Hydrological assessments of ten wetlands in the Wellington region and recommendations for sustainable management: a holistic approach.

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Landscape amenity values at Foremans Lagoon (cover)

Biodiversity values at Carter's Bush (above)

CONTENTS

EXECUTIVE SUMMARY

This project was conceived by staff of the Greater Wellington Regional Council (GWRC) towards the end of 2009 in order to gain a better understanding of the hydrology of key wetlands in the GWRC Wetlands Database and of the extent to which wetlands are supported or influenced by different groundwater sources – surface and subsurface.

GWRC staff identified ten significant wetlands in the Wellington region which are, or potentially soon could be, under hydrological stress and would therefore benefit from having more information about them gathered and assessed. These wetlands are considered to be generally representative of wetland systems throughout the region and they scored highly in an earlier GIS-based vulnerability assessment model conducted by the GWRC. This model assessed the proximity, depth and volume of consented groundwater takes in relation to known wetlands.

Twelve days of fieldwork were carried out during a three-week period in March - April 2010. Hydrology plays a central role in the functioning of wetlands, and the survey therefore took a holistic approach by integrating observations on hydrology and sources of groundwater, with studies of water quality, soils, stratigraphy, catchment land-use, vegetation, plant indicators and plant community ecology.

Each wetland is unique in terms of its structure and specific hydrological and chemical needs. Groundwater inputs may be point-source and diffuse surface flow, or discharges from subsurface confined and unconfined aquifers. Some wetlands receive inputs from all sources, some from only one type, and deep aquifer interaction is still speculative for four wetlands. Hydrology must be understood more thoroughly than any other parameter of wetland functioning if a wetland is to be managed sustainably. Thus, hydrology is the primary determinant of wetland class and vegetation type. Hydrology and water quality interact when low flow rates promote eutrophication processes, and when chemical signatures can be used to identify the sources of water inputs. Exotic species can often suppress the growth of natives, but fast-growing weedy species can also influence hydrology by interfering with water flow.

All of the wetlands surveyed are, to a greater or lesser extent, already, or are potentially, vulnerable to declining water supplies and increasing nutrient loads through catchment development, particularly intensifying agriculture. Wetlands are the ‘canaries of the landscape’ – they are excellent indicators of catchment health and landscape change processes, so the monitoring of wetlands for progressive changes in hydrology and water chemistry is not only essential for biodiversity management, it also provides information on overall catchment processes. Loss of wetlands is a significant threat to the wider environment.

Large wetlands, such as Carters Bush and Allen-Lowes Bush, have high habitat diversity and therefore high species diversity, but although the smaller wetlands, such as Foremans, Waingawa or Kathihiku, generally have lower plant species diversities, they still have important values as specialised biogeographical types, and they also share other important values, such as recreation, wildlife, landscape amenity, water conservation, carbon sequestration, flood mitigation and nutrient processing, with the larger wetland complexes.

1. INTRODUCTION

1.1 Project background

Little is known regarding the hydrology of most wetlands in the Wellington region and the effect of nearby water abstraction on these wetlands. Greater Wellington Regional Council (GWRC) funding has therefore been assigned to wetland hydrology monitoring to obtain hydrological information on ten significant wetlands in the Wellington region considered to be vulnerable to stress from groundwater abstraction.

This hydrological information will assist in developing policies and rules for the protection of these, and other, wetlands to ensure that suitable water allocation regimes are set up and adverse effects of consented water takes on wetlands can be better identified and managed. Gaining more information about the hydrology of, and stresses on, important representative wetlands in the region will also assist in decision-making for future hydrological monitoring of wetlands and allocation of water

1.2 Project scope & report organisation

GWRC staff identified ten significant wetlands in the Wellington region (Figure 1.1) which are, or potentially soon could be, under hydrological stress and would therefore benefit from having more information about them gathered and assessed. These wetlands are considered to be generally representative of wetland systems throughout the region and they scored highly in an earlier GIS-based vulnerability assessment model conducted by the GWRC. This model assessed the proximity, depth and volume of consented takes in relation to known wetlands. The selected wetlands were:

Wairarapa	**Kapiti Coast/Upper Hutt**
Taumata Stream	Te Hapua
Foremans Lagoon	Haruatai Park Bush
Ruamahanga Loop Complex	Otaki River South (Kathihiku)
RW Tate Reserve	
Barton's Lagoon	Mangaroa Swamp
Allen-Lowes Bush	
Waingawa Wetland	
Carters Bush	

Fieldwork was carried out on twelve days between 23 March and 22 April, 2010. The RW Tate Reserve was found to have irretrievably lost its wetland features and was deleted from the list. The Ruamahanga Loop Complex was deleted after encountering difficulty over access.

Information was sought in the following categories:

- Condition monitoring assessment including mapping of wetland types.
- Assessment of hydrological drivers including establishment of plots and completion of wetland record sheets that document such things as the location, classification, quality indicators, wildlife present, and pressures present.
- Recommendations for potential permanent hydrological monitoring (establishment of ground and surface water monitoring stations).

- Potential hydrological thresholds as per the proposed National Environmental Standard on Ecological Flows and Water Levels (Ministry for the Environment, 2008).
- Assessment of indicators of stress on the wetland such as water level modifications, undesirable species, invasive species, water abstractions, and animal access.
- Water quality sampling (for selected parameters such as nutrients, pH, dissolved oxygen, conductivity, and temperature) at a representative site(s) in the wetland to establish a baseline.

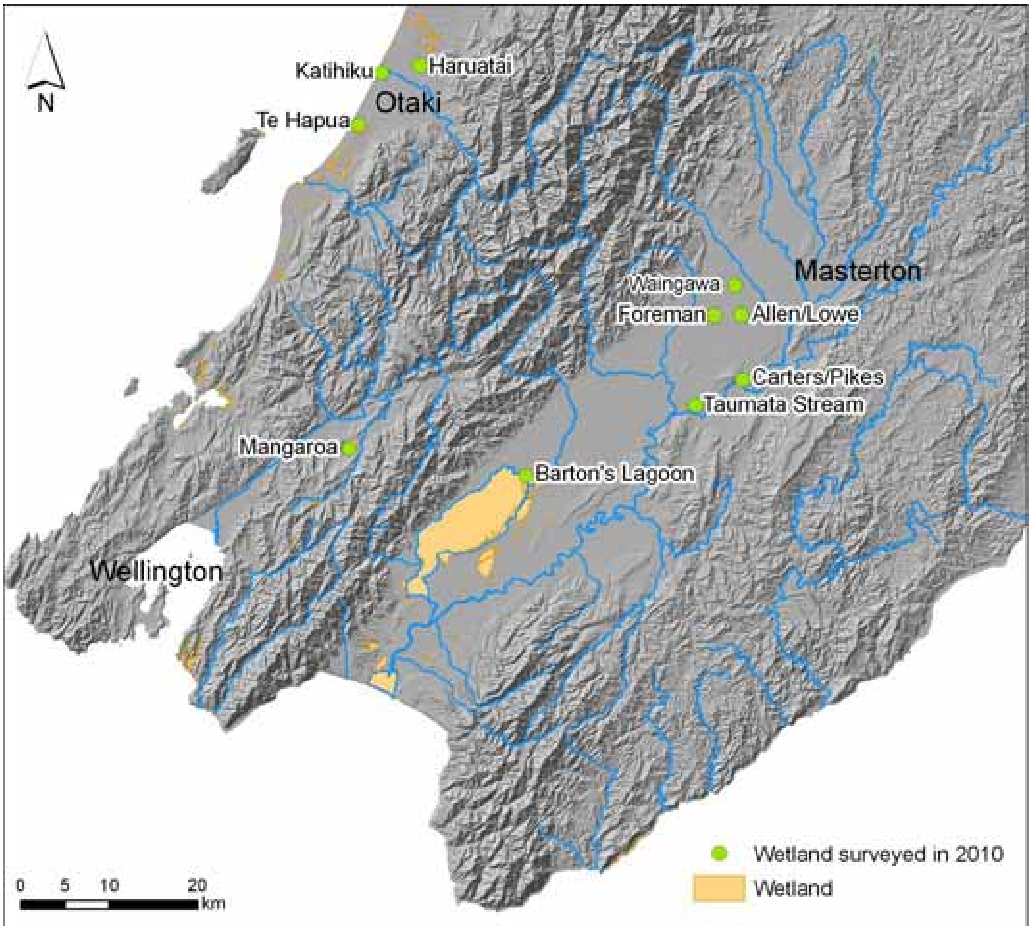


Figure 1.1: The ten wetlands studied in this report.
[Map after Tidswell *et al*, 2010]

The ten wetlands studied incorporate at least 15 distinct wetland types, ranging from oligotrophic (Waingawa Wetland) to hypertrophic (Te Hapua complex). Each wetland is described and discussed in a separate chapter, with an aerial map depicting the main features, a table of 18 water quality parameters, and lists of threats and recommendations for actions and further study. A final chapter collates the findings from individual wetland studies and prioritises future actions and suggestions for monitoring.

Scientific terms are defined in Chapter1 (wetland types, hydrodynamics, water chemistry and chemical signatures, soil types, plant indicators), 135 taxa mentioned in the text are listed in an appendix, with both scientific and vernacular names, 50 photographs characterise the wetlands studied, and there is a bibliography of 40 references.

1.3 Methodologies employed

There were some practical limitations to what could be achieved during these brief surveys and these are summarised below. Thus, for instance, time constraints did not permit completion of all sections of the wetland condition monitoring record sheets (Tables 8 & 9) of the *Handbook for Monitoring Wetland Condition* (Clarkson *et al*, 2003) during the present surveys, although all the most important issues in these record sheets are investigated in enough detail to be confident about assessments and recommendations in this report. Table 9 of the *Handbook* is included in this report as Appendix A, in order to provide a summary of the issues addressed for each wetland.

