approximately 8.4 ha, surrounded by 10.21 ha of continuous wetland vegetation (Fig 1) that is fenced to exclude stock. The lake catchment is primarily pastoral with intensive dairy land use. Runoff from the surrounding dairy farms enters Lake Mangahia via a network of farm drains. A weir, sited at the outlet, sets minimum lake levels and feeds the Mangahia Stream, a tributary of the Waipa River.

Figure 1: Catchment map for Lake Mangahia (Environment Waikato, 2008).

Lake Mangahia and the surrounding vegetation were on a single, privately owned, property title (Fig 2). In February 2008 the landowners adjacent to the Lake Mangahia title acquired the land surrounding the lake through an adverse effects claim and the title of the lake bed was transferred to the Crown (Land Information New Zealand).

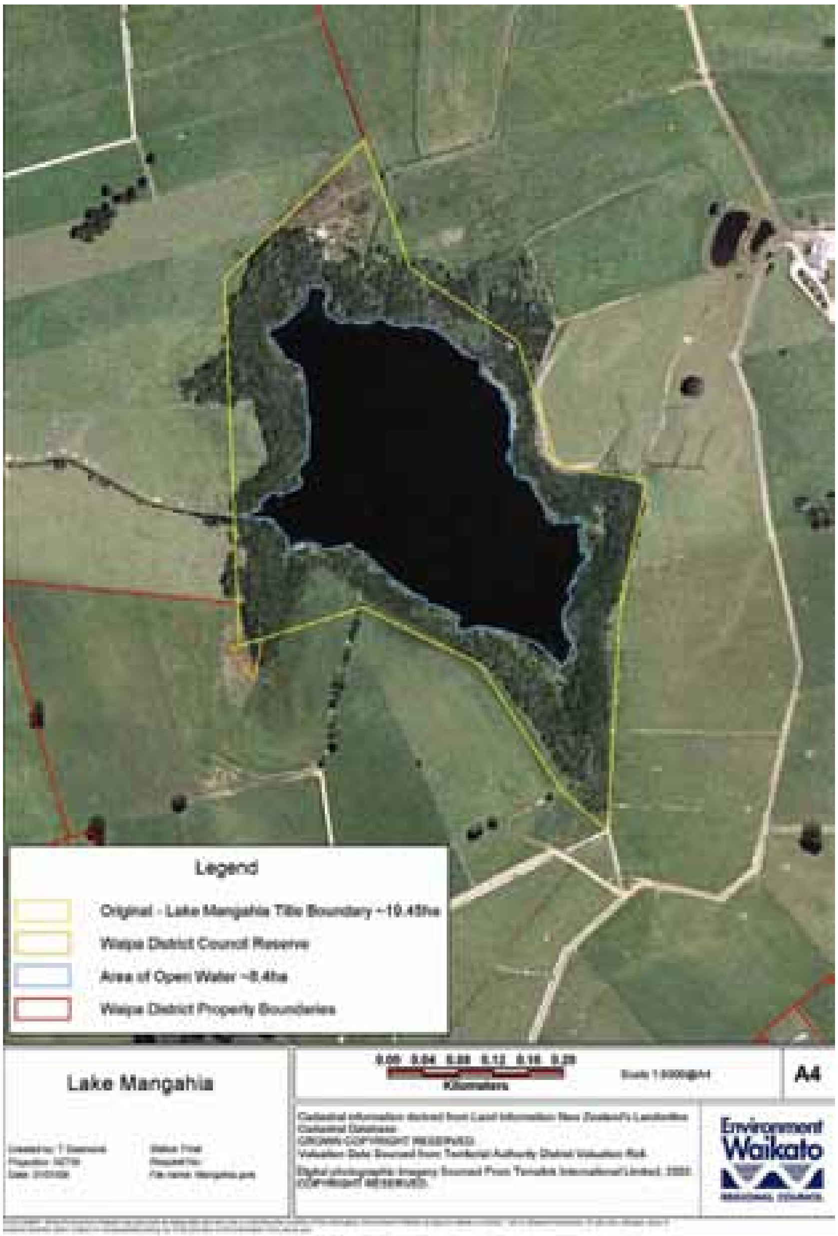

Figure 2: Waipa District property boundaries for Lake Mangahia and surrounding farmland, pre-February 2008.

Lake Mangahia has typical properties of a dystrophic lake (Chapman & Boubee, 1977; Waikato Valley Authority, 1985), including dark-brown, peat stained water with a high humic content and low pH (acidic). However, dairy farming, drainage, peat shrinkage and increased nutrient inflow have altered its peat lake characteristics by increasing nutrient levels and increasing pH towards neutral. High chlorophyll *a* and total phosphorus concentrations and a very low Secchi depth (0.3 m) reflect the hyper-eutrophic status of the lake (Chapman & Boubee, 1977; Waikato Valley Authority, 1985).

Lake depths records have varied markedly with Irwin (1982) recording a maximum depth of 2.3 m in the 1979 bathymetric survey, 3.2 m was recorded in 1982 by Waikato Valley Authority (1985) and 1.5m in 2007 by Edwards et al. (2007). However, lake levels fluctuate by about 1 m depending on recent rainfall.

A 1957 aerial photograph reviewed by Champion et al. (1993) showed a native canopy of predominantly manuka (*Leptospermum scoparium*) with grey willow (*Salix cineria*) restricted to the north east margin of the lake. Significant changes in canopy composition from around 1979 to 1993 occurred with grey willow invading open manuka stands and colonising cleared areas, to surround the lake margins on all sides except for the north east edge where a 7 m-tall, pure stand of manuka remained (Thompson & Champion, 1993). The understorey vegetation was typical of a peat influenced substrate, with a diverse range of herbaceous and woody species dominated by manuka, flax (*Phormium tenax*) and *Baumea* spp. (Champion et al. 1993). Cattle exclusion from marginal vegetation has allowed the predominantly native understorey and emergent lake vegetation to remain intact throughout.

Despite its high ecological values Lake Mangahia has ranked lower in priority for restoration or protection than some other Waipa District peat lakes due to issues of private ownership and lack of public access, legal protection and management actions (Waipa District Council, 2006).

Recent changes in land ownership and title boundaries for Lake Mangahia, plus a requirement for Environment Waikato to review the height of a recently installed weir and its operation, have led to the Regional Council undertaking a wider consideration of management at Lake Mangahia. As part of the recent acquisition process, Environment Waikato has held discussions with both adjacent farm owners and identified several potential goals for the lake:

- Protect the lake water quality from further degradation.
- Enhance lake water quality over the long term.
- Remove grey willow as the dominant canopy vegetation.
- Provide suitable buffers for enhancing lake health and for establishing and improving native vegetation.
- Legally protect the lake for future generations.

In addition Environment Waikato would also like to reduce or stop peat subsidence.

Environment Waikato engaged NIWA to:

(1) review the summer minimum water level;

(2) conduct a vegetation survey to describe the current vegetation, set priorities for weed control, determine aerial spray exclusion zones, determine set backs for fencing, and recommend locations and species for planting;

(3) present options for nutrient removal from inflow water, including indicative information on the use of an infiltration filter system similar to the one proposed for Lake Serpentine, after reviewing water quality data for the lake.

This report is broadly divided into three sections: lake water levels, vegetation and lake water quality. Each section includes methods, results and discussion. Recommendations and timeframes for implementation are summarised at the end section of the report (Section 7).

2. Methods

Lake Mangahia was visited on 11 February 2008 with landowners and Environment Waikato staff to view the marginal vegetation, farm drains and discuss current management of the lake environs. On 26 February 2008 a bathymetric survey and vegetation survey of the lake margins were undertaken. Further detailed methods are contained within the respective sections.

3. Lake water levels and bathymetry

3.1 Methods

The weir and water level gauge were visited on 26 February 2008 and lake water level recorded (Fig. 3).

Historical water levels for the lake were reviewed as far as possible from available data and compared to the current water level and depth of the lake.

Sonar traces were recorded across two transects using an ecosounder / GPS (SeaCharter 500C DF Eagle LCD colour plotter/sounder, 200 kHz transducer, profile chart recorder). One transect was in a south-north direction and the other transect was in an east-west direction (Fig. 4).

3.2 Results

The water level gauge was 0.2 m and was low for the lake after a dry summer as obvious water marks were seen on the weir up to 0.4 m higher (Fig. 3). At this time the water level was approximately 0.3 m below the weir structure.

The two sonar transects recorded are reproduced in Figure 5. The transects had a very gradual slope with the maximum depth recorded for the lake only 1.5 m and average estimated to be ~0.8 m.

Figure 3: Lake Mangahia weir and water level gauge with water level at 0.2 m. Previous water levels indicated by marks on the gauge were at levels up to 0.4 m higher (arrows).

Figure 4: Lake Mangahia sonar transects with the solid line being Transect A and the dotted line being Transect B. The dot was the area of the deepest readings.

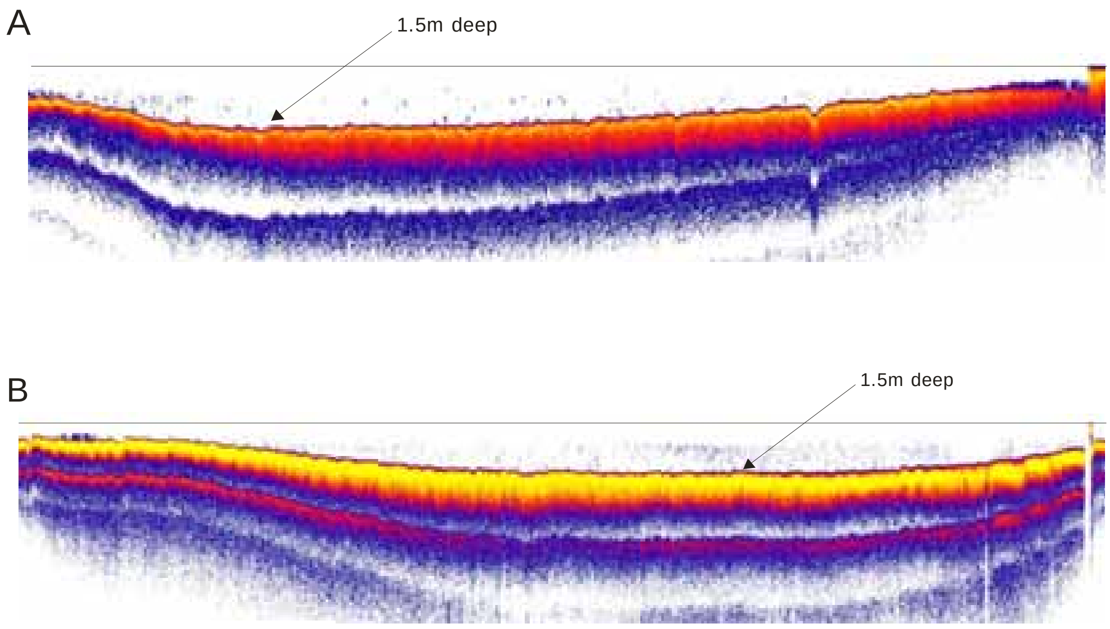

Figure 5: Lake Mangahia sonar transects: A running south – north and B running east – west (see Fig. 4 for locations) showing a shallow lake with a maximum depth of 1.5 m and a profile with low slope.