1.3.1 Vegetation survey

Each designated wetland area was surveyed to establish the different wetland types; some of these are described in more detail than others. Vegetation surveys were only aimed at characterising communities and acquiring enough familiarity to be able to assess ecological status and threats (such as aggressive exotics) and to be able to make reasonably confident management recommendations.

Where necessary, plant specimens were collected and identifications made later. Cyclostyled plant species lists were already available for two wetlands, but no community or habitat information was provided with these lists.

1.3.2 Hydrology survey

Staff from the GWRC's Environmental Monitoring and Investigations Department provided background on what was already known about groundwater flows and aquifers around the selected wetland areas. All known water sources were inspected in the field, but others could only be inferred. Rough flow gauging was carried out on a few occasions, sometimes employing an engineer's level.

1.3.3 Soil analysis

Soil type was identified and taken into account at all sites. In particular, types and depths of peats, organic soils and litter were recorded, but lake sediments were only sampled at two locations. Soil samples were not taken from every wetland, because samples are only useful when they are needed to characterise some important parameter of a wetland type or community. In most wetlands, additional soil chemical information would not have been particularly illuminating.

On a few occasions a D-section peat borer and a 10cm hand-augur were employed for examination of soil profiles or to facilitate water collection of samples for water quality analyses.

1.3.4 Plant analysis

The *Handbook for Monitoring Wetland Condition* (Clarkson, 2003) recommends that foliage samples of the dominant plant species be taken at surveyed wetlands for analysis of nutrient content (total nitrogen and total phosphorus). However, to be of value, sampling should be consistent, replicated, and part of a time-series that looks for changes, particularly trends. It was decided that no significant benefits would accrue from any plant analyses during the present survey, because too many samples would have been needed to cover the different wetland types, different species have different physiologies and chemical characteristics, and there was no proposed experimental strategy for follow-up sampling.

Foliar analysis is widely used in agriculture as a measure of nutrient availability for growth, but there are already good comparative data in the farming context and also the range of crop and pasture species which need to be sampled is very limited. In natural wetlands, there are many variables affecting leaf nutrient content: species, proximity of sample to growing point, time of year, etc. Phosphorus, for instance, is usually mobilised seasonally or at a particular stage in a plant's growth; some plants are very effective at internally recycling nitrogen from old tissues to new (many rhizomatous species, for instance). Interpreting tissue analysis is a specialised technique and probably not useful in the present, more general, study.

1.3.5 Water quality analysis

Between one and three locations at each wetland were sampled for water chemistry analyses. The need for more extensive and intensive sampling at some sites is discussed in later chapters, but time did not permit this during the present study.

Samples were collected (filtered or unfiltered, as appropriate) in sterilised containers (glass or plastic, as appropriate), stored in chillybins with ice and despatched same day by courier to Hill Laboratories for analysis. Details of field sampling and laboratory analyses are given in Appendix C and D.

pH and conductivity (EC) were also determined in the field, as both of these measures can change during storage, due to continued biological and chemical activity in the sample containers..

Oxygen concentrations were not determined (except at Taumata, Ch. 9), because they are only useful in shallow water wetlands and, even then, only when more detailed surveys are being carried out than the present one. Other features, such as algal and water fern growths, water colour and sediment type, water temperature and flow rate, were adequate to characterise waters for the present study.

1.4 Wetlands structure

The term 'wetland' means different things to different people, so management is only possible if precise descriptions are available. Most wetlands incorporate more than one wetland type, often more than one class, and each variant has different management requisites.

1.4.1 Wetland definition

Wetlands are defined primarily by their **hydrosystems**, which take into account both the landform setting and the water regime (source, level, fluctuation, flow, chemistry, temperature, etc). There are many different types of hydrosystem, so the definition of *wetland* has to be very broad. The following definition is basically the same as that used by the Resource Management Act (RMA), but has been expanded a little to make its scope clearer:

'Wetlands' is a collective term for permanently or temporarily wet areas, shallow water and land-water margins. Wetlands may be fresh, brackish or saline, natural or artificial, and are

characterised in their functional state by plants and animals that are adapted to living in wet and waterlogged conditions.

1.4.2 Wetland hydrosystems

The main wetland hydrosystems are:

riverine– Flowing shallow water systems and their margins.
lacustrine – More or less static shallow water systems and their margins. Lakes usually have higher biomass than riverine systems, particularly for algae.
estuarine - brackish systems and freshwater wetlands influenced by tidal effects.
palustrine - typically not, or rarely, flooded 'land'-based systems, such as swamps and marshes.
seep/spring/artesian – A sub-set of palustrine systems, but supplied from subsurface water sources. Seeps and springs typically tap unconfined subsurface aquifers; artesian sources (properly called artesian springs) derive from confined aquifers under pressure (i.e. with positive piezometric heads) at depth. These hydrosystems are usually the ultimate source of rivers but, where they break surface, they create unique wetland systems, such as dune slacks and spring mires.

Most wetlands are palustrine, and they overlap with other types on, for instance, river and lake floodplains and coastal plains. Palustrine systems may be peat-forming or mineralised (see soils section, below).

1.4.3 Wetland classes

At the second level of classification, each hydrosystem supports a range of different wetland types, or **wetland classes**. These include the following, all of which are encountered in this report:

bog – These are the only wetland types supplied by rainwater alone, and they are consequently acid and low in nutrients. They are always palustrine in New Zealand and always accumulate peat. However, sometimes bogs are influenced by adjacent groundwater flows, particularly when the bogs are in hollows. These are called *transition bogs* and they may have pH values of 5 and other chemical signatures of groundwater. There is a continuum from bog through transition bog to poor fen to fen. A New Zealand transition bog would be likely to have flax and manuka components, for instance.

fen – Groundwater-fed palustrine wetlands that always accumulate peat because flow is year-round. The water is not usually derived from rivers or lakes, but from runoff from adjacent mineral soils. They are rarely flooded and nutrient status is low-medium. They overlap in characteristics with swamps.

swamp – Groundwater-fed and usually of medium-high nutrient status. There is a wide variety of types, usually palustrine, ranging from permanently waterlogged or flooded to only seasonally so (ephemeral wetlands). The wetter types are often dominated by flax and reeds such as raupo, and the drier by sedges and grasses. Swamps also occur within riverine and lacustrine hydrosystems, and many are spring-fed. Permanently flooded swamps usually accumulate peat.

shrub swamp - A sub-type of swamp, in which shrubs such as coprosma, manuka and tauhinu are mixed with sedges.

marsh – Groundwater-fed and with a mineral substrate. Usually fluctuating from seasonally inundated to dry, or with good drainage and well-oxygenated so that peat does not accumulate. Usually medium-high nutrient status. Vegetation usually sedges, rushes and herbs of low stature.

swamp forest – Trees such as kahikatea and pukatea predominate. Flooding is typically seasonal, but there are also permanently flooded examples. Substrates are typically mineralised, but may be shallow peat where water sources are year-round. There may be sedge-dominated pools in canopy gaps in mature swamp forests, but all herbaceous ground flora is low-light adapted.

swamp carr – This term describes a wetland type that really has no New Zealand counterpart. Willows and alder are species introduced from Europe, where the term is used to describe wetlands dominated by low-stature, deciduous trees with a light-demanding (compared with swamp forest) herbaceous understorey. Although many of the herbaceous species are exotic too, many native sedges and some herbs are found in willow carr, particularly when the canopy is more open. Grey willow carr (not common in the Wellington region) is permanently waterlogged or flooded; crack willow carr is typically only seasonally flooded.

seep/flush/spring – A wetland supplied by water issuing from a subsurface aquifer. They can be very localised and ephemeral, but they can also permanently supply, or partly supply, whole wetland complexes.

turf wetlands – Plant communities with low stature (usually under 10cm) and (usually) high species diversity. Typically they occur along lake edges and are regularly inundated and then exposed. Up to 40 species of indigenous turf plants are recorded for Lake Wairarapa alone. Where exposure is more prolonged, turfs can become mixtures of natives and exotics.

dune slack/dune lake – Dune lakes are formed in hollows between sand dunes, where the groundwater table breaks surface and is maintained by storage in the adjacent dunes. Slacks have similar hydrology but are, to a greater or lesser extent, seasonal and palustrine; the less seasonal ones usually accumulate peat. Both are typically low in nutrient status and high in species diversity, but human activities have often reduced dune storage and raised nutrient levels considerably.

shallow water – Aquatic systems, often with submerged, floating and emergent vegetation, eg rivers and lakes, and permanently flooded parts of swamps. Most deeper lakes, and most eutrophic shallow ones, accumulate deposits of *lake peat* – a mixture of planktonic algal cells and mineral silt. This often jelly-like ‘organic silt’ is called *gyttja* and it is often very high in organic nitrogen and phosphorus. As historical lakes gradually fill in with sediment, the lake peat remains in the soil profile and often becomes a nutrient source for a lush palustrine swamp – often raupo and flax.

lagoon – A term often used for a lake which is hydrologically linked to a river, a larger lake or the sea. The term is often loosely used, though – as with Foreman’s Lagoon in the present study.

floodplain – These may be fed by rivers, streams, lakes or springs (particularly from faults) and water levels fluctuate seasonally. They may support a variety of swamps and marshes.

artificial/constructed wetlands – Wetlands are often constructed for recreational (eg hunting, wildlife) or ornamental purposes. More often they are modified by, for instance, native plantings or excavation to increase the open water area. Where earthworks are involved, disturbance usually raises the nutrient status and the system may take many years to stabilise. The insertion of weirs and bunds also modifies the hydrology and therefore the wetland character, sometimes in unpredicted ways, so any modifications, such as hydrology or water quality changes, need to be carefully planned or allowed for.

wetland complexes – Most wetlands are amalgamations of different sub-types, determined principally by variations in hydrology (flow-rate, water depth, seasonality, source, etc) throughout the complex. Thus many of the above wetland types may co-exist and overlap within a complex. Most lowland wetlands are now only remnants of former complexes: the larger a complex, the more 'natural' it usually is and the more stable its hydrology.

1.4.4 Wetland types

Each hydrosystem provides for several wetland classes, and each wetland class includes a number of wetland types, with each one representing a structural class, such as treeland, reedland, sedgeland, (Atkinson, 1985), or a particular ecological assemblage (of specified plant species), such as raupo swamp, sedge - tall fescue swamp, totara semi-swamp forest.

The classification of wetland types may therefore be based upon hydrology, topography, nutrient status, substrate type and floristics, but in order to reflect the relative importance of the different methods it is necessary to use all of them in a hierarchical classification scheme (Thompson, 1987; Stephenson *et al*, 1983). Greater detail on wetlands classification can be obtained from Johnson & Gerbeaux (2004) and Hunt (2007).

There are 85 ecological regions and 268 ecological districts in New Zealand.
Less than 10% of New Zealand's wetlands remain, and most of those that do are modified by drainage, high nutrient levels and introduced plant species, particularly those in lowland areas. Some regions and districts have lost more wetlands than others, but the aim everywhere is to try to retain good and valuable examples. The most recent estimates for the Wellington region (Aussiel, 2004) suggest that only about 3.5% of the former extent of wetlands remain.

1.5 Wetland dynamics and management

Since most wetlands today are merely remnants of what they once were, their water supplies are now subject to competing demands and their water quality has often changed significantly.

Wetlands are naturally dynamic systems (i.e. they are continually changing over time) - sediments accumulate, water courses change, nutrient inputs favour different species. This means that they are more difficult to manage than most other ecosystem types; there are so many different **forcing functions** (ecological drivers) that can bring about significant change. Fence a forest and it will still be there in 50 years; fence a wetland and it may well be unrecognisable after five decades, or even less, unless it is actively managed. Rates of change can be rapid, as with water diversion or prolonged flooding, but also slow, as with nutrient increases and exotic weeds. It is important to remember that all plant species have specific ecological tolerance ranges, and if the tolerance limits are exceeded, species will show performance decline.

Wetland ecosystems cannot be managed like public gardens, because ecological factors and species interact in complex ways. Trend monitoring is a critically important management tool, because this is the only reliable way to pick up slow processes of change, but it does require a regular monitoring programme.

The following sections on hydrology, chemistry, soils and biology give some background to wetland processes and to the various descriptors and indicators used in wetland ecological survey. A methodology for standardising wetland surveys is provided by Clarkson *et* al (2004), and more detail, technical and non-technical, can be found in the useful general reference Maltby & Barker (2009).

1.5.1 Hydrology

Hydrology is by far the most important of the **forcing functions** in wetland dynamics, because hydrology is the primary determinant of wetland type – to put it simply, without water, wetlands would not be wet! Every wetland type has its own characteristic hydrological regime and every significant wetland needs its own hydrological management plan – there is no one-size-fits-all, and a major problem is that wetland water supplies usually cross property boundaries.

To show how rate of water supply can change a wetland's character, compare a **supply-driven** wetland with a **demand-driven** one. The former has such a high rate of input that any further increase would not change the wetland's character. A river is the ultimate example, but there are several wetlands in the Wairarapa with very high stream or race inputs which also fit this definition. Wetlands augmented by weirs on outfall streams may also (but not always) be supply-driven. Most wetlands, however, are demand-driven and show features such as seasonal contraction and flooding (eg floodplains), where evaporation becomes a major hydrological determinant. Wetlands with high demands and low, or very seasonal, inputs are the most vulnerable.

Recharge wetlands and **discharge wetlands** are another 'hydrological pair'. The former is a valley wetland supplied, partly or wholly, by water stored in adjacent hills during the winter. A discharge type is located on flat land and is either wholly supplied by direct rainfall (eg a domed bog), with water 'shedding' off it around the edges, or else it is supplied by a river or stream, with the water 'piling up' at one end as it hits the wetland, and then dissipating in several directions.

Whereas bogs are very clearly discharge wetlands, the difference between groundwater recharge and discharge wetlands is often simply one of the scale of the water supply. For example, Lake Rotomanuka (Waikato) was, in its former natural state, a recharge wetland supplied in early summer from water storage in surrounding hills. Since local drainage water has been routed through from a culvert, it has become a discharge wetland, shedding water into its riparian zone during the summer period (Stockdale, 1995). An example studied in the present report of a discharge wetland receiving recharge from adjacent high ground storage is probably Pateke Wetland (see Ch. 6).

Most wetlands are managed passively: i.e. 'wait for a problem to arise then fix it'. But in order to actively manage the hydrology of a wetland, the following parameters must be either measured or estimated:

$$dS = P + Qi + Gi - E - Qo - Go$$

Where: dS = change in water storage
P = rainfall
E = evapotranspiration losses
Qi/Qo = surface groundwater inflow/outflow
Gi/Go = subsurface groundwater inflow/outflow

This water balance equation (a more detailed version can be found in Maltby & Barker, 2009) can also represent the **small water cycle** (Kravčík *et al*, 2008), in which water outflow may best be described as 'drainage' and local evaporation 'losses' are at least partly replenished when water is returned as rain to the region from which it was evaporated. New Zealand has an oceanic climate, in which most rainfall derives from evaporation elsewhere, but there is still no doubt that land management which increases drainage and evaporation losses does lead to enhanced droughts. Wetlands are valuable water storage systems in drought-prone regions.

It is relatively easy to measure dS, either manually, by monitoring water levels in dip-wells (plastic piezometer tubes) with a dipstick, or digitally in real time with an electronic recorder, linked to a capacitance probe, which can be downloaded to a laptop every three months or so. The advantage of the digital record is that hydrological events can be recorded exactly when they happen, thus enabling better correlation with causation. Levels can be converted to flow rates by using weirs on water-courses.

Combining digital water level recording with monitoring water quality for chemical signatures will provide the best information as a basis for management advice. For instance, hydrological monitoring can determine the **residence time** for water in a wetland, sometimes called the **turnover period.** If the turnover period is slow (Q and G parameters are low), but the water quality high (= low nutrient content), then there is no imminent threat of eutrophication and algal blooms. But if a low turnover wetland has high nutrient status, algal species have plenty time to reproduce and 'bloom' before being flushed from the wetland. Dune lakes, for instance, are particularly threatened by nutrient increases because they typically have low turnover rates. So some of the algal problems resulting from high nutrient waters can be mitigated by increasing the rate of water throughput.

High flow rates can also increase growth rates of some emergent plants, such as raupo and flax. This happens partly through increased oxygen availability to the roots and partly by ensuring a good replacement rate of nutrients to the roots.

Groundwater inflows and seepage losses are particularly difficult to estimate, and chemical records are again valuable here, because water chemistry usually carries a signature of origin. Different aquifers are separated by impermeable layers – clays, ironpans, rock, etc. These 'separators' may be absolute (ie **aquicludes**), or they may only slow down water movement between aquifers (**aquitards**). Such a 'contained' aquifer is referred to as a **confined** aquifer.

Often a deeper aquifer will be at a positive pressure and this can be estimated by drilling a borehole into it and noting how far the water rises up the tube (its **piezometric head**). When aquifers under positive pressure develop 'leaks' (for instance, near a geological fault), the water can reach the surface as an **artesian spring.** Most small springs, particularly those with flows varying seasonally, derive from **unconfined aquifers**, which sit on aquitards or aquicludes at depth, but are not constricted at the surface – water storage in hills and sand dunes are examples.

1.5.2 Water chemistry

Water chemistry has two main roles in wetlands management: on the one hand, it is useful for identifying water sources through their different **chemical signatures**, and on the other, nutrient concentrations correlate well with particular species assemblages in wetlands and also enable predictions to be made of threats from fast-growing plants, such as algae and aggressive exotic species.

All water quality data in this report are given as concentrations, but sometimes it is necessary to convert concentrations, using additional measurements of hydrological flow rates, into **chemical mass flows** (e.g. quantity of nitrogen per second). This conversion is necessary, for instance, to ensure that statements like '50% reduction in nitrogen concentration' has not been achieved simply by doubling the volume flow of water. Knowing the chemical mass flow is important in environmental management, because nutrients all end up somewhere – like a lake or an estuary – where they can determine **trophic status** and influence aquatic biomass and biodiversity.

1.5.2.1 *Chemical signatures: nutrients*

Waters can be classified, therefore, in terms of their chemical signatures and their trophic status. This is a measure of their biological state or biological potential, where the important measures are the concentrations of nitrogen and phosphorus (the most important nutrients), the concentration of chlorophyll-a (an estimate of algal biomass), and the dissolved oxygen concentration (a measure of oxygen-consuming biological activity, particularly by bacteria). These measures, between them, can provide estimates of trophic status, or the potential for **eutrophication**.

Table 1.1 characterises the main trophic categories in terms of the major nutrients and chlorophyll-a as a proxy for photosynthetic aquatic biomass. There is considerable overlap between these states, but the present author has presented these as reasonable New Zealand averages (see also Verbu *et al*, 2010). Studies elsewhere (eg Carlson & Simpson, 1996; Wetzel, 1983) also support these groupings.

trophic category	**total phosphorus** g/m³	**total nitrogen** g/m³	**chlorophyll-a** g/m³
oligotrophic	<0.02	<0.6	<0.006
mesotrophic	0.02-0.05	0.6-0.9	0-006-0.02
eutrophic	0.05-0.2	0.9-2.0	0.02-0.06
hypertrophic	>0.2	>2.0	>0.06

Table 1.1: Approximate correlates of trophic states.
[Note: these are only guidelines, as other factors, such as temperature, turbidity, dissolved carbon and water flow rate can also influence the trophic state]

High dissolved nitrogen concentration can be a chemical indicator of a eutrophic water, but only if the phosphorus concentration is also high. Table 1.1 shows that a N:P ratio of 10:1 characterises each trophic level; if the ratio is higher or lower, either nitrogen or phosphorus becomes **limiting** to algal growth, and either nutrient can be limiting at all trophic levels.