3.3 Discussion

Historical records of lake depth provide some information of past water levels (Table 1). Several recordings were made in the 1970’s but the most accurate was the 1979 bathymetry survey undertaken by Irwin (1982) which recorded a maximum lake depth of 2.3 m. The water level at this time was bench marked to 1.53 m below the bench mark located at the former pa site on the western side of the lake. It is interesting to note that this depth (deeper than anything recorded recently) was recorded despite it being a dry year prior to the survey with 256 mm less rain recorded at Hamilton Aerodrome than the norm for years 1961 – 1990 (NIWA National Climate Database).

The deepest measured depth was in 1982 with a maximum lake depth of 3.2 m (Waikato Valley Authority, 1985). Lake depths of 2 m deep or less have been recorded since 1992 and depths around 1.5 m have been common since that time. Shallower lake depths could either be due to lake infill, lower water levels or significant peat shrinkage of surrounding margins. However, the 1982 figures presented (Table 1) show a water depth fluctuation of 0.9 m within a month, and

Chapman & Boubee (1977) noted that most of the lakes in the Waipa District are known to vary about 0.5 m in depth during the year, indicating the difficulty of drawing conclusions about changes in water levels by comparing limited depth / level data. Examination of lake sediment cores and / or re-measuring water levels in relation to the bench mark used by Irwin would help clarify the situation.

Table 1: Historical records of lake depths for Lake Mangahia.

Author	Date of survey	Maximum recorded depths
Chapman & Boubee (1977)	Jan – Feb 1977	c. 2.1 m
Boubee (1978)	Summarises Chapman & Boubee (1977)	2 m (rounded down, pers. comm.)
Irwin (1982)	Sept 1979	2.3 m (bathymetric survey)
Waikato Valley Authority (1985)	Jan – Mar 1982	3.2 m
Environment Waikato (Unpublished data)	Feb 1982	2.3 m
Environment Waikato (Unpublished data)	Feb 1989	2.0 m
Environment Waikato (Unpublished data)	Oct 1992	1.5 m
Environment Waikato (Unpublished data)	Dec 1992	1.9 m
Environment Waikato (Unpublished data)	May 1993	2.0 m
Environment Waikato (Unpublished data)	Jun 1994	1.8 m
Edwards et. al. (2007)	Feb 2007	1.5 m
Environment Waikato (Unpublished data)	Dec 2007	1.5 m
Current report	Feb 2008	1.5 m
Environment Waikato (Unpublished data)	Mar 2008	1.3 m

Lake Mangahia has a single artificial outlet (natural outlet was c. 250 m north of this) on the west side of the lake margin, the Mangahia Stream, which flows into the Waipa River. In June 2001 Environment Waikato constructed a concrete weir in response to the alleged removal of a natural clay sill that had previously maintained lake levels. The lack of definitive historic data meant the height required for the weir to restore previous water levels could only be estimated. Based on the recent depths recorded in Table 1, the water level of Lake Mangahia still appears to be lower than it was before the early 1990's.

It is relevant in this discussion to note that the water level at the time of our survey was 0.3 m below the weir overflow. Draining of peat wetlands and conversion to agriculture leads to peat shrinkage with the average annual subsidence of peat for the Rukuhia area being 25 mm per year for dry peat (Environment Waikato, 2006). The amount of peat subsidence and area affected is correlated to drain depth, the deeper the drain the greater the effect (Environment Waikato, 2005). Drainage of peat wetlands also lowers the groundwater table and minimum lake levels will not be determined by weir height when the groundwater table is lower than the weir. Weir height will not 'set' the minimum level the lake attains but it will increase average water levels and the duration of water inundation within the wetland margin. Regardless of historical water levels, more water in the wetland would be beneficial to maintaining it in good condition. For example, dry conditions have enabled more terrestrial pest plants such as blackberry and gorse to invade native wetland.

The maximum lake depth recorded in February 2008 was 1.5 m when lake water levels were 0.3 m below the weir. Therefore, the lake depth if the water level was at the current weir height would be 1.8 m. This is 0.5 m less than the surveyed depth recorded in September 1979 (Irwin, 1982) during a dry year. It would therefore seem reasonable to set the weir at 0.5 m higher than it is at present.

In summary, a 0.5 m rise in the weir height is recommended based on:

- Lake depths since 1994 have been consistently below 2 m.
- The existing weir height sets a lake depth of 0.5 m below that recorded by Irwin (1982) in a dry year.
- Lowered lake levels have enabled the establishment of terrestrial weeds.
- More water in the lake margins would benefit native wetland vegetation.
- Previous extent of lake open water was 6.9 ha greater than present (refer discussion 4.3.2).

4. Vegetation

4.1 Vegetation methods

An overview of marginal lake vegetation was obtained on 26 February 2008 by walking around the paddock perimeter, through sections of the wetland and circumnavigating the lake margin by boat. Paddock margins were also examined for wetland plant species that indicated the extent of lake influence. Five transects perpendicular to the lake edge and well spaced around the lake (Fig. 6) were selected through grey willow dominated vegetation. Species presence, height (estimated to nearest half metre) and cover (% cover) were recorded along the transect from the lake edge to the fence to give detailed vegetation descriptions and assess areas not suitable for aerial spraying.

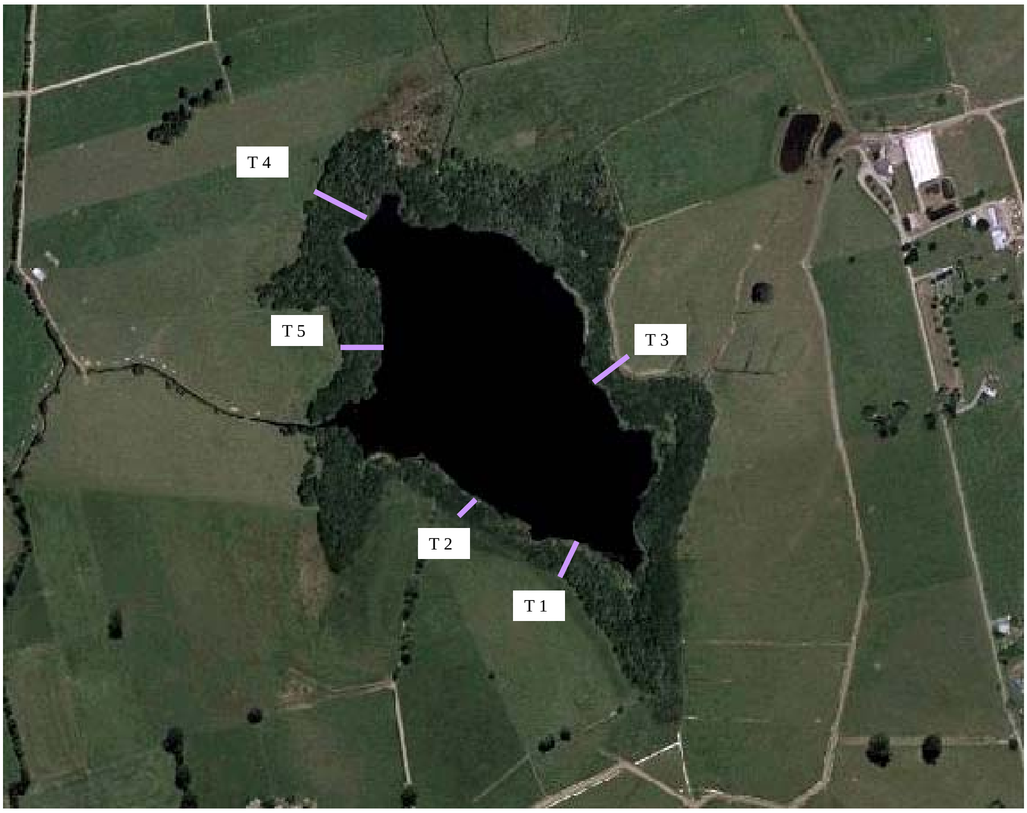

Figure 6: Location of five marginal vegetation transects at Lake Mangahia.

4.2 Vegetation survey results

Six different vegetation types were discerned at Lake Mangahia; erect emergent, sprawling emergent, grey willow, kahikatea (*Dacrycarpus dacrydioides*), vineland and manuka. The 68 plant species identified included 41 indigenous species (Appendix 1).

4.2.1 Vegetation types

Erect emergent

The dominant species in the emergent zone around the lake was bamboo spike sedge (*Eleocharis sphacelata*) in dense beds up to 10 m wide. Bamboo spike sedge occupied approximately 22% of the shoreline around Lake Mangahia. Four beds of raupo (*Typha orientalis*) and several individual plants comprised approximately 14% of the shore line (Fig. 7).

Figure 7: The emergent zone on the eastern shore of Lake Mangahia showing native raupo with gypsywort growing up through it (February, 2008).

Sprawling emergent

Floating mats of vegetation up to 2 m wide extended into the lake between the grey willow and the bamboo spike sedge zones (Fig. 8). These mats were primarily exotic grasses and herbaceous species, dominated by Mercer grass (*Paspalum distichum*), up to 90% cover, or gypsywort (*Lycopus europaeus*) interspersed with occasional native plants. Mercer grass mats occupied approximately 27% of the shoreline. Less common were flax, pukio (*Carex secta*) and water pepper (*Persicaria hydropiper*), which occupied approximately 9% of the shoreline.

Figure 8: The erect emergent zone with bamboo spike sedge (mid ground) and sprawling emergent zone with Mercer grass (foreground) on the southern margins of Lake Mangahia (February, 2008).

Grey willow

Grey willow ranged from 70% - 90% canopy cover with trees 3.5 – 5 m tall forming an almost continuous band around the lake although it only occupied approximately 28% of the shoreline. Beneath the grey willow canopy was a predominantly native understorey with a diverse range of herbaceous and woody species dominated by swamp coprosma (*Coprosma tenuicaulis*) (30% average cover) and to a lesser extent flax (11% average cover) (Fig. 9). Ground cover was a diverse range of ferns, monocots, herbs and some dense areas of the native moss sphagnum (*Sphagnum* *cristatum*). Native species dominated the ground cover overall but the exotic species royal fern (*Osmunda regalis*) and creeping bent (*Agrostis stolonifera*) obtained high covers when present.

Figure 9: Grey willow zone with a predominantly native subcanopy of swamp coprosma and flax at the southern end of Lake Mangahia (February, 2008).

Kahikatea

The emergent kahikatea stand at the northwest end of the lake was approximately 10 m tall with the pest plant royal fern abundant in the understorey, along with native *Carex* species, swamp coprosma, flax and the pest plants grey willow and Japanese honeysuckle (*Lonicera japonica*). On the paddock side of this stand was a damp area with a mass of arum lily (*Zantadeschia aethiopica*) and a sward of *Juncus* rushes grading into pasture.

The vegetation from the east of this stand had occasional emergent kahikatea trees amongst a grey willow canopy. Under this canopy was dense regeneration of kahikatea seedlings and saplings up to 3 m tall and swamp coprosma shrubs (Fig. 10). Ground cover species were rautahi (*Carex lessoniana*), pukio (*C. secta*) and exotic species royal fern and marsh bedstraw (*Galium palustre*).

Figure 10: Kahikatea zone included dense regenerating kahikatea saplings at the north end of Lake Mangahia (February, 2008).

Vineland

The vineland area at the northeast end of the lake comprised a dense thicket of the pest plants Japanese honeysuckle, blackberry (*Rubus fruticosus*), gorse (*Ulex europaeus*), Himalayan honeysuckle (*Leycesteria formosa*) and pampas (*Cortaderia selloana*), interspersed with native bindweed (*Calystegia sepium*), bracken (*Pteridium esculentum*), mature wheki tree ferns (*Dicksonia squarrosa*) and parasol fern (*Gleichenia microphylla*) (Fig. 11).

Figure 11: Dense vineland area between grey willow (left and background) and manuka (right) at the northeast end of Lake Mangahia (February, 2008).

Manuka stand

The manuka stand on the northeast lake margin had a sparse canopy of grey willow with an understorey of swamp coprosma, flax and cabbage tree (*Cordyline australis*). Previously cleared manuka stumps were evident in open clearings dominated by bracken and blackberry interspersed with flax, gorse and to a lesser extent pohuehue (*Muehlenbeckia australis*), *Baumea rubiginosa*, a native fern *Hypolepis distans*, the exotic soft rush (*Juncus effusus*) and Japanese honeysuckle (Fig. 12).

Figure 12: Manuka stand with sparse canopy and a cut manuka stump in the foreground.

4.2.2 Vegetation transects

Transect one was 45 m long with an additional 10 m wide band of bamboo spike sedge emergent within the lake. A 7.4 m long section of floating sudd was comprised of 90% Mercer grass with 5% gypsywort, 1% swamp willow weed (*Persicaria decipiens*), swamp millet (*Isachne globosa*), and the exotic species beggar's tick (*Bidens frondosa*), water primrose (*Ludwigia peploides*), lotus (*Lotus pedunculatus*), Yorkshire fog (*Holcus lanatus*) and creeping bent. On the landward margin of the floating sudd was a 2 m zone of flax, manuka, pakihi sedge (*Baumea teretifolia*), swamp coprosma, pukio and *B. rubiginosa* with a canopy of grey willow overhanging from 8 m to 9.7 m. The remainder of the transect comprised grey willow approximately 5 m tall and with 70% canopy cover. The subcanopy was 3.5 m tall swamp coprosma (40%), 2.5 m tall flax (10%), royal fern (5%) and *Baumea* species. Ground cover was sphagnum (60%), creeping bent (30%), the native species kiokio (*Blechnum novaezelandiae*), manuka seedlings, *Hydrocotyle pterocarpa,* New Zealand blueberry (*Dianella nigra*), *Centella uniflora*, bindweed, swamp millet, sphagnum and leather-leaf fern (*Pyrrosia eleagnifolia*) and exotic species blackberry, lotus and Yorkshire fog.

Transect two was 30 m long with no emergent vegetation in the lake. It comprised grey willow, approximately 5 m tall, with 85% canopy cover. The subcanopy ranged in height from 1 – 2 m and included swamp coprosma (30%) and flax (5%).

Groundcover was creeping bent (50%), sphagnum (25%), ferns (20%), *Baumea* species (2%), sharp spike sedge (*Eleocharis acuta*), New Zealand blueberry, *Hypolepis ambigua*, *Isolepis distigmatosa*, kiokio, bindweed, *Carex virgata*, swamp millet, *Nertera scapanioides*, *Centella uniflora*, *Hydrocotyle pterocarpa*, *Hypolepis ambigua*, hounds tongue (*Microsorum pustulatum*), wheki, *Gonocarpus micranthus* and water fern (*Histiopteris incisa*) and exotic species royal fern, blackberry, beggar's tick, lotus, Yorkshire fog, gypsywort, spearwort (*Ranunculus flammula*), water purslane (*Ludwigia palustris*) and Australian fireweed (*Senecio bipinnatisectus*).

Transect three was 35.5 m long with a bed of bamboo spike sedge emergent from the lake. The shore margin was dominated by flax interspersed with other native species; *Baumea rubiginosa*, swamp millet, common water milfoil (*Myriphyllum propinquum*), kiokio and sphagnum, and the exotics Chinese privet (*Ligustrum sinense*), creeping bent, lotus, Mercer grass, water pepper, gypsywort, beggar's tick and blackberry. A continuous canopy of grey willow (90% cover) approximately 5 m tall extended 33 m distance to a drain near the fenceline. The subcanopy was swamp coprosma (60%) and flax (5%) with a ground cover comprised of the native species leafless rush (*Juncus pauciflorus*), dwarf bog rush (*Schoenus maschalinus*), *Carex virgata*, kiokio, swamp millet, *Hydrocotyle pterocarpa*, kahikatea seedlings, *Baumea rubiginosa* and slender spike sedge (*Eleocharis gracilis*) and exotic species *Juncus acuminatus*, royal fern, gypsywort, beggar's tick, spearwort and Japanese honeysuckle. The drain, from 33 m to 35.5 m, contained the exotic plants beggar's tick, spearwort, water purslane, American fireweed (*Erechtites hieraciifolia*) and water pepper. An additional 15.5 m section of damp ground occurred on the pasture side of the fence line with water pepper at 80% cover.

Transect four was the longest transect at 59 m with no emergent vegetation in the lake. Grey willow, approximately 4 m tall, extended from the lake edge to the paddock margin with 85% canopy cover. The subcanopy was flax (30%) and swamp coprosma (8%). Ground covers were native *Carex* species (5%), flax, kahikatea seedlings, swamp coprosma, kiokio, pukio, *Carex virgata*, *Hydrocotyle pterocarpa*, *Nertera scapanioides*, sphagnum and parasol fern (*Gleichenia microphylla*) and exotic species creeping bent, *Juncus acuminatus*, beggar's tick, Japanese honeysuckle, blackberry and royal fern. Bare ground and damper soils became evident near the fence. Damp ground extended 25 m into the paddock with soft rush and rautahi near the fence.

Transect five was 46 m long with grey willow throughout, approximately 3.5 m tall, with 85% canopy cover from the lake edge to the paddock. The subcanopy was royal fern (40%) up to 1 m tall, swamp coprosma (10%) and flax (5%). Ground covers were the native species kiokio (5%), parasol fern (2%), *Hypolepis distans*, *Baumea* *arthrophylla*, jointed twig rush (*B. articulata*), swamp millet, sphagnum, *Carex virgata*, drooping spleenwort and leather-leaf fern and exotic species gypsywort, Yorkshire fog, lotus, water pepper, creeping bent and blackberry.

4.3 Vegetation discussion

The vegetation surrounding Lake Mangahia comprised grey willow / swamp coprosma forest, based on the Atkinson (1985) vegetation classes. It formed an almost continuous band around lake margin broken by a kahikatea stand on the northwest margin, and a vineland area and manuka stand on the north east margin.

The vegetation of Lake Mangahia was similar to that described by Champion et al. (1993). It retains high wetland ecological values but the abundance of pest species has increased and the overall vegetated area has declined substantially.

4.3.1 Significant vegetation

Stock exclusion from the marginal vegetation has allowed the dense and diverse understorey to remain intact and dominated by native wetland plant species and peat influenced vegetation such as swamp coprosma, flax, seedling and sapling kahikatea, manuka seedlings and scrub, *Baumea* spp., parasol fern and bamboo spike sedge. Parasol fern, while less common in the marginal vegetation of other Waikato Lakes (Champion et. al., 1993), occurs in prominent thickets at Lake Mangahia. The ensemble of peat influenced native vegetation contributes to this site's high ecological value, together with the kahikatea forest and subcanopy on the north margin of the lake. No other lakes within the Waipa District have known kahikatea regeneration occurring. In addition the manuka scrub zone on the east margin of the lake is the remnant of a vegetation type that used to border most of the lake margin.

4.3.2 Historical vegetation changes

Historical aerial photographs show the canopy vegetation was manuka dominated, with grey willow first appearing around 1957 (Champion et al. 1993). A considerable area of manuka scrub and forest up to 7 m tall was removed from the north eastern lake margin in the early to mid 1990's (Champion et al. 1993). In 1992 and 1993 areas of manuka and grey willow were cleared on the northern margin for pasture development with clearance on the west margin, around the pa site and on the southern margin occurring some time prior to this (Champion et al. 1993). Over the last fifteen years additional clearance at the north and east margins has further narrowed the vegetation buffer between paddocks and the lake. The extent of the reduction in wetland vegetation since 1979 is apparent when comparing the bathymetric map of Irwin (1982) to current aerial photographs (Fig. 13). Grey willow now encompasses the entire lake margin with low cover only at the north end of the lake. It is also apparent that bamboo spike sedge shoreline occupation has contracted from 91% (Champion et al. 1993) to 22% and flax / pukio shoreline occupation has reduced while floating mats of Mercer grass extending out over the water have increased.

A combination of encroachment of marginal vegetation (Fig. 13) and lower lake levels have probably contributed to the reduction in open water area from 15.3 ha in 1943 (Thompson & Champion, 1993) to 11.3 ha in 1993 (Champion et al. 1993) and to 8.4 ha (Environment Waikato, 2007, Fig 2). Most of the vegetation encroachment on Lake Mangahia is from the expansion of grey willow with more recent loss of open water areas to extensive floating mats of Mercer grass, particularly in the southern half of the lake, and raupo has increased from one to four beds on the lake margin. A larger open water area could probably be achieved through increased lake levels in combination with nutrient removal and the control of pest plants.

Figure 13: An aerial photograph (Environment Waikato) of Lake Mangahia overlaid on the 1979 bathymetric survey map by Irwin (1982) illustrates marginal vegetation lost and loss of open water area through vegetation encroachment over 28 years.

4.3.3 Pest plant control

Pest plants can alter the ecological structure and function of the native ecosystem and need to be targeted for control to prevent degradation of lake marginal vegetation. Pest plants have been ranked as high, medium or low priority according to the threat they pose to ecological integrity of the site (Appendix 2). Those plants ranked as high or medium priority should be targeted at Lake Mangahia and are listed in Table 2 with control methods.

Table 2: Prioritised pest plants for Lake Mangahia with treatment options.

Priority ranking	Common name	Species	Treatment
High			
1	Grey willow	*Salix cinerea*	Aerial spray triclopyr or glyphosate, drill & inject metsulfuron / glyphosate
2	Royal fern	*Osmunda regalis*	Metsulfuron, dig out
3a	Japanese honeysuckle	*Lonicera japonica*	Triclopyr
3b	Arum lily	*Zantadeschia aethiopica* cv. green goddess	Metsulfuron, dig out
4	Chinese privet	*Ligustrum sinense*	Saplings cut & paint with metsulfuron, seedlings dig or pull out
Medium			
5a	Blackberry	*Rubus fruticosus* agg.	Metsulfuron
5b	Gorse	*Ulex europaeus*	Metsulfuron
6a	Pampas	*Cortaderia selloana*	Haloxyfop
6b	Himalayan honeysuckle	*Leycesteria formosa*	Triclopyr
7	Mercer grass	*Paspalum distichum*	Haloxyfop

High priority pest plants often out-compete native plants and pose the greatest threat to the ecological structure and function of the native ecosystem invaded. Grey willow is identified as the highest priority pest plant as it has displaced manuka as the dominant canopy species and has reduced area of open water in the lake. Royal fern is shade tolerant and can displace native subcanopy species. It was occupying up to

100% of the subcanopy in some parts of Transect five and under the kahikatea stand. Japanese honeysuckle and arum lily are equally ranked third. Japanese honeysuckle is a vine that proliferates in open, drier areas, such as the vineland and pasture margins, but can also smother natives under grey willow canopy. Arum lily grows in damp soil in both full light and shade conditions, outcompeting native wetland plants to form dense swards. Chinese privet is not yet abundant at Lake Mangahia but it is shade tolerant with seedlings established under the grey willow canopy and is potentially a future canopy component.