On the other hand, high phosphorus and low nitrogen can still produce eutrophic conditions, because cyanobacteria (formerly called blue-green algae) have the unique ability (among photosynthetic micro-organisms) to fix their own nitrogen from atmospheric sources. Some common cyanobacteria produce compounds that are toxic to humans, dogs, stock and wildlife (water birds, for instance), so cyanobacterial blooms can not only dominate water bodies and reduce dissolved oxygen concentrations, they can also have direct toxic effect on other organisms.

Another distinction between nitrogen and phosphorus is in the number of distinct chemical states they have. Nitrogen has the reduced forms or organic nitrogen and the mineralised ammonia, the more oxidised forms of nitrite and nitrate and then the even more oxidised forms of nitrogen and nitrogen oxide gases:

$$\text{Organic\_N}/NH_3/NH_4 \text{ ---}\rightarrow\text{---- } N_2 \text{--}\rightarrow\text{----- NO--}\rightarrow\text{----- } NO_2^{-} \text{ ---}\rightarrow\text{---- } NO_3^{-}$$

Increasing oxidation state

Wetlands are very effective at removing nitrogen from the system, because nitrate is readily converted to the volatile gases under anaerobic conditions and in the presence of organic carbon, which is abundant in most wetlands. Most nitrogen is transported in its soluble forms.

With phosphorus, on the other hand, there is no equivalent to the denitrification mechanism and phosphorus is largely transported by surface waters in its particulate form adsorbed to sediments. Its interactions in wetlands are complex, but in general, it is mostly immobile in its organic form and when bound to aluminium, iron or calcium. Its ‘active’ form (available for plant uptake) is measured as **dissolved reactive phosphate** (DRP) and it is released from its immobilised forms mainly under anaerobic (reducing) conditions. Thus, the phosphorus in the sediment of lakes will largely stay there if there is plenty of dissolved oxygen, but when the oxygen is used up by, for instance, microbial decomposers, phosphorus can be released to trigger eutrophication processes. The situation is more complicated in palustrine wetlands, but phosphorus is still usually the key driver of eutrophication processes there.

Nitrogen and phosphorus are therefore **chemical indicators** of eutrophic conditions - or of eutrophication potential. Chlorophyll-a, on the other hand, is a biological measure, and is very useful, because it integrates chemical and physical conditions – algal blooms, therefore, are **biological indicators** of high nutrient levels and eutrophic conditions. Such a ‘trophic package’ can be called a **chemical signature.** The **trophic level index (TLI)** is used in New Zealand (see Verbug *et al*, 2010) to assess eutrophication: it incorporates nitrogen, phosphorus and chlorophyll-a concentrations, and turbidity measurements.

Eutrophication is a condition to avoid if possible in high-value wetlands. It involves excessive growth of algae and cyanobacteria, reduction in habitat quality for fish and invertebrates, decline in species diversity (fast-growing plants are favoured), and often loss of organic soils.

1.5.2.2 *Chemical signatures: major ions*

Well aerated waters low in nutrients, such as rainwater and dune lakes, are often referred to as 'high quality' waters. If they are also low in dissolved solids such as calcium, they will have low **buffering capacity** against not only pH changes, but also additions of nutrients such as phosphate. It is easier to control eutrophication processes in a water body with high total dissolved solids (TDS), than in a high quality water.

There are many other useful chemical signatures. Sand dunes, for instance, often impart high calcium, high bicarbonate and a high pH from stored water. Younger dunes may have a more marine sodium chloride signature. Deep confined aquifers typically have high electrical conductivities (representing high concentrations of dissolved ions), due to the long residence time in various mixed sediments where chemicals are slowly dissolved. Sodium, chloride and sometimes sulphate are good deep aquifer indicators, depending on the nature of the minerals in the aquifer. Limestones would impart high calcium. Guggenmos *et al* (2011) discusses deep aquifer signatures in the Wairarapa context. The shallower subsurface unconfined aquifers have shorter residence times in contact with sediments and rocks, so will have chemical signatures intermediate between deep aquifers and surface waters

High nitrate is a common shallow aquifer signature in lowland agricultural areas, because nitrate is very mobile in soils.

1.5.3 Soils

Wetland soils are important functional components of wetland ecosystems. Most wetland substrates have a high organic matter content, varying from 50-90% (of dry matter) for peats, to 15-50% for organic soils. There is no universal agreement on these percentages and some classifications require peats to contain only 20% organic matter. The carbon content of dry organic matter is usually 50-60% and the nitrogen content usually about 1%. Organic matter (and therefore peat), typically has a very high **cation exchange capacity** (which is why it is so important in agricultural soils) and a high water-holding capacity. Peats, for instance, typically have **field capacities** of up to 70% (by volume), which is over 30% more than most mineral soils. The field capacity is the amount of water a soil will hold against gravity, so it is not necessarily waterlogged

These features have considerable importance for wetlands functioning and management. Organic soils and peats store both water and nutrients and chelate (hold in a bound chemical form) heavy metals. When they decompose they release nutrients and when they dry out they shrink as the water is removed and, finally, they oxidise to carbon dioxide with further shrinkage. So the management of wetlands is also about the management of water resources so that wetland soils are kept wet. Peat shrinkage can, for instance, change the nature of the boundary between a wetland and adjacent pastureland, which can make delineation difficult.

One type of peat is often overlooked in wetland and soil management – **lake peats.** Swamp plants, such as raupo, do not release large amounts of nutrients when they decompose, because they only contain about one percent (dry weight) of nitrogen and maybe a tenth of a percent phosphorus. However, planktonic algae, which usually contribute most of the organic detritus in shallow water bodies, have very little structural material in their cell walls and so their carbon/nitrogen and carbon/phosphorus ratios are very low (nitrogen and phosphorus contents high).

This type of (algal) organic silt (often called a **gyttja**) has a carbon content of about 10-15% and carbon: nitrogen ratios of less than 10:1. Peat farmers are often surprised at their high soil nitrogen tests (and sometimes their Olsen phosphorus tests too) when cultivation hits an organic silt layer.

So soil composition and depth is always an important parameter in wetland survey. Seasonally waterlogged floodplain or terrace soils, for instance, can hold clues to flooding duration and water table depth in the extent of **gleying** apparent. Waterlogged soils are usually anaerobic and iron compounds are therefore present in their reduced form, which imparts a blueish grey colour to the freshly-cut soil. Channels of reddish brown can be seen where oxygen from plant roots has enabled iron bacteria to oxidise the greenish-blue ferrous compounds to the reddish-brown ferric form. Gleyed soils therefore have a grey/brown mottled appearance.

1.5.4 Plant indicators

As noted above, plants are 'integrators' of environmental conditions. Chemical tests are date-specific, but biological indicators integrate the influence of chemical, physical and biological factors in the environment to give a wetland status perspective based upon the response-time of species, or community, indicators. Thus, the presence of a cyanobacterial bloom indicates that a suite of chemical and physical conditions are in place which permit that to happen, a lush growth of raupo is an indicator of high water flow rate and/or high nutrient levels – maybe, for instance, a spring-head, or a drain discharge point. The 'lichen line' on wetland tree-trunks indicates the mean high winter flooding level.

Plants found in wetlands can have one of two types of survival strategy: waterlogging **tolerance** or waterlogging **adaptation.** Tolerant plants are either opportunists or are living outside the zone of permanent waterlogging; waterlogging-adapted plants have metabolic and/or physical modifications which enable them to grow in long-duration waterlogged conditions.

However, all species have optimal ecological ranges and tolerance and adaptation limits, so species' **presence and absence** from wetlands, or parts of wetlands, can indicate prevailing conditions without the need for longer-term monitoring records. However, **relative species abundance** can tell a story beyond presence/absence, because this measure refers to how common or rare a species is relative to other species in a given location or community. It requires recording **frequency of occurrence** as well as some estimate of numbers of individuals or **ecological dominance**.

Relative species abundance and **species richness** (number of species per unit area) describe key elements of biodiversity. Simple species lists can demonstrate species richness for a wetland, but they don't provide information on **habitat diversity** within wetland complexes, or whether the richness is due to some ecological constraint, such as shading or nutrient availability. Low nutrient concentrations, for instance, usually increase species diversity, because they constrain the performance of aggressive, nutrient-demanding species – low nutrients can 'level the playing field'.

The converse, of course, is that excessive nutrient levels – and **eutrophication processes** – favour fast-growing species, usually exotics, which change habitat conditions and suppress many less aggressive natives, resulting in low species diversity. Several native species also have aggressive, weedy characteristics, including the impenetrable reedland that raupo can produce and the all-smothering *Isolepis prolifer*.

Maintaining wetland communities and species diversity is mainly about preserving habitat condition and habitat diversity, because plants cannot change their tolerance ranges – they can only grow in suitable habitats.

Plants can also be biological indicators of ecosystem health and of processes of environmental change, as when trees develop pathological features such as branch die-back or epicormic shoots (vertical 'water shoots' from trunk or branch) – both being signs of stress (tolerance range being exceeded). Drought or flooding damage are the commonest stress-producing factors for wetland species..

However, even identifying plant indicators of ecological status will not usually be enough to assess rates of change, so trend-monitoring programmes are an essential part of wetlands management planning. Since ecological changes are often slow, recovery from undesirable changes will also be slow, so early warning systems need to be in place.

1.5.5 Exotic plant species

A great number of exotic plant species are now firmly naturalised in wetlands of the Wellington region (and throughout New Zealand as a whole). Lowland wetlands in particular are very susceptible to the spread of introduced species. Most of these are now simply common components of wetland floras, but a growing list of aggressive, weedy species need to be monitored and controlled where possible. Willows, alder, glyceria grasses and water fern are obvious examples. Seasonal wetlands are very susceptible, because wetland tolerant plants (rather than wetland adapted ones), such as bracken, tall fescue and gorse, can dominate.

Whilst priority must be given to native plant species and, especially, communities dominated by assemblages of native species, wetlands dominated by exotic plants can still have significant wildlife, recreational or aesthetic (landscape amenity) values. A wetland comprising predominantly introduced species, and often even a constructed wetland, is usually better than no wetland at all.