Medium priority pest plants (Table 2) are terrestrial weeds that now have greater habitat available as a result of decreased lake levels. Blackberry and gorse are concentrated in the vineland zone on the east margin of the lake but scattered clumps were found around the lake both on the edge of paddock margins and under grey willow canopy. Pampas and Himalayan honeysuckle were largely on the east margin of lake in open areas. All of these pest plants do well in disturbed sites so control by digging should be kept to a minimum.

If the lake water level is increased sufficiently, particularly over summer, it will reduce the threat of reinvasion of these species. Control of Mercer grass, the lowest priority pest plant, may be considered as its floating mats reduce open water habitat.

Low priority wetland pest plants are not included for targeted action in Table 2 as they are often difficult to control, look very similar to native wetland plants and are widespread. They are mostly pasture plants that require light and drier soils to survive or small wetland plants that don't threaten the ecological structure of the wetland and are difficult to target.

Aerial application of triclopyr (Garlon 360®) is a cost effective means of controlling large areas of grey willow. Timing is best when grey willow are in full leaf and actively growing, in summer from about November onwards, depending on the weather. Triclopyr does not affect grasses but there are grazing restrictions that need to be taken for milking cows (see product label).

A second aerial spray option is glyphosate (e.g. Roundup®) and best results are also achieved when applied during the growing season. However, more non-target damage is expected with glyphosate as it is a non-selective, broad spectrum herbicide.

Not all areas of grey willow are suitable for aerial treatment. A more open grey willow canopy will allow spray penetration into the understorey killing non-target native plants. Aerial treatment would also kill non-target plants where the canopy is a mix of grey willow and native species or where exotic trees are to be retained. Grey willow at

Lake Mangahia can be aerially sprayed except in the four aerial spray exclusion zones identified as 1-4 below (Figs 14 – 17).

1. The grey willows at the southern end of the lake (Fig. 14) with a lower canopy cover (approximately 70%) and patchy open areas would allow too much herbicide to penetrate and affect the healthy native understorey of swamp coprosma, flax and sphagnum.

Figure 14: Aerial photograph (Environment Waikato) of the southern end of Lake Mangahia with the vegetation transects (purple line) and aerial spray exclusion zone (red).

2. The north east zone (Fig 15 & 15b) of manuka / tree fern canopy has patchy willow canopy. Aerial treatment of willows would be difficult without affecting manuka, tree ferns and the native understorey of swamp coprosma, flax and wetland ground cover species. There was also a single kahikatea tree on the drain edge to be avoided. One small area of dense willows within this zone could be aerially treated.

Figure 15a: Aerial photograph (Environment Waikato) of the north eastern lake margin of Lake Mangahia showing the aerial spray exclusion zone (red) with the manuka/tree fern and single kahikatea tree (red circle) also excluded.

Figure 15b: Aerial photograph (Environment Waikato) of the north eastern lake margin of Lake Mangahia with the vegetation transect (purple line), aerial spray exclusion zone (red) and with the small area of dense willows that could be aerially treated (yellow).

3. The kahikatea stand at the northern end of the lake including emergent tree ferns, cabbage trees and kahikatea to the east (Fig. 16).

Figure 16: Aerial photograph (Environment Waikato) of the northern lake margin of Lake Mangahia with the vegetation transect (purple line), aerial spray exclusion zone (red) and individual trees (red circles) not to be sprayed.

4. The poplar lined paddock drain and a single swamp cypress (*Taxodium distichum*) amongst the willows at the south western side of the lake were excluded from the aerial spray zone at the request of the land owners (Fig. 17).

Figure 17: Aerial photograph (Environment Waikato) of the south western lake margin of Lake Mangahia with the former pa site (beige), vegetation transect (purple line), poplar aerial spray exclusion zone (red elipse) and swamp cypress tree (red circle) not to be sprayed.

Following aerial treatment of willows, remaining live willows should be drilled and injected with herbicide (for details see http://www.waitakere.govt.nz/cnlser/pw/plantweed/pdf/cntrlwillow.pdf). Dead willows should remain standing and not be removed as they reduce weed invasion and provide shade, shelter and habitat.

The large populations of royal fern on the north western lake margin will require post aerial treatment by spot spraying (Table 2). Smaller populations and individual plants around the lake could be treated when ground treatment of grey willow occurs.

The large area of arum lily on north western lake margin and individual plants in the vineland area can be treated (Table 2) early in the weed control programme.

Japanese honeysuckle was largely found on the east side of the lake, particularly on the paddock margin in the open areas of the vineland and manuka stand. Smaller amounts were also found under the kahikatea stand. Treatment of this pest plant will be difficult as it is a vine and at times grows on native plants.

Royal fern, arum lily, Japanese honeysuckle and many pest plants all do well in disturbed sites so digging as a method of weed control is best kept to a minimum.

The optimal time for pest plant control would be after water levels are increased and post aerial operations, to target weeds when they are most stressed. Control operations are usually targeted at a time of year, usually spring or summer, when the plant is actively growing but before it flowers or sets seed. Skilfully targeted application of herbicide, appropriate timing and diligent follow up work are required to successfully control or eradicate pest plants most effectively.

4.3.4 Wetland enhancement

The Lake Mangahia wetland was sharply defined by drains and fences. Environment Waikato asked NIWA to consider setback distances for fencing to enhance the wetland. Based on wetland vegetation patterns, the ecological set back distances recommended for fence lines range from 0 m (current fence line) up to approximately 150 m and include the small Waipa District Council reserve that the Council requested to have incorporated in the wetland margin fencing (Fig. 18). Figures 19a to 19f illustrate former wetland areas now identified by damp peat soils and marginal wetland species. The set back distances could be increased further, by 20 m – 50 m, should a terrestrial vegetation buffer be desired between wetland vegetation and paddock margins.

Figure 18: Aerial photograph (Environment Waikato) with Lake Mangahia surrounded by current wetland forest margins then farmland. The proposed fence line (orange) is based on the ecological wetland margin and also includes the Waipa District Council reserve (green).

Figure 19a: Lake Mangahia north western area. Pasture in the foreground is flanked by a sward of rushes, then arum lilies and grey willow forest. Kahikatea forest (not associated with Lake Mangahia) in the background on the left.

Figure 19b&c: The proposed ecological wetland margin at the north and north eastern head of the lake has the largest set back area. It includes a large area of rushes interspersed with several kahikatea trees in the north (top) and damp ground covered with water pepper in the north east (bottom).

Figure 19d: Lake Mangahia eastern margin ring drain with grey willow on the lake side and water pepper on the paddock side.

Figure 19e: Lake Mangahia eastern margin drain arm. Water pepper, the lime green area midground, is surrounded by brown and dark green pasture.

Figure 19f: Lake Mangahia south western lake margin with grey willow behind the current fence line. The brown and lime green area in front of the fence was pugged pasture and water pepper, the darker green area was pasture grasses with a sharp transition to dry, brown pasture at the base of the hill.

Areas identified for replanting include: the pasture areas when fenced off, the Waipa District Council reserve area (Fig. 18), the vineland area and some of the grey willow areas.

Priority should be given to the north end of the lake as it offers an opportunity to support and expand the existing kahikatea and manuka stands and to replace the exotic vineland area with native wetland species.

Species recommended for planting fall into two categories:

- nurse species that are tolerant of open conditions, provide quick cover to reduce weed invasion, retain soil moisture and provide shade and shelter; and
- canopy species that are shade tolerant and require protection from exposed conditions.

Recommended nurse species include manuka, pukio, swamp coprosma, flax and cabbage tree for the fenced open pasture areas and the vineland once initial weed control work has been successful. Swamp coprosma and pukio should be planted more towards the lake margins, manuka throughout, with localised plantings of flax and cabbage tree. To prevent rapid recolonisation of the vineland area with weeds a dense planting of the nurse species manuka at one meter intervals or less is recommended.

Sedges, rushes and other native understorey species will largely colonise the lake margins naturally as a considerable population of these species already exists.

Assessment of natural regeneration should be undertaken one year after aerial treatment of willow. Manuka, kahikatea and swamp coprosma may be planted under dead grey willow if natural regeneration has not occurred, along with smaller numbers of flax and cabbage tree. Ideally, kahikatea should be planted to expand the area where stands occur. Consideration should be given to the placement of any new kahikatea stands to keep lake views for existing houses.

It is recommended that any vegetation planted is ecosourced, i.e. grown from local seed, ideally seed would be collected from plants at Lake Mangahia.

Planting is best carried out April to September when soils are moist and rainfall is high to ensure optimal survival of plants. Planting of nurse species in retired open pasture areas and the Waipa District Council reserve may commence once fencing is complete and initial pasture control undertaken. Planting of nurse species in the vineland may start once pest plants are under control. Regular and rigorous follow up in this area is essential as vines are particularly fast growing and will rapidly smother native plantings.

Planting of shade tolerant species under dead grey willow may commence once surveillance and evaluation of natural regeneration has been undertaken one year after the aerial treatment of willows. Planting should not occur in close proximity to grey willow that require follow up treatment.

New plantings will require follow up control of pasture plants and pest plants to aid their survival. Pasture plants provide some benefits such as the prevention of soil loss and retention of soil moisture but it is important to keep them below the height of planted natives to reduce smothering and competition. Once native vegetation cover is established, the native plants will shade out the pasture plants.

Pest plants are usually quick to establish and grow, particularly in recently disturbed areas. Multiple treatments and rigorous follow up is required to prevent native vegetation being out competed and smothered. Pest plants that require light to survive will be less vigorous or outcompeted once a canopy is established. Other pest plants, such as Chinese privet and royal fern, tolerate shade and will require ongoing maintenance.

5. Lake water quality

5.1 Lake water quality methods

Water quality has been monitored periodically by Environment Waikato since the early 1980's. There was an initial period of weekly sampling in January and February 1982, a period of irregular measurements (2-3 per year) from 1988-1991, a more intensive period of monthly sampling from late 1992-mid 1994 and a final period of four summer time measurements in 2006-2007. All sampling from 1988 was conducted at a site in the lake centre. Two different sites (northwest and southeast) were sampled in 1982.

Water quality data provided by Environment Waikato for the period 1982 to 2007 were de-seasonalised and evaluated using the trophic level monitoring method developed by Burns et al. (2000) which looks to identify trends over time and categorises nutrient status. The chlorophyll *a*, secchi depth, total nitrogen (TN) and total phosphorus (TP) de-seasonalised data and residual values were plotted against time to detect any significant time trends following Burns et al. (2000).

5.2 Lake water quality results

5.2.1 Key parameters

Chlorophyll *a*, secchi depth and TN do not show any significant time trends (Fig. 20). Only TP shows a significant (p<0.05) time trend with concentrations increasing by 0.017 g P m^{-3} y^{-1} since the early 1980's. Chlorophyll *a* concentrations increased at a rate of 0.001 mg chl*a* m^{-3} y^{-1}, but the trend is not significant at the 95% confidence level (p<0.05).

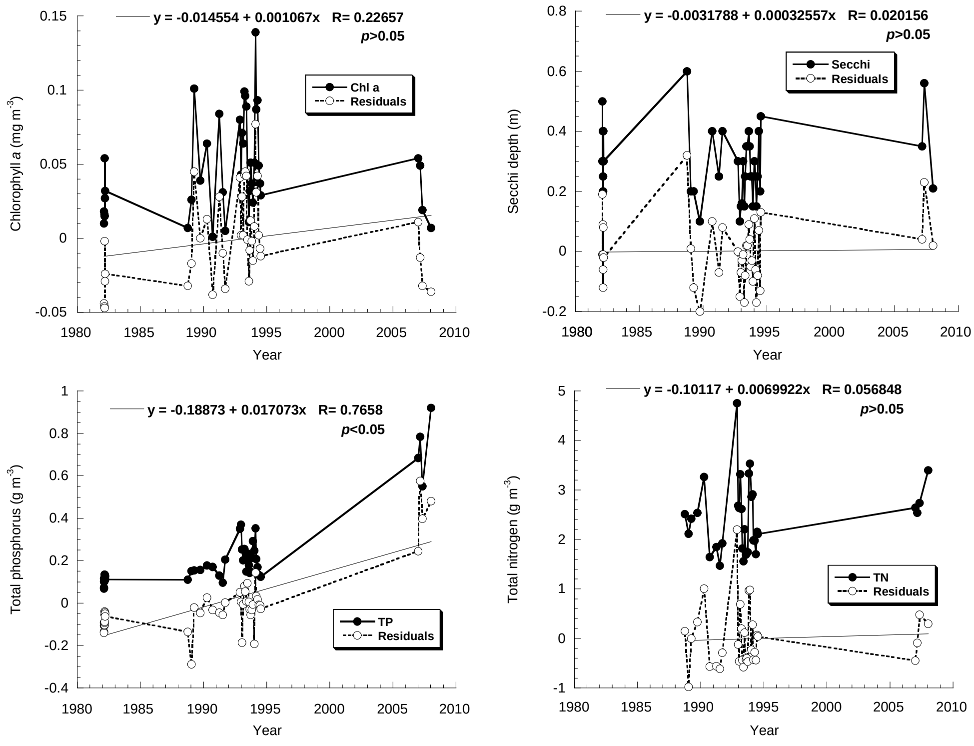

Figure 20: Time trends for key Lake Mangahia water quality parameters (chlorophyll *a*, secchi depth, total phosphorus and total nitrogen) with data de-seasonalised and linear regression of residuals calculated according to Burns et al. (2000). Significant time trends are indicated by $p<0.05$ (95% confidence level). TN = TKN (Total Kjeldahl N = Organic N + NH4) + nitrate.

5.2.2 Lake trophic status

The annual trophic level index (TLI) and trophic classification has been calculated using the procedure outlined in Burns et al. (2000) (Table 3). TLI data indicate a possible increase in lake trophic status from 1982 to 2007; however only Years 1992-93 and 1993-94 have sufficient monitoring data (collected at least once per season) to calculate a robust TLI index. The individual TL parameters (i.e., TLc, TLs, TLp and TLn) and annual average concentrations (Table 4), suggests that increased nutrient concentrations, in particular TP, may be responsible for the rising trophic level of the lake within the last decade.

Table 3: Annual TL, TLI values and trophic classifications for Lake Mangahia.

Period [a]	TLc	TLs	TLp	TLn	Min n [b]	TLI	SE TLI [c]	Classification
Sep81-Aug82	5.75	6.18	6.17	nd [d]	0	6.03	0.14	Hypertrophic
Sep88-Aug89	6.38	6.37	6.51	nd [d]	0	6.42	0.05	Hypertrophic
Sep89-Aug1990	6.06	5.99	6.76	6.57	1	6.35	0.19	Hypertrophic
Sep90-Aug91	6.29	6.23	6.52	6.15	3	6.30	0.08	Hypertrophic
Sep92-Aug93	**6.77**	**6.44**	**7.09**	**6.58**	**11**	**6.72**	**0.14**	**Hypertrophic**
Sep93-Aug94	**6.75**	**6.40**	**6.98**	**6.62**	**9**	**6.69**	**0.12**	**Hypertrophic**
Sep06-Aug07	6.31	5.87	8.48	6.69	2	6.83	0.57	Hypertrophic
Sep07-Aug08	4.33	6.63	8.87	7.02	1	6.71	0.93	Hypertrophic

[a] standard lake year (runs September to August)
[b] minimum no. of samples that any TL value comprising the TLI index calculated from.
[c] standard error of the TLI
[d] nd; no data available

Table 4: Annual average values for components of the TLI index in Lake Mangahia; chlorophyll *a* (Chl*a*), secchi depth (Sec), total phosphorus (TP) and total nitrogen (TN).

Period [a]	Chla (mg m^{-3})			Sec (m)			TP (g m^{-3})			TN (g m^{-3})		
	Av [b]	SD	n	Av	SD	n	Av	SD	n	Av	SD	n
Sep81-Aug82	25	15	7	0.33	0.10	14	0.109	0.020	13	nd [c]	nd [c]	nd [c]
Sep88-Aug89	43	41	4	0.28	0.22	4	0.143	0.022	4	nd [c]	nd [c]	nd [c]
Sep89-Aug90	33	45	2	0.40	nd [c]	1	0.174	0.004	2	2.415	0.535	6
Sep90-Aug91	40	40	3	0.32	0.08	3	0.144	0.056	3	1.748	0.244	3
Sep92-Aug93	62	28	11	0.26	0.10	11	0.226	0.078	11	2.431	0.950	11
Sep93-Aug94	61	38	9	0.27	0.10	9	0.208	0.079	9	2.507	0.661	9
Sep06-Aug07	41	19	3	0.46	0.15	2	0.673	0.117	3	2.638	0.100	3
Sep07-Aug08	7	nd [c]	1	0.21	nd [c]	1	0.920	nd [c]	1	3.398	nd [c]	1

[a] standard lake year (runs September to August)
[b] Av Average; SD standard deviation; n number of samples
[c] nd; no data available

5.2.3 Bioavailable forms of N and P

Total P comprises two components, dissolved reactive phosphorus (DRP) and organic phosphorus, and total N comprises inorganic N forms (NO_3 and NH_4) and organic N. DRP, NO_3 and NH_4 are considered to be the most bioavailable forms of these nutrients. Data collected beginning in 1988 suggest that the bioavailable proportion of total P and N pools has been increasing at a rate of 1.5% and 1.7% y^{-1}, respectively

(Fig 21). However, the bioavailable proportion of both remains below 50%; 2006-08 mean 42% of TP and 34% of TN.

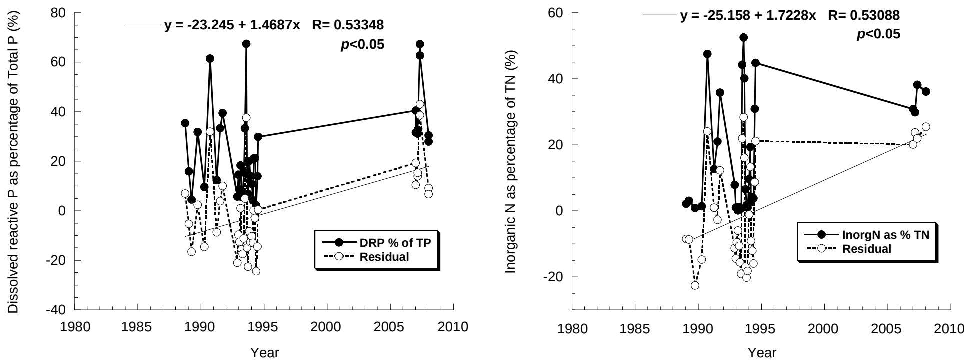

Figure 21: Time trends for bioavailable forms of N and P as a percentage of total nutrient pools. Data de-seasonalised and linear regression of residuals calculated according to Burns et al. (2000). Significant time trends are indicated by $p<0.05$ (95% confidence level). Bioavailable forms of P and N are DRP and inorganic N (NO_3 and NH_4).

5.2.4 N:P ratio

The N:P ratio shows a significant decreasing trend since 1988 of 0.4 units y^{-1} (Fig 22). Recent data suggest that the lake waters are N limited, with high levels of TP relative to TN. The Redfield N:P ratio for balanced algal growth is 7:1 (by mass) with an N:P ratio <7 indicating N limitation and a ratio >10 indicating P limitation.

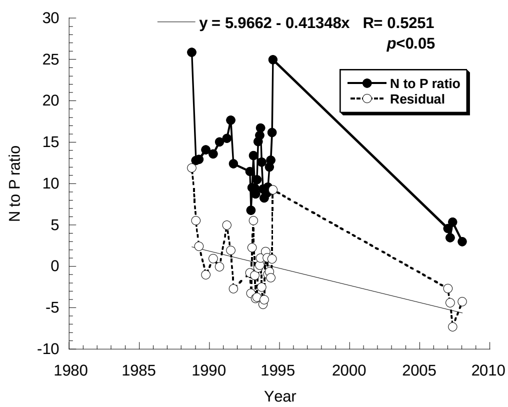

Figure 22: Time trends for N:P ratio with data de-seasonalised and linear regression of residuals calculated according to Burns et al. (2000). Significant time trends are indicated by $p<0.05$ (95% confidence level).

5.2.5 Dissolved oxygen

Dissolved oxygen measurements have been made in Lake Mangahia surface waters periodically (1982, 1988-1994) and also in bottom waters in 1982. A dissolved oxygen/temperature profile is recommended to detect lake stratification and significant deoxygenation events and to calculate the hypolimnetic volumetric oxygen depletion rate. Although the lake is shallow and may not often stratify, some deoxygenation of bottom waters was evident in the summer of 1982 (Figure 23).

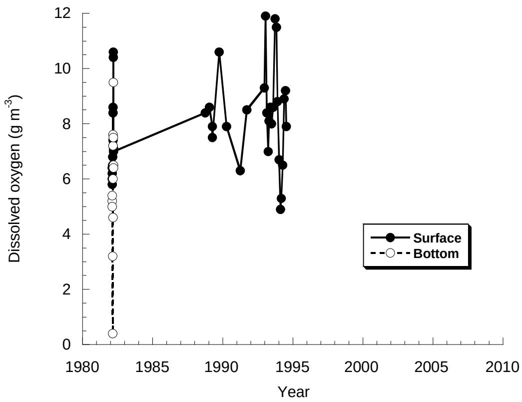

Figure 23: Dissolved oxygen readings taken in Lake Mangahia surface and bottom waters.

5.2.6 Turbidity and suspended solids

Turbidity measurements were recorded from the late 1980's to the mid 1990's and again in 2006-07. Total suspended solids were measured in 1982 and again in 2006-07 when the volatile (organic) component (VSS) was also determined. Turbidity data were deseasonalised and a significant time trend was indicated with concentrations increasing by 0.85 NTU y^{-1} since 1988 (Figure 24). However, recent data are limited and further readings are recommended to confirm this trend. A different turbidimeter was used for the later (2006-07) measurements (Hach 2100N vs. Hach 2100A) but readings should be comparable. Total suspended solids data are limited and no significant time trend is evident. The recent VSS measurements suggest that approximately half (40-60%) of the suspended matter is organic in nature.