1.5.6 Guidelines and regulations

The above sections on hydrology, water quality, soils and plant indicators deal with practical aspects of wetlands management and the setting of guidelines and development of best practice for maintaining the quality of wetlands. However, since wetland water supplies are usually drawn from sources which are, or could be, impacted by activities beyond the wetland's statutory boundary, regulations are needed to ensure that the guidelines (such as adequate flow to maintain that particular type of wetland) are implemented.

1.5.7 Wetland values

By drawing attention to their multiple values and the ecosystem services they provide, *Wetlands: A Diminishing Resource* (Stephenson *et al*, 1983) did much to raise the profile of wetlands in New Zealand at a time when drainage subsidies were still being provided by the Ministry of Works and conservation was still in its infancy.

Wetlands are now much more widely recognised to have a wider range of values than probably any other natural ecosystem. As listed by Fuller (1993) they cover the social, economic, utility, productivity, intrinsic and conservation spheres, and the most important values in the current context are recreation, education, water supply and flood regulation, nutrient processing, conservation and education.

Wetlands provide tangible benefits way beyond conservation and recreation. Their indirect benefits, such as water conservation and nutrient processing for agriculture, both justify and demand significant management investment from several sectors outside conservation, biodiversity, recreation and landscape amenity.

2. WAINGAWA WETLAND
Wairarapa

2.1 Introduction

Waingawa comprises three wetlands, hydrologically linked (Eastern to Central to Western), but largely separated by roading. The most ecologically valuable part is the 10.6ha Western Wetland, which is protected by QEII National Trust Open Space Covenants on two adjacent properties.

Beadel *et al* (2000) note that Waingawa Wetland is the largest remaining example of semi-coastal, lowland, non-forest wetland on the older aggradation land type left in the Wairarapa Plains District.

An account of the wetland complex by Park (2008) provides a good overview of the ecology and management issues. Wilson (2010) gives an account of the hydrology of the wetland and its adjacent geological fault.

Waingawa Wetland was visited) on 13 April 2010.

2.2 Topography and stratigraphy

The wetland is located on the immediate downstrike side of the Waingawa (Masterton) fault. The escarpment drops 4-5 metres (GWRC LiDAR data) to the northern margin of the wetland and the groundwater table falls 2-4 metres across the fault.

The wetland substrate is gravels and pebbles from river terrace material and fault debris, overlain by no more than 30-40cm of recent organic sediments.

Immediately to the north of the escarpment crest is a gravel quarry, with a proposed extraction level only 1-2 metres above the mean water level of the wetland (Wilson, 2008).

2.3 Hydrology

There are two (linked) sources of water. The Taratahi Water Race, estimated to be supplying about 50 L/s on 13 April 2011, originates from the Waingawa River, about 9 km to the north. The other sources are local springs arising above and below the faultline escarpment and deriving from a shallow unconfined aquifer which underlies pastureland to the north. One of these springs (Sample 2) was gauged on the present visit at about 10 L/s (GWRC gauged this at 14 L/s in March 2008). The 2010 early summer was wet, so 13 April would have been about the lowest water level for the 2010 summer.

The chemistry of Sample 3 (particularly sodium/chloride/conductivity) is intermediate between sampling sites S1 and S2, which suggests similar volume contributions from the two water sources.

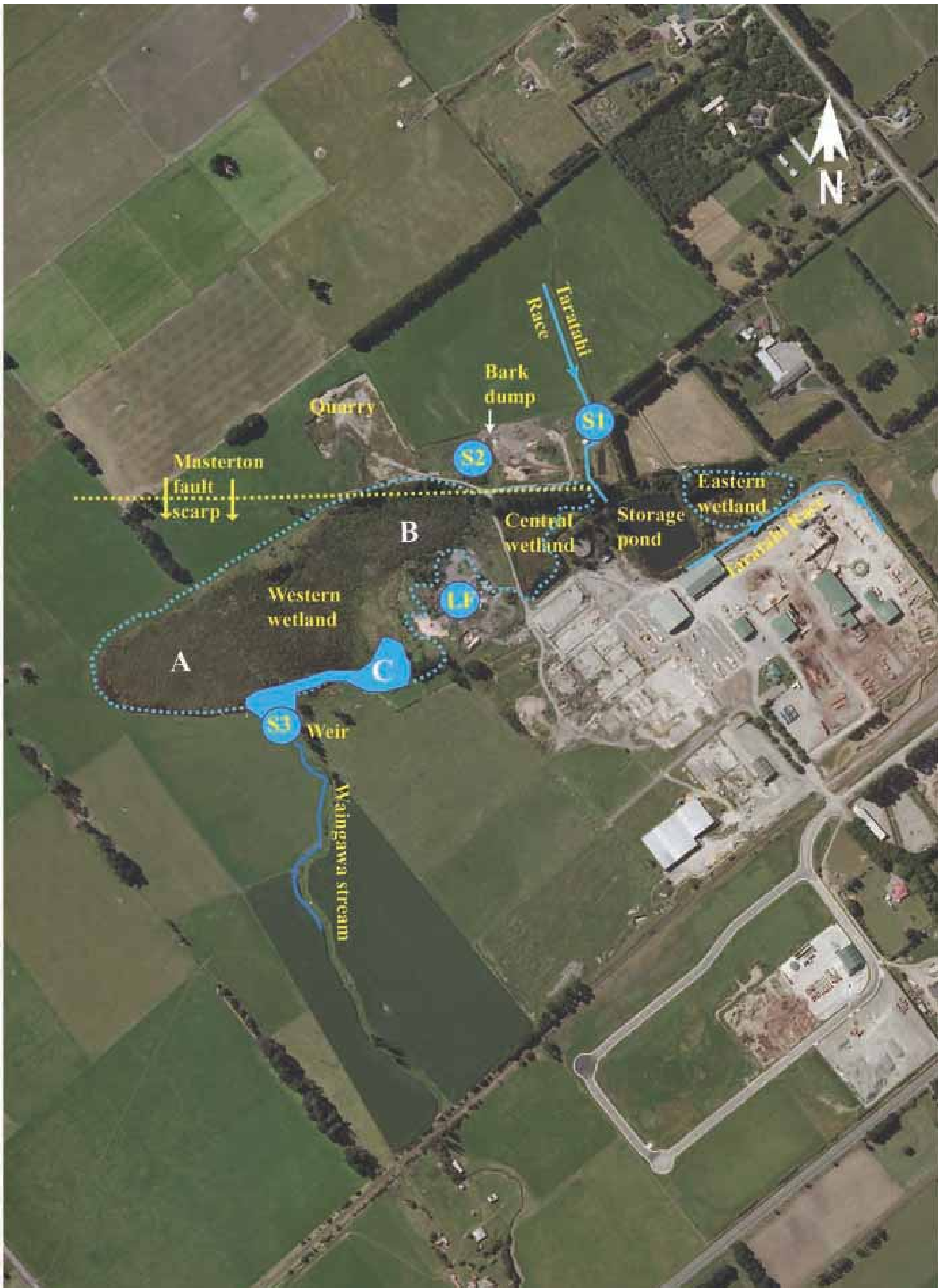


Figure 2.1 WAINGAWA WETLAND

S1 Water sampling location

LF Landfill material

A Raupo / flax reedland

B Manuka shrub swamp

C *Isolepsis* and open water

The outlet stream's nitrate content is also consistent with 30-50L/s of spring water being diluted by about 50L/s of race water.

As Wilson (2010) observes, the Waingawa Wetland exists only because the elevation of the groundwater table above the fault has provided a hydraulic gradient to bring the water table to the surface immediately below the faultline.

The hydrological balance of the Waingawa Wetland has not been modelled in detail, but using even approximate hydrological estimates suggests that the Taratahi Water Race (plus local rainfall) does not seem to supply enough water during the summer to supply all the wetland's evaporative and outflow needs. There is therefore certain to be significant additional supply from the fault.

Peat deposits are only found close to the faultine, and in fact extend along it to the west, beyond the wetland. Peat is always a sure sign of a reliable water source and is therefore confirmation that the fault is providing a significant water supply. Also, artesian sources were identified within the wetland during the present field visit.

During the winter, local spring and seepage inputs are likely to far exceed the flow of the Taratahi race. For instance, GWRC records show that groundwater can inundate the quarry up to 1-2 m deep in winter, whereas the groundwater level during the present visit on 13 April 2010 was 70 cm below ground level.

Water exits the Western wetland at a single point, over a dilapidated weir, where it becomes the Waingawa Stream. It was flowing at about 10 L/s on 13 April 2010 (the present study) and 6 L/s in March 2008 (Wilson, 2008). The weir is an important structure, as it controls the water level in the wetland and particularly in the ecologically valuable open water zone bordering the west and south of the Wetland.

Moreover, not only would the wetland not exist in its present form without the groundwater inflow from the faultline, but also the weir is needed to maintain present water depths.

If the weir flows year-round, the wetland will be supply-driven and seasonal levels will be much more stable than if the weir ceases to flow for part of the summer. Natural groundwater-fed wetlands are usually demand-driven and have greater water-level amplitudes and wider marginal shallow-water zones.

During an average summer (ca 200mm rainfall), which 2010 probably was, the water supply for the wetland is good, and even during the drought summer of 2008 the outflow was maintained. Nevertheless, any increased intensification of farming to the north could further deplete faultline springflows during a dry summer. The race is the main stem of the Taratahi so that flow rates are unlikely to be compromised so long as its consents are maintained.

However, the volume flow diverted from the Taratahi Race to the wetland is managed, so there could be some variation in supply if, for instance, diversion is based upon a percentage of current flow. Wetlands always change their character if there is a significant change in water supply.