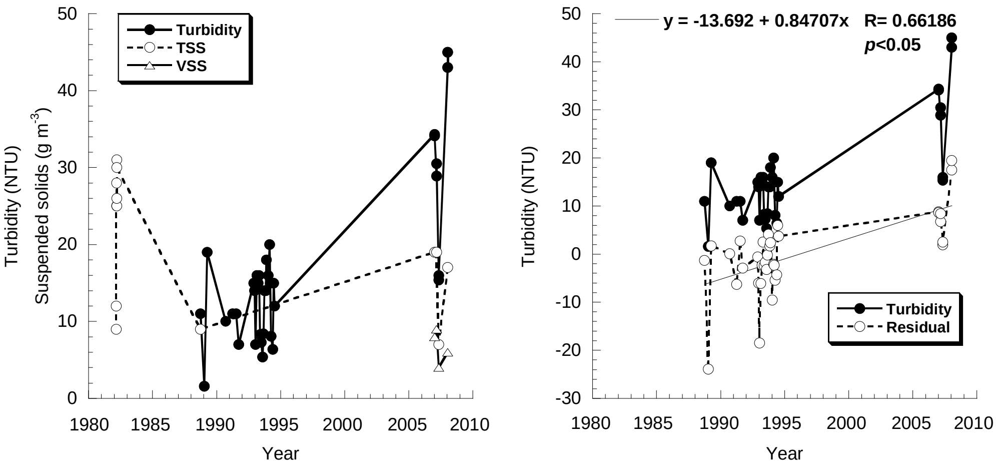

Figure 24: Turbidity and suspended solids data (left graph) and turbidity time trend (right graph) for Lake Mangahia. Turbidity data de-seasonalised and linear regression of residuals calculated according to Burns et al. (2000). A significant time trend is indicated by $p<0.05$ (95% confidence level).

5.2.7 pH

pH data have been collected periodically since 1982. However, recent data is limited. Nevertheless, a small, but significant time trend is evident for the de-seasonalised data with pH increasing by 0.03 units y^{-1} since 1982 (Figure 25).

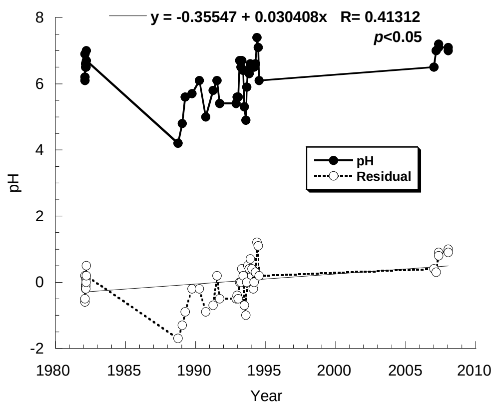

Figure 25: pH measurements for Lake Mangahia. Data de-seasonalised and linear regression of residuals calculated according to Burns et al. (2000). A small but significant time trend is indicated by $p<0.05$ (95% confidence level).

5.3 Water quality discussion

Lake Mangahia water quality appears to have declined since records began in the 1980's. Analysis indicates an increasing trophic status from the lower end to the higher end of the hypereutrophic category, increased concentrations of total phosphorus, increased turbidity, an increased proportion of bioavailable nutrients and decreased N:P ratios (indicating N limitation). However, recent data in particular are limited and further ongoing measurements collected at least seasonally are recommended to confirm these trends. A relatively comprehensive dataset collected in the 1992-1994 period provides a useful baseline against which to compare any future data.

Increased concentrations of bioavailable nutrients and total phosphorus within a lake would be expected to stimulate algal growth and cause an associated decrease in water clarity (measured as secchi depth, turbidity and/or suspended solids). Although Lake Mangahia turbidity shows a significant increasing time trend, secchi depth is apparently unchanged and the increasing trend in chlorophyll *a* concentrations (i.e., algal biomass) is not statistically significant. A possible explanation is that algal growth is somewhat limited by the lower levels of N relative to P although the actual concentrations of both nutrients are high and not at growth limiting levels. Increasing turbidity in the lake may be attributable to increased concentrations of fine silt and other suspended solids in catchment runoff. However, declining water clarity as a result of algal or silt contamination should be reflected in both turbidity and secchi depth data. The lack of consistency between these two parameters in the analysis may be due to the relatively limited dataset for these parameters over the study period.

Increased nutrient concentrations within the lake are likely derived from activities in the predominantly agricultural catchment such as increased fertiliser application and increased stocking rates. These activities inevitably lead to higher concentrations of nutrients leached from the land into shallow groundwater aquifers and drains which then flow into the lake. Although it is the lake P concentrations that are showing a significant increasing trend, the low N:P ratios suggest that lake algal biomass could be most sensitive to any increase in N concentrations. Consequently, inputs to the lake of both N and P nutrients should be minimised where possible.

5.4 Nutrient delivery pathways

To date no detailed investigation of nutrient delivery pathways (i.e., groundwater vs drains) to Lake Mangahia has been undertaken. However, as with other Waikato peat lakes, such as the Lake Serpentine complex (Sukias et al. 2006), drains are likely to be a significant source of water and thus sediment and nutrient delivery to Lake Mangahia.

The existing drainage system comprises of a series of interconnecting drains that de-water surrounding paddocks and culminate into four main inflows which discharge water, nutrients and sediments directly into Lake Mangahia (Fig. 26). The largest of these drains was located at the northern end of the lake and was maintained clear of vegetation. The three remaining inflow drains had no water present, were maintained clear of vegetation in the paddock areas but contained wetland plants from the fence/willow margin to the lake edge which would aid nutrient and sediment removal.

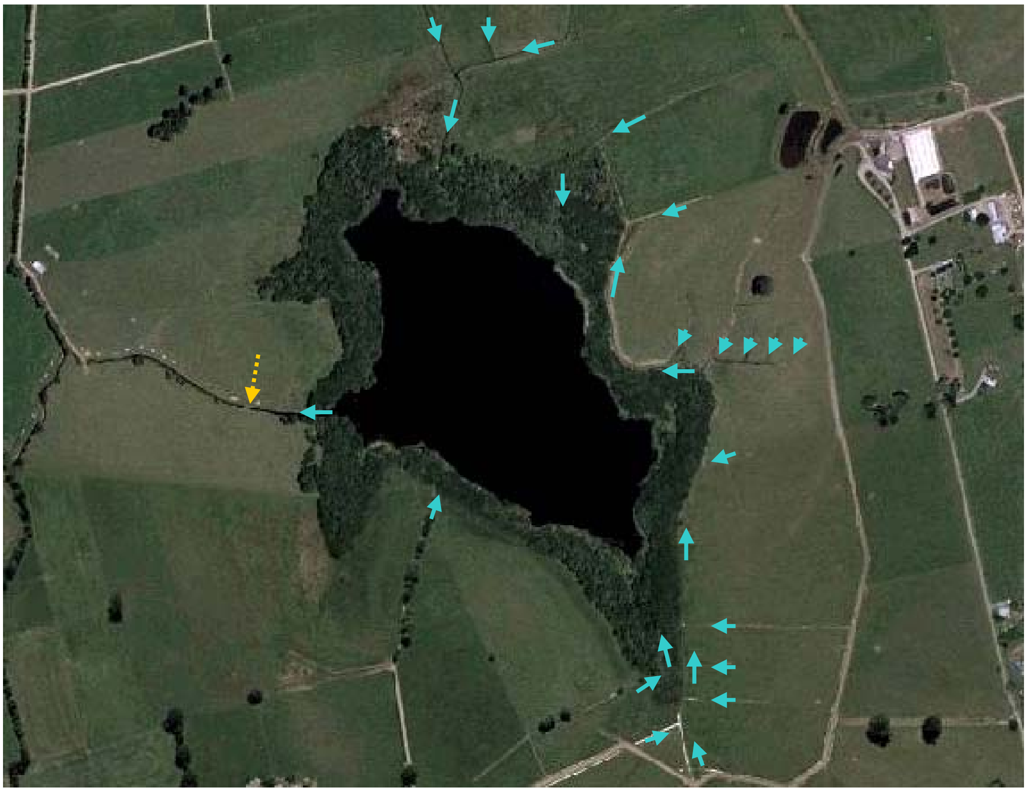

Figure 26: Aerial photograph (Environment Waikato) of Lake Mangahia. Aqua arrows indicate the water flow directions of drains, inflows and one outflow. The weir location is shown by the yellow dashed arrow.

During the site visit in February 2008 the northern drain was 1.13 m deep with 0.38 m depth of water, and the only drain to contain water at this time. This drain de-waters not only the paddocks immediately surrounding Lake Mangahia but also extends in a northwest direction towards the Rukuhia Peat Bog to draw on a large area of the catchment (Fig 1). The absence of vegetation in the northern drain and its direct flow into Lake Mangahia currently short circuits any potential nutrient removal by the existing wetland margin of the lake.

5.5 Nutrient removal options

Sukias et al. (2006) provided a list of fourteen nutrient mitigation options for the Lake Serpentine complex. This list has been modified for Lake Mangahia and expanded to include management options and relative costs (Appendix 3).

Given the necessity for the many drains in the catchment it is assumed that catchment soils are not free-draining and that surface drain flows represent the most likely route for nutrient delivery to the lake, particularly following any significant rainfall events. Overland flow might also be a significant route during very high rainfall events if soil and/or drain capacity is overwhelmed. Therefore, the recommended nutrient removal strategies below focus on these primary delivery routes as priority areas for action. Secondary nutrient removal options from Appendix 3, such as farm nutrient budgets, could also be used as complimentary measures.

5.5.1 Infiltration filter

An experimental system, know as an infiltration filter, for treatment of farm drainage water prior to lake entry has been developed by NIWA with funding from the Department of Conservation at Lake Serpentine. At this latter site, the methodology involves the diversion of existing drains which entered that lake into an infiltration filter of 278m^2. Water then passes as subsurface or overland flows through a buffer zone of wetland plants before entry to the lake. This system is based on a constructed wetland vegetation buffer with the addition of a settling basin. Further details on this treatment system are available from Amy MacDonald at the Department of Conservation Hamilton office (refer to Sukias et al. (2006) client report).

A system similar to that proposed for Lake Serpentine could be used at Lake Mangahia, modified to include an additional treatment step of a woodchip area (Fig. 27). Under this revised system water from existing drains would initially be diverted into a settling basin, such as a large tank or settling pond, to remove suspended solids. Water would then flow into a woodchip area, an additional treatment step from the Lake Serpentine system that allows denitrification to occur. Both the settling basin and the woodchip area would remove organic forms of nitrogen and phosphorus.

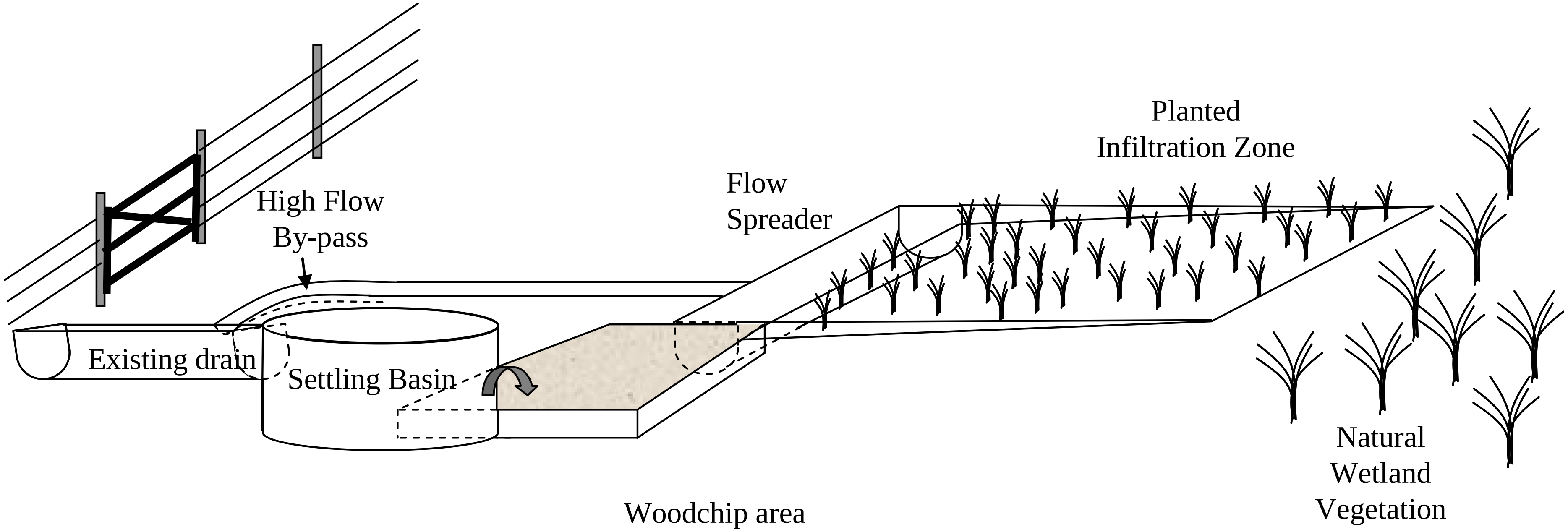

Figure 27: Infiltration system based on Lake Serpentine (Sukias et al., 2006) modified to include a woodchip area.

From the woodchip area, water then enters the infiltration filter which comprises a channel several metres wide. The wedge-shaped channel is approximately 1 m deep, with the deepest end furtherest away from the lake. Bamboo spike sedge planted in the infiltration filter, would remove bioavailable forms of nitrogen and phosphorus. Water would then move through the soils, root zone and plants of the wetland allowing further removal of nutrients before finally entering the lake.

The complete infiltration filter system would be best located at the north end of the lake (Fig. 28, not to scale). The next best location would be to divert water to the east margin ring drain, locate the infiltration filter in the adjacent paddock and inundate the vineland area before water enters the lake.

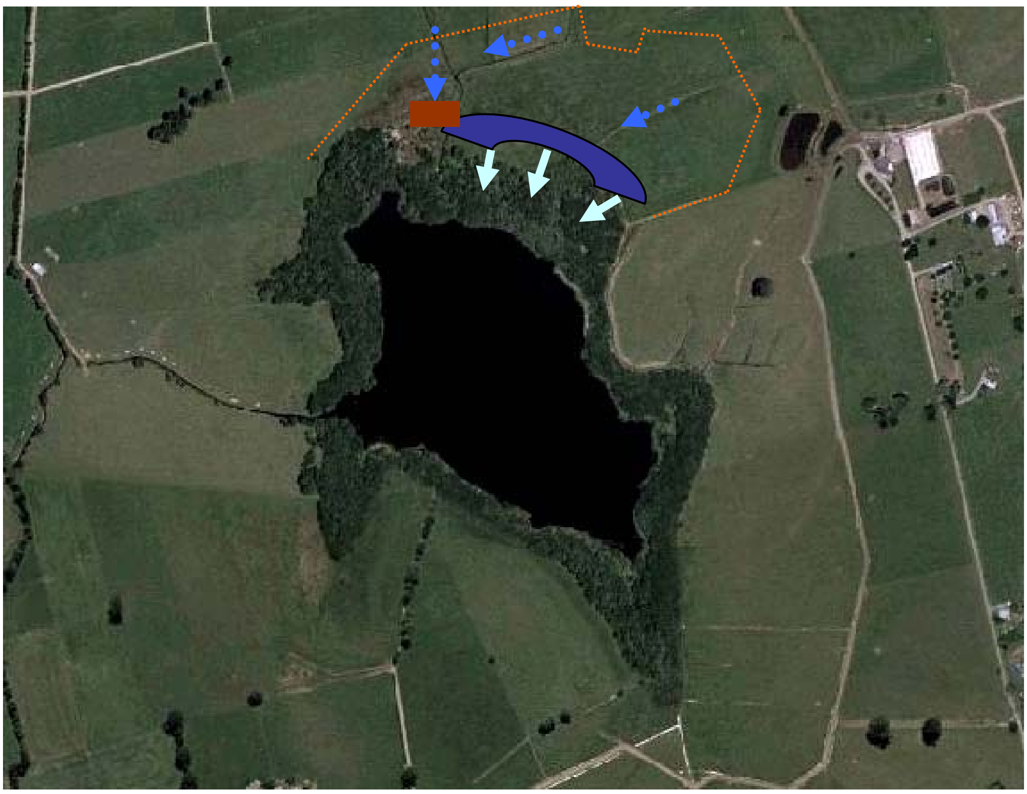

Figure 28: Aerial photograph (Environment Waikato) showing the location of the potential fence line (orange dotted line), inflow of drain water (blue dotted arrow), woodchip area (brown square), infiltration filter system (solid blue arch, not to scale) and dispersion of filtered water (blue solid arrow) into Lake Mangahia.

Land area required for modified infiltration filter treatment

The land area calculations for the complete infiltration filter system have two parts: the woodchip area, and the infiltration filter.

The use of the woodchip treatment is a new development that removes more nitrogen and occupies less area than a constructed wetland built to perform the same function. An area approximately 0.13 ha (126 m long, 10 m wide and 1 m deep) would be required for the woodchip area to remove more than 80% TN. Mean residence time for water in the woodchip treatment area in this system would be just under 3 hours. By comparison, approximately 30% of nitrate is removed by a constructed wetland, where the wetland occupies of 1% of the drainage area, although 3% is considered optimal. In the case of Lake Mangahia, with a catchment area of 357 ha, a constructed wetland of 3.6 ha minimum (1% drainage area) or 10.7 ha optimal (3% drainage area) would be required to remove 30% of the nitrate (McKergow et al. 2007).

Calculations for the woodchip area were based on the amount of TN in the lake for 2007 from EW monitoring data, measured rates of woodchip removal of nitrogen as nitrate (unpublished data, Sukias), and the following assumptions: (1) 75% of the total lake catchment drains into the north drain (2) no nutrient removal occurs in the drain prior to reaching the filter system, (3) 6.3 ha of catchment = 1 L/s water based on Lake Serpentine (Sukias et al. 2006) and (4) the concentrations of TN in the lake is the same as in the north drain.

The minimum area required for the infiltration filter to treat the mean inflow is approximately 0.7 ha, based on the assumptions above and the calculations developed by Sukias et al. (2006). The wedge-shaped infiltration filter would have a depth increasing from 0 m on the lake side to 1 m on the paddock side. The length to width ratio is about 3:1, that is 150 m long by 47 m wide, to enable sufficient contact between the drain water and the roots, soil and plants before entry to Lake Mangahia. The mean residence time for water in the infiltration filter would be just under a day.

The total area required for the complete infiltration filter system is 0.83 ha. Mean residence time for water to pass through the complete system would be approximately one day.

Construction

The complete infiltration filter system should be constructed in late spring or early summer when the ground is firm enough for specialist heavy machinery. Planting of the treatment system with bamboo spike sedge should occur as soon as possible after construction and before autumn conditions suppress plant growth. Initially there may be insufficient water available to fill the treatment system and support the wetland plants. If this is the case, lake water may be pumped into the treatment area.

Standing dead grey willows, post the aerial treatment, could be selectively removed and chipped on site to fill the woodchip treatment area. Care would need to be exercised in their removal to minimise damage to native vegetation.

Indicative costs for construction of the complete infiltration filter system, based on Sukias et al. (2006) and on commercial rates as if done by a contractor, are approximately $200,000 for a system of 0.83 ha. The cost of construction can be reduced significantly through volunteer labour, growing plants onsite and the use of onsite machinery. In comparison, the cost of a constructed wetland is approximately $200,000 occupying 3.6 ha based on estimates by McKergow et al. (2007).

It is anticipated that the performance of the woodchip area would gradually decline over time however, the life span is unknown. The performance of one woodchip filter area is still going well after 5 years (J. Sukias, pers. comm.). Maintenance costs for the constructed wetland are estimated at $9,000 per annum based on McKergow et al. (2007).

The anticipated benefits of the complete infiltration filter system would be similar to that of a constructed wetland in a smaller area. The system would remove at least 80% nitrogen, 60-80% phosphorus, reduce suspended sediments and reduce *E. coli* from the main drain into the lake (Sukias et al., 2006; McKergow et al., 2007). These reductions would slow down decline in lake water quality and reduce the rate of sediment infilling. In future they have the potential to improve lake water quality and maintain wetland vigour.

The above estimates of area, cost and performance are purely a conceptual study for Lake Mangahia based on the Lake Serpentine experimental infiltration filter. Further information is required to refine calculations for Lake Mangahia including the flow and sources of water to the lake, the nutrient levels in the main drain and the volume of settleable particulate matter in the main drain. Upscaling of the experimental infiltration filter from 278 m^2 at Lake Serpentine to the approximately 8,300 m^2 required for Lake Mangahia is a large step.

5.5.2 Vegetation buffers

The existing vegetation buffer that encircles the lake is likely to intercept a proportion of the shallow groundwater seepage from the catchment, encouraging permanent removal of a proportion of the N nutrients (as NO_3) by the denitrification process but also temporarily sequestering both N and P nutrients into plant biomass. Increasing the proportion of catchment runoff (i.e., drain flow and shallow groundwater) that passes slowly through lake edge buffer zones and interacts with these soils and the root zone of the vegetation is considered likely to enhance permanent removal and sequestration of nutrients, with lesser quantities then entering the lake waters.

Extending the buffer zone where possible to include adjacent wet pasture areas, excluding stock from the buffer zone, and dispersion of drain flow through the buffer zone (e.g., in natural or constructed wetland areas) are suggested as ways to enhance nutrient removal.

6. Fish, submerged vegetation and birds

While the scope of this work did not cover fish in Lake Mangahia, a large koi carp and gambusia were seen in the lake during the February 2008 site visit (Figure 29).

Figure 29: A koi carp in Lake Mangahia, February 2008.

There were no records of fish for Lake Mangahia in the Freshwater Biodata Information System (FBIS) database which holds fish data collected since 1920, but two fish species were recorded downstream of the outlet in Mangahia Stream; the native black mud fish (*Neochanna diversus*) and the pest fish gambusia (*Gambusia affinis*). Eels were recorded as present in the lake by Chapman & Boubee (1977) with notes of recreational eeling (Waikato Valley Authority, 1985).

Submerged vegetation was not present in Lake Mangahia in 1977 (Chapman & Boubee 1977) 1992 (Champion et al. 1993) or 2005 (Edwards et al. 2007) surveys.