All wetlands can endure some summer drawdown - indeed it is often good for nutrient processing and seed germination – but Waingawa is a wetland type which needs to maintain aeration and, if there is no consistent throughflow, stagnation could lead to blue-green bacterial blooms and avian botulism in the open water areas and establishment of weedy plant species within the vegetated areas. But with high water levels and flow rate maintained, exotic species like tall fescue will probably be replaced through natural succession by the native sedge *Carex geminata*.

2.4 Chemistry

Three near-surface water samples were taken for water quality analysis (see Figure 3.1 for locations) : Sample 1, from the Taratahi Race, is chemically typical of Waingawa river water; Sample 2 from a local spring above the faultline, is similar to shallow groundwater influenced by pasture development and septic tank discharges to the north; Sample 3 was collected at the weir, where the Waingawa Stream exits the wetland.

TEST	**Site**	**Waingawa**	**Waingawa**	**Waingawa**
	Material	**Water**	**Water**	**Water**
	Lab nos	**783408.1**	**783408.2**	**783408.3**
	Location	**Taratahi**	**Spring**	**Outfall**
	Date	**13.04.10**	**13.04.10**	**13.04.10**
	Sample	**S1**	**S2**	**S3**
WATER	**UNITS**			
1. total nitrogen TN (3+4+5)	g/m^3	0.23	2.7	0.68
2. ammoniacal nitrogen (NH_4_N+NH_3_N)	g/m^3	<0.010	0.19	0.018
3. Kjeldahl nitrogen TKN (2+organic N)	g/m^3	0.23	0.22	0.115
4. nitrite (NO_2_N)	$g/_m3$	<0.002	<0.002	<0.002
5. nitrate (NO3_N)	g/m^3	<0.002	2.5	0.56
6. nitrite+nitrate (NO_2+NO_3)	g/m^3	0.0026	2.5	0.56
7. total phosphorus (all organic P+8)	g/m^3	0.029	0.031	0.025
8. dissolved reactive phosphorus DRP	g/m^3	0.0070	0.0142	0.0072
9. sum anions (HCO_3+CO_3+Cl+SO_4)	Meq/L	0.69	0.97	0.77
10. sum cations (K+Na+Ca+Cl)	Meq/L	0.68	0.99	0.78
11. pH Laboratory	pH	7.4	6.1	6.8
12. pH Field	pH	8.3	4.7	7.1
13. electrical conductivity (EC) Lab	mS/m	6.9	10.8	8.2
14. electrical conductivity (EC) Field	mS/m	7.5	11.0	9.5
15. total alkalinity (as $CaCO_3$)	g/m^3	24	14.4	19.3
16. bicarbonate (HCO_3)	g/m^3	29	17.6	24
17. total hardness (Ca+Mg as $CaCO_3$)	g/m^3	22	27	22
18. dissolved calcium (Ca)	g/m^3	7.0	7.0	6.2
19. dissolved magnesium (Mg)	g/m^3	1.17	2.3	1.72
20.dissolved potassium (K)	g/m^3	0.69	1.45	0.71
21. dissolved sodium (Na)	g/m^3	5.0	9.6	7.1
22. dissolved chloride (Cl)	g/m^3	4.6	10.5	7.7
23. dissolved sulphate (SO_4)	g/m^3	3.9	9.9	6.2

Table 2.1: **Waingawa Wetland water quality data.**

The current Taratahi water supply is of high quality, with relatively low nitrogen and phosphorus concentrations in the lower mesotrophic range. This is good as it restricts plant growth rates and does not favour weedy species. With a higher nutrient status, even native raupo would become ‘weedy’, resulting in denser stands and fewer associated plant species within its canopy coverage.

Some of these 'weedy trends' can be seen along the northern wetland margin, where livestock have easy access due to inadequate fencing.

As noted above, the sodium/potassium and chloride concentrations, and the electrical conductivity values, suggest race and spring inputs in a ratio of about 50:50. The very high nitrate concentration in S2 compared with S1 is a clear indication of pastoral farmland input. Some of this nitrate will be denitrified in the wetland, but the outflow concentration is still elevated enough to be consistent with a combined springs input of about 30-50L/sec.

Waingawa Wetland is a good candidate for a nitrogen isotope study. This would resolve the water supply balance and also provide the basis for a hydrological model to identify with greater accuracy the amount of water needed from the Taratahi Race diversion.

Nitrogen levels within the wetland (as indicated by S3) are in the lower mesotrophic range and DRP levels are in the oligotrophic, so algal blooms are unlikely at Waingawa, except where stock have access or if water is allowed to stagnate in the wetland. Nutrient inputs from birds can also be significant when water throughput rates are low.

The low pH at S2 could be due to the water passing through a bark dump just north of the sampling point. There is no increase in TKN nitrogen, which might have indicated organic acids, although the S2 total alkalinity is much lower than that of the race.

There are other landfills around the wetland, the largest being located along the eastern margin of the Western Wetland (LF on Figure 2.1). Some of these dumps are waste bark chips, but there are also materials discarded by the former freezing works, including chemical drums (maybe even sulphuric acid), which could be contributing, or could potentially contribute, quantities of nitrogen, sulphate and chloride, etc to the wetland waters.

2.5 Ecology and land use

Waingawa Western Wetland is basically a palustrine wetland, especially along its northern interface with the faultline, where there is both historical peat and recent organic sediments. However there are areas, along the southern margin, of lacustrine wetland maintained through impoundment by the weir, and also patches of spring flush wetland, where springs erupt from the fault complex. The eastern end of the open-water area is dominated by a sward of *Isolepis prolifer*.

A raupo community, reedland with flax (A, Figure 2.1), characterises most of the wetland, with isolated (artesian) spring-fed open flushes dominated by watercress communities. Most of the raupo communities are of only medium stature, indicating high quality water (relatively low nutrient concentrations), but spring locations and seepage zones can be identified by lusher, taller raupo and flax patches.

Manuka, and the now regionally rare *Olearia virgata,* are scattered throughout, but characterise, with flax, carices and some twisted willows, a palustrine, manuka shrub swamp (B, Figure 2,1) along the eastern margin of the wetland. There are extensive areas of open water along the south-western margin. The poorly-fenced northern boundary has a mix of exotics (tall fescue, water speedwell and other dicots) and natives (*Juncus gregiflorus*, *Myriophyllum triphyllum*, etc) on a (historical) peaty substrate.

In other words, there is a good range of wetland communities and ample habitat for wildlife. Beadel *et al* (2000) note records for dabchick and white heron, breeding pied stilt, as well as pukeko and harrier. Bittern have also been seen at Waingawa.

2.6 Threats

- There is a great deal of subdivision activity to the north of Waingawa Wetland, with potential threats of additional water abstraction and further septic tank inputs (Scott Ihaka, *pers. comm.*). There could be some farming intensification too, with effects on both nutrient loads and water volumes. Farming does not appear to be intensive to the north-west and west of the wetland at the moment, but if this does happen, there will need to be safeguards to prevent its effects from impacting on the wetland.

  Reduction in Taratahi race summer flow could also raise nitrogen concentrations in the wetland, because of the increased proportion of spring water and its increased residence time in the wetland. Landuse intensification, and associated impacts, to the north pose the greatest risk to the wetland hydrology and water quality, because groundwater flows come from that direction.

- Factors affecting the flow rates of local springs are not well known and any activity which could alter groundwater flows, either by water abstraction or diversion would be a potential wetland threat. For instance, a lower groundwater table north of the wetland would diminish the hydraulic gradient across the faultline and probably decrease springflow to the wetland. Similarly, a lower groundwater table in the Industrial Park area south of the wetland would increase the rate of seepage loss from the wetland through the substrate. Hydrological changes, especially if the weir ceases to flow during summer, would result in vegetation changes.

- The Waingawa Western Wetland is largely protected against any increase in silt load from the Taratahi Race because the storage pond acts as a settling tank. This is an advantageous arrangement. Large silt inputs are unlikely, but increased surface runoff and erosion from farmland could potentially increase phosphorus loading to the wetland.

- In March 2009, Wairarapa Aggregates was awarded consents to extend gravel extraction from the quarry site and to abstract 10L/s from the Taratahi Race on 120 days in the year for gravel washing. Sediment leakage and use of part of the wetland’s water supply are therefore credible threats. Increased evaporation from the exposed water table in a further-excavated quarry could also reduce springflow to the wetland.

- Apart from external threats to the north, there are internal threats due to decomposition of, and leaching from, dumps of discarded bark and wood chips along the eastern margin of the Western wetland. Steel drums, believed to still contain chemicals, are also dumped in several places.

- The wetland is not entirely fenced from stock and adjacent private farmland is divided between two separate properties.

2.7 Conclusions and recommendations

- Hydrology is the most important factor in the management of any wetland and water quality is the second most important. At present both appear to be good in Waingawa Wetland, but it is important to establish a robust monitoring system that is able to identify sustained changes, or signs of instability, so that corrective management measures can be taken as soon as possible.

- The weir should be properly engineered and fitted with a variable crest so that flow, and wetland level, can be controlled if necessary. A digital water-level measuring device (capacitance probe) should also be installed at the weir, so that flow-rates can be recorded.

  Presumably the flow-rate of the Taratahi race is monitored, so that the proportion to be diverted to the wetland can be calculated. If this is not the case, or if the quantity diverted is determined by the proportion which should be left in the race, then it could be appropriate to establish an additional flow gauging point at the culvert linking the Central Wetland to the Western Wetland. This is the race-derived inflow to the wetland. The aim would be to
  establish the minimum ecological flow required for sustainable management of the wetland, so that the proportion of the Taratahi Race flow that is diverted does indeed provide this.

- Springflows and seepage from the fault scarp cannot be gauged directly, but they are not likely to be evenly distributed along the faultline. There may well be defined flow channels at particular locations (as there are at Foremans Lagoon, Ch. 5)). Discrete artesian zones are referred to in the ecological section above. Before there is any resumption of gravel extraction in the quarry, attempts should be made to identify any significant seepage points which may be immediately to the south of the quarry, so that monitoring of any hydrological effects can be appropriately targeted.

- The water abstraction rate for quarrying should be defined in terms of the maximum permitted percentage of the Taratahi water available *at the time*, rather than a fixed volume take irrespective of the total flow rate, or an allocated amount per season. The amount of water diverted from the race to the wetland should take priority over the quantity allocated to the quarrying operation. The quarrying operation also needs to be monitored for sediment release.

- Quarterly monitoring of water chemistry should be carried out by the Regional Council at the three sites used in the present study and at other known spring/artesian input locations. Water quality at the culvert linking the Central and Western Wetlands should be checked to ensure that it is identical with that in the Taratahi Race. If a reliable fault-zone water source can be located, it may be possible to estimate the proportion of non-Taratahi water supplying the wetland using the seasonal chemical signature at the weir. Otherwise, water chemistry can be used (as in the present study) to estimate the springflow contribution.

- Gorse, pampas, blackberry and Himalayan honeysuckle are present in the shrub community B, particularly along the margin of the landfill and some weed control there is desirable. At some stage the willows will need to be removed.

- The extent to which landfill wastes may be altering the chemistry of the Western Wetland is a worthwhile monitoring project, as a waste materials dump does not really belong adjacent to a covenanted wetland. Ideally the materials should be excavated and removed to expand the open water area (if the exposed ground is not too contaminated). At the very least, waste dumps are usually hydrologically isolated, as far as possible, from high value wetlands. If neither of these options is considered feasible, at least a monitoring project should be established to investigate the extent to which landfill wastes may be affecting (or could affect in the future) the chemistry of the Western Wetland. Evidence-based decisions could then be taken on the future management of the dumped material. Perhaps this study could be undertaken by a Masters student.

- Fencing of the wetland boundary should be completed. It would be preferable if any fencing could be located at least 20m beyond the ecological boundary (as opposed to the property boundary) of the wetland, so as to reduce surface runoff from adjacent farmland.

2.8 Waingawa photographs

Photo 2.8.1: Northern margin of wetland from fault escarpment (note fault debris at base of scarp). Lush raupo middle left indicates seepage inflow from fault. Shrubs in wetland are tauhinu, manuka and mingimingi.

Photo 2.8.2: Looking east to photopoint of 2.1 (above) at middle left on fault escarpment. Shrub swamp of Vegetation Zone B (see Figure 4.1) middle right.

Photo 2.8.3: Unfenced southwestern margin of wetland. Native flax and purei sedges top left and pugged pasture with exotic soft rush in foreground. Ecological boundary of wetland clearly falls outside the property boundary here.

Photo 2.8.4: Taratahi race enters pond top right (flow rate ca 50L/sec) and flows through drop-drain (foreground) to storage pond, then to wetland. Red floating water fern around pond margins.

Photo 2.8.5: Spring input sample site S2. Low flow rate of 10L/sec and high nutrient levels encourage dense growth of aquatic plants. Note bark dumps at top.

Photo 2.8.6: Quarry above escarpment, flooded to over one metre deep during winter. Bark dumps in distance to the right.

Photo 2.8.7: Single surface outflow of the wetland over a weir to Waingawa Stream. Clumps of purei sedge middle-distance and flax of wetland visible beyond. Functional wetland again extends beyond cadastral boundary.

3. BARTON'S LAGOON
Wairarapa
Also known as the Lake Domain Recreation Reserve

3.1 Introduction

Barton's Lagoon, often referred to as Simmonds Lagoon (see Fig. 3.1), together with the nearby Tauherenikau Wetland Reserve to the southeast, is administered by the South Wairarapa District Council (SWDC). These wetlands are not easily accessible beyond their margins. On the other hand, the wetland block referred to in the present report as the Southern Wetland (SW) is accessible because it has a recreational use (hunting), and is administered by Fish & Game New Zealand.

In the late 1990s, the SWDC carried out an analysis of reserves for which it was responsible and decided that the Lake Domain (which includes Barton's Lagoon) is a low priority for management by the District Council (Airey *et al*, 2000). However, Wildlands Consultants Ltd (2012), in their study of the significance of the Wairarapa Moana wetlands, concluded that the wetlands of the Barton's Lagoon area have 'regional (i.e. more than just 'local') significance'.

The Lagoon is approached along the Lake Wairarapa foreshore track, from the South Soldiers' Settlement Road, and access is via a footbridge, or else by four-wheeled drive across the gravel bar at the mouth of the Lagoon outlet stream into Lake Wairarapa. Access has recently been reduced due to the collapse of the vehicular bridge.

Barton's Lagoon was visited on 1 April and again on 15 April, 2010.

3.2 Topography & Stratigraphy

Simmonds Lagoon Wetland rest on lake silts, which overlie mixed river sediments deposited in a large alluvial fan extending inland as far as Featherston. The lagoon is stopbanked along its eastern boundary but the transition to pasture along the northeastern and northern boundaries is gradual and subject to seasonal flooding.

The Southern Wetland is hydrologically separated from Barton's Lagoon by a stopbank (see Fig. 3.1), which is continuous with the Tauherenikau Seepage Drain containment bank.

Most of the wetland around the lake is underlain by 30-40 cm of lake peat (a fine-grained mix of silt and planktonic detritus) over alluvial clay, and this organic sediment also extends into the paddocks to the northeast, indicating that a larger lagoon existed in the past.

Bore logs have not been examined for the area around Simmonds Lagoon, so any potential for an artesian input to the wetland can only be speculative. However, although there may be some supply into the wetland from gravels below the silts (as there is further south in the lake), it is not likely to be significant compared with the substantial surface input from the Tauherenikau River into Simmonds Lagoon.

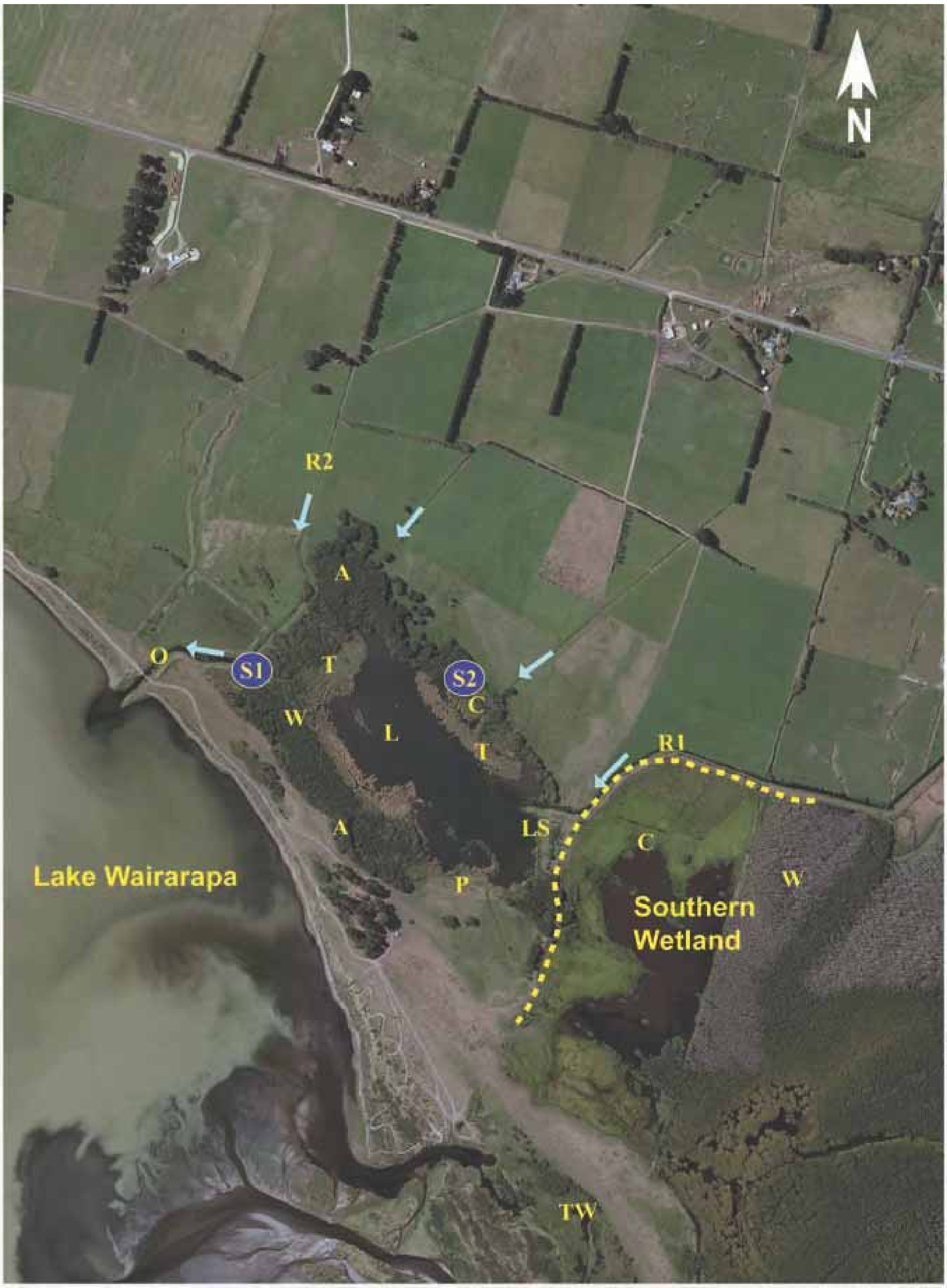


Figure 3.1 SIMMONDS LAKE DOMAIN RECREATION RESERVE

R1	Tauherenikau Seepage Drain	L	open water
R2	Western inflow drain	A	alder carr
O	outflow to Lake Wairarapa	W	willow carr
TW	Tauherenikau River Mouth & Tauherenikau Wetland Reserve	T	raupo reedland
S1 S2	sampling sites for water chemistry	C	creeping sedge sward
			large sedge sward
(yellow dashed line)	stopbank	P	rehabilitation planting

3.3 Hydrology

The majority of the water supply is channelled down a deep race (R1, Fig. 3.1) from the east, known as the Tauherenikau Seepage Drain, which originates from seepage beneath the stopbank and gravels of the Tauherenikau River. The estimated flow rate of this race in April 2010 was at least 500 L/s and it is known to sustain a high baseflow year-round, even during very dry summers. Water is also delivered by three drains from the north and northeast (particularly R2), but quantities are low in the summer (probably around 25 to 50 L/s).