Waikato Valley Authority (1985) noted that large numbers and variety of water bird use of lakes was due to the nature of the wetland margin. They recorded the following birds at Lake Mangahia with their current conservation status shown in brackets (Department of Conservation, 2005); paradise shelduck (*Tadorna variegata*), shoveler (*Anas rhynchotis*), mallard duck (*A. platyrhynchos*), grey duck (*A. superciliosa*) (nationally endangered), black swan (*Cygnus atratus*), pukeko (*Porphyrio porphyrio*), spotless crake (*Porzana tabuensis*) (sparse) and bittern (*Botaurus poiciloptilus*) (nationally endangered). Thompson & Champion (1993) also recorded the presence of fernbirds (*Bowdleria punctata*).

7. Summary of recommendations and timing

Suggested timing of high priority actions are:

- grey willow aerial treatment in October or November 2008 with grey willow follow up and other high priority weeds treated around December 2008;

- weir height increased at the end of summer 2009, when lake levels are at their lowest, to facilitate construction;

- fence setback and planting could occur in winter 2009, after aerial treatment of willows and pest plants have been controlled. The priority area for action is the northern lake margin;

- construction of a nutrient removal system should occur in spring or very early summer when the ground is firm enough to hold heavy machinery, with plantings as soon as possible after construction and before autumn conditions suppress plant growth.

A summary of recommendations from this report include:

Lake water levels:

- Raise the weir outlet height by 0.5 m to 37.3 m (Moturiki Datum).

- Re-measure the height difference between the benchmark and lake water level.

Vegetation:

- Control / eradicate pest plants of high priority (grey willow, royal fern, Japanese honeysuckle, arum lily, Chinese privet) and medium priority (blackberry, gorse, pampas, Himalayan honeysuckle, Mercer grass) with follow up weed control as required.

- Exclude aerial treatment of grey willow in zones identified, including areas with low canopy cover or other desirable canopy trees, and use ground based control techniques, such as drill and inject.

- Monitor vegetation 3-4 months after the grey willow aerial treatment and again a year later to measure success of aerial spraying, non-target damage and recovery of native species.

- Repeat vegetation monitoring annually along the five transect lines to measure the success of ground based weed control.

- Move fences to the proposed set back distances with priority given to the wetland area at the northern end of the lake.

- Plant identified areas with recommended species, with priority given to the wetland area at the northern end of the lake, then the narrow vegetation margins.

- Assess natural regeneration before planting canopy species under grey willow.

Lake water quality and nutrient removal:

- Quantify nutrient inflows and water volume of inflows, particularly in the northern drain, to enable targeted removal of nutrients to the lake.

- Undertake nutrient removal for inflowing waters using one or more options identified in this report.

- Confirm water quality trends by undertaking three monthly monitoring of lake water quality parameters.

- Ensure other minor drains do not feed directly into the lake but run parallel to the lake with the provision for treatment of water by wetland vegetation.

- Undertake a dissolved oxygen/temperature profile to detect lake stratification and significant deoxygenation events and to calculate the hypolimnetic volumetric oxygen depletion rate.

Appendix 1: Wetland plant species list for Lake Mangahia.

Species	Common name
**Agrostis gigantea*	redtop
**Agrostis stolonifera*	creeping bent
Asplenium flaccidum	drooping spleenwort
Baumea arthrophylla	
Baumea articulata	jointed twig rush
Baumea rubiginosa	
Baumea teretifolia	pakihi sedge
**Bidens frondosa*	beggar's tick
Blechnum novaezelandiae	kiokio
Calystegia sepium	bindweed
Carex lessoniana	rautahi
Carex secta	pukio
Carex virgata	
Centella uniflora	
Coprosma tenuicaulis	swamp coprosma
Cordyline australis	cabbage tree
**Cortaderia selloana*	pampas grass
Dacrycarpus dacrydioides	kahikatea
Dianella nigra	NZ blueberry
Dicksonia squarrosa	wheki
Eleocharis acuta	sharp spike sedge
Eleocharis gracilis	slender spike sedge
Eleocharis sphacelata	bamboo spike sedge
**Erechtites hieraciifolia*	American fireweed
**Galium palustre*	marsh bedstraw
Gleichenia dicarpa	tangle fern

Species	Common name
Gleichenia microphylla	parasol fern
Gonocarpus micranthus	
Histiopteris incisa	water fern
**Holcus lanatus*	Yorkshire fog
Hydrocotyle pterocarpa	
Hypolepis ambigua	
Hypolepis distans	
Isachne globosa	swamp millet
Isolepis distigmatosa	
**Juncus acuminatus*	
**Juncus effusus*	soft rush
Juncus pauciflorus	leafless rush
Leptospermum scoparium	manuka
**Leycesteria formosa*	Himalayan honeysuckle
**Ligustrum sinense*	Chinese privet
**Loniceria japonica*	Japanese honeysuckle
**Lotus pedunculatus*	lotus
**Ludwigia palustris*	water purslane
**Ludwigia peploides*	water primrose
**Lycopus europaeus*	gypsywort
Microsorum pustulatum	hounds tongue
Muehlenbeckia australis	pohuehue
Myriophyllum propinquum	common water milfoil
Nertera scapanioides	
**Osmunda regalis*	royal fern
**Paspalum disticum*	Mercer grass
Persicaria decipiens	swamp willow weed
**Persicaria hydropiper*	water pepper

Species	Common name
Phormium tenax	harakeke
**Phytolacca octandra*	inkweed
Pteridium esculentum	bracken
Pyrrosia eleagnifolia	leather-leaf fern
**Ranunculus flammula*	spearwort
**Rubus fruticosus agg.*	blackberry
**Salix cineria*	grey willow
Schoenus maschalinus	dwarf bog rush
**Senecio bipinnatisectus*	Australian fireweed
**Senecio jacobaea*	ragwort
Sphagnum cristatum	sphagnum
Typha orientalis	raupo
**Ulex europaeus*	gorse
**Zantedeschia aethiopica*	arum lily

* denotes introduced species.

Appendix 2: Prioritised pest plant species list for Lake Mangahia.

Species	Common
High priority wetland weeds	
**Ligustrum sinense*	Chinese privet
**Lonicera japonica*	Japanese honeysuckle
**Osmunda regalis*	royal fern
**Salix cinerea*	grey willow
**Zantedeschia aethiopica* cv. Green goddess	arum lily

Medium priority dry margin weeds	
**Cortaderia selloana*	pampas grass
**Leycesteria formosa*	Himalayan honeysuckle
**Rubus fruticosus agg.*	blackberry
**Ulex europaeus*	gorse
**Paspalum distichum*	Mercer grass
Low priority wetland weeds	
**Juncus acuminatus*	
**Juncus effusus*	soft rush
**Ludwigia palustris*	water purslane
**Ludwigia peploides*	water primrose
**Lycopus europaeus*	gypsywort
**Persicaria hydropiper*	
Other pasture & wetland weeds	
**Agrostis stolonifera*	creeping bent
**Agrostis gigantea*	redtop
**Bidens frondosa*	beggar's tick
**Erechtites hieraciifolia*	American fireweed
**Galium palustre*	marsh bedstraw
**Holcus lanatus*	
**Lotus pedunculatus*	lotus
**Phytolacca octandra*	inkweed
**Ranunculus flammula*	spearwort
**Senecio bipinnatisectus*	Australian fireweed
**Senecio jacobaea*	ragwort

* denotes introduced species.

Appendix 3: Possible nutrient removal options and management actions for Lake Mangahia based on Sukias et al. (2006).

Option	Description	Benefits	Relative cost
A	Land acquisition & retirement	A lesser quantity of nutrients applied within the catchment	Very high
B	Land acquisition to extend riparian buffer zones	Nutrient removal potential via riparian plant uptake and microbial denitrification increased	Varies depending on desired buffer width [a]
C	Drain level control structures	Agricultural production enhanced via water table management, assists preservation of peat soils, direct flows to lake reduced, infiltration of standing water and percolation through riparian buffer zones enhanced	Low
D	Margin buffer strips (1 m+) for drains	Reduces proximity of dung and urine patches to drains, potential trap for sediment in overland flow, and vegetation at buffer strip edges may still be grazed.	Low
E	Intercept (bypass) drain	High flows (and associated nutrients and sediments) following large rainfall events bypass the lake, discharging directly into the lake outlet.	Moderate (requires drain to be constructed between main inflow drain and outlet)
F	Drain end infiltration filters (2-5% catchment area) [b]	Nutrient removal increased via infiltration, microbial denitrification (and plant uptake if vegetation present).	Low to moderate (depends on number constructed and size)
G	Use of artificial treatment materials in filters & intercept drains (e.g., zeolite, modified zeolite, woodchips)	Nutrient removal via infiltration filters and intercept drains further enhanced. Zeolite absorbs NH4+ and PO43- while woodchips encourage NO3- removal via microbial denitrification	Low to moderate (depends on number of filters & intercept drains constructed and size)
H	Constructed treatment wetlands (2-5% catchment area) [b]	Nutrient removal increased via wetland plant uptake and denitrification	Moderate to high (requires information on drainage flows and nutrient concentrations)
I	Existing riparian vegetation cover increased	Enhanced overland flow infiltration, reduced flow channelization, enhanced nutrient removal via plant uptake, additional plant carbon to encourage microbial denitrification	Low

Option	Description	Benefits	Relative cost
J	Lake water level management to enhance wetland plant community development and protect peat deposits [c]	Enhanced nutrient removal via plant uptake, additional plant carbon to encourage microbial denitrification	Low to moderate
K	Channelling significant overland flows from prone areas to settlement ponds or drain filters	Nutrient removal increased via infiltration, microbial denitrification (and plant uptake if vegetation present).	Moderate, would require construction of further drains
L	Agri-business consultant to prepare a 'Farm Environmental Plan' and 'Nutrient Budget' for the main landholders	Minimise nutrient application within the catchment yet maintain farm productivity	Low to moderate
M	Incentives for farmers to use slow-release fertilisers (e.g., reactive phosphate rock instead of superphosphate) if agri-business consultant deems feasible	Reduces the risk that flushes of nutrients migrate to drains and groundwater	Low
N	Use of urease or nitrification inhibitors if agri-business consultant deems feasible	Reduces the risk that flushes of nutrients migrate to drains and groundwater	Low
O	Main landholders to adopt "best management practices" [d]	Predicted reductions in the N and P loadings to the lake (8% for N, 35% for P)	Low
P	Main landholders to adopt "optimal management practices" [e]	Predicted reductions in the N and P loadings to the lake (43% for N, 55% for P) [c]	Low

[a] a 50 m buffer width recommended by Thompson and Champion (1993) for peat lakes.
[b] based on size of constructed treatment wetlands recommended to treat nitrate in dairy drainage waters (Sukias et al. 2006).
[c] 0.2 m operating range for 90% of the time as recommended by Stockdale (1995).
[d] Best management practices defined as all farm dairy effluent land applied and no N fertiliser applied in winter (but annual total fertiliser application unchanged), and the effluent block receiving no N fertiliser and reduced P fertiliser according to maintenance requirements (Jenkins and Vant 2007).
[e] In addition to above use winter management practices including a winter feed/stand off pad and nitrification inhibitors and undertake riparian management (Jenkins and Vant 2007).

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