Historically (braids are visible on the aerial photograph and also during ground inspection), there appears to have been a major north-south flowline entering the lagoon at its northern end and the R2 drain appears to carry some of that water, although a significant amount may have been overland flow, at a time when the area was dense native vegetation.

There is a strong flow into Lake Wairarapa from the Barton's outflow channel (O): at least 200 L/s, but often higher. On 22 April 2009, for instance, the outflow was gauged (GWRC) at 450 L/s under weather conditions similar to those during the present site visit in 2010.

The Lagoon hydrology is therefore 'supply driven'. Because both inflow and outflow are consistently high, the water level in Barton's is held in dynamic balance, with little seasonal variation, largely buffered against summer evaporation losses (probably only about $250m^3$/day, or 1% of the flow down the input race). This dynamic balance could only be altered by increasing the rate of outflow (not feasible) or by reducing the inflow rate.

GWRC records show that water backs up into Barton's Lagoon during winter highs in Lake Wairarapa (monthly average 10.2–10.4m asl), but inundation of the Lagoon only occurs during extreme events, such as the 2004 flood (over 12m asl).

The adjacent Southern Wetland, on the other hand, does not appear to have defined inflow or outflow channels, and water levels may be controlled by levels in the Tauherenikau Wetland Reserve. Vegetation patterns in the Southern Wetland suggest that seasonal water level amplitude is about 400-500mm.

3.4 Chemistry

Water sample S1 was taken from the wetland outlet stream and Sample S2 from groundwater in the peaty-silt substrate (6% carbon) on the northeastern margin of the wetland. The cation signatures of S1 and S2 are clearly linked with the same water supply – the Tauherenikau Seepage Drain. Since the flow rate of the Drain is high, residence time in the wetland will be less than two days, so nitrates in Barton's water discharged to Lake Wairarapa are more than likely to be close to nitrate concentrations entering the wetland from the Tauherenikau Seepage Drain.

However, nitrite-N is slightly elevated in the outflow stream, which may seem anomalous for such well-aerated waters, but this is water which has been in contact with a reducing organic substrate during its travel across the wetland. The high-carbon sediment is maintaining a more reducing environment at the interface with the overlying wetland waters. Sample S2, for instance, has all its nitrogen in the organic form (TKN), and the zero sulphate (compared with Sample S1) shows that this must also apply to sulphur. There are also at least three drains from pastoral land entering the Lagoon and these could be delivering ammoniacal nitrogen. They do need to be sampled.

TEST	Site	Simmonds	Simmonds
	Material	Water	Water
	Lab nos	780739.2	784374.2
	Location	outlet stream	20cm silt
	Date	31.03.10	15.04.10
	Sample	S1	S2
WATER	**UNITS**		
1. total nitrogen TN (3+4+5)	g/m^3	1.23	0.63
2. ammoniacal nitrogen ($NH_4\_N+NH_3\_N$)	g/m^3	0.0125	<0.010
3. Kjeldahl nitrogen TKN (2+organic N)	g/m^3	0.34	0.63
4. nitrite (NO_2_N)	$g/_m3$	0.0163	<0.002
5. nitrate (NO3_N)	g/m^3	0.88	<0.002
6. nitrite+nitrate (NO_2+NO_3)	g/m^3	0.89	0.002
7. total phosphorus (all organic P+8)	g/m^3	0.054	0.098
8. dissolved reactive phosphorus DRP	g/m^3	0.0082	0.028
9. sum anions ($HCO_3+CO_3+Cl+SO_4$)	Meq/L	1.25	1.01
10. sum cations (K+Na+Ca+Cl)	Meq/L	1.16	1.09
11. pH Laboratory	pH	6.9	6.6
12. pH Field	pH	6.6	64
13. electrical conductivity (EC) Lab	mS/m	13.0	10.3
14. electrical conductivity (EC) Field	mS/m	15.0	10.0
15. total alkalinity (as $CaCO_3$)	g/m^3	34	36
16. bicarbonate (HCO_3)	g/m^3	41	44
17. total hardness (Ca+Mg as $CaCO_3$)	g/m^3	34	29
18. dissolved calcium (Ca)	g/m^3	8.8	6.9
19. dissolved magnesium (Mg)	g/m^3	2.9	2.8
20.dissolved potassium (K)	g/m^3	1.36	2.2
21. dissolved sodium (Na)	g/m^3	10.2	10.6
22. dissolved chloride (Cl)	g/m^3	11.9	10.0
23. dissolved sulphate (SO_4)	g/m^3	8.6	<0.5
SOIL	**Lab**	**784422.1**	
	Location	**S1 org silt**	
	Date	**16.04.10**	
24. Total carbon (C) as dry weight	%DW	6.6	
25. Total recoverable phosphorus (P)	mg/kg DW	1008	
26. total nitrogen (N) as dry weight	%DW	0.62	
27. bulk density (volume weight)	g/mL	0.66	

Table 3.1: Barton's Lagoon water quality and soil chemistry data.

Although the assumptions made regarding the chemistry of Tauherenikau Seepage Drain water are reasonable, further interpretation would require analysis data from an actual sample taken from the Drain.

The substrate sample collected from the edge of the willow swamp at S1 characterises the substrate in Barton's Lagoon. It has a bulk density of 0.66g/mL, which is well below that of normal soils and clays, which are usually 1.0 -1.6g/mL. Organic soils are normally less than 1.0g/mL, because of high carbon levels. Although Barton's sediments are only 6.6% carbon it is expected that a high proportion of diatoms (planktonic algae with silica cell walls) will account for the low density, for the relatively high nitrogen content of 0.62% and for the low C:N ratio of 10:1 (equivalent to the ratio expected in a good forest litter layer).

Although nitrogen levels are high in Lagoon water, available phosphorus (DRP) is only in the oligotrophic range and even total phosphorus is only mesotrophic. With a phosphorus limitation, there is no immediate danger of a eutrophic algal blooms or other consequences of eutrophication.

The plentiful nitrogen and stable water levels in the lagoon create ideal conditions for the growth of raupo, which can form an aggressive sward in a eutrophic water body. Its distribution in the lagoon is probably limited only by water depth.

3.5 Ecology and land use

Barton's Lagoon is mostly a lacustrine wetland, with some fringing palustrine wetland along the northern margin. The Southern Wetland is partly shallow lacustrine and partly floodplain, and it ranges from regularly-flooded palustrine wetland to infrequently-flooded marsh.

The wetlands are characterised by six main community types:

- **Open water.** A large open water body (L, Fig. 3.1), which can only be approached easily from the southeast. Airey *et al* (2000) notes the presence of the aggressive submerged aquatic hornwort on the 'northern side of the Lake Domain' and this infestation needs re-surveying.

- **Willow and alder carr.** Extensive alder/willow swamp (more properly referred to as 'swamp carr'), with alder forming the outer fringe (A, Fig. 3.1) and crack willow the inner (W, Fig.3.1). Some alder has been cleared along the northwestern boundary of the wetland, in order to try to remove the source of a spreading weed problem.

  Much of the willow is mature, with an open canopy and sparse (largely exotic) ground cover, including *Bidens, Polygonum* and *Rorippa*, but also the occasional native *Carex secta* and *Isachne globosa.* In places, alder also has this ground flora, but occasionally also dense swards of *Apium nodiflorum* and *Isolepis prolifer* occur under alder.

- **Typha reedland.** Most of the water body is fringed with a *Typha* sward (T, Fig. 3.1), which is clearly responding vigorously to the relatively high nitrogen concentrations and rapid water throughput.

- **Tall sedgeland.** A *Carex geminata/*tall fescue community (C, Fig. 3.1) fringes part of the southwestern margin of the lake, behind the raupo sward, but the area is heavily modified and pugged through stock access from the grazed stopbank. *Juncus pallidus, J. articulatus* and the aggressive weed *Cyperus eragrostis* also occur in this mixed community.

- **Small sedgeland.** Also behind the dense raupo fringe on the eastern margin of the lagoon, but further north from the *Carex/*tall fescue community, where the un-stopbanked margin slopes gradually from paddock to open water, an extensive, almost monospecific, sward of

Isolepis prolifer, creeping sedge (C, Fig. 3.1) has developed, on lake peat about a metre deep.

Most of the large Southern Wetland is dominated by *Isolepis* (C, Fig. 3.1), but here the substrate grades from clay, near the stopbanks, to peat closer to the shallow open water body to the east. This is a classic gradient from a seasonally flooded marsh to a permanently waterlogged fen.

- **Turf communities.** Lake Wairarapa, and some of the ponds cut off from it, have submerged turf communities rich in native species (Airey *et al*, 2000; Ogle *et al*, 1990). The margins of Barton's Lagoon need to be surveyed in more detail for this community type, although it was not seen during the present study. Most of the suitable habitat has been dominated by willows and raupo for many years. The almost-permanently shallow-flooded area of the Southern Wetland may be another suitable habitat for submerged turfs.

  The Southern Wetland has turf-type communities which are only seasonally-inundated and not strictly comparable with normally-submerged lake-margin turfs. They also contrast in that they are rich in exotic plant species, although they may well be nurseries for small natives. The low stature and high species diversity of the turfs are to some extent maintained by stock and they transition along a gradient of drier to wetter from a *Juncus pallidus, J. articulatus, J. effusus, J. articulatus, Rumex crispus, Hypochaeris, Schedonorus, Cyperus ustulatus* community near the stopbank to a *Agrostis, Galium palustre, Ranunculus flammula, Lotus, Trifolium, Isolepis* turf, then to a wetter *Isolepis, Myriophyllum triphyllum, Ranunculus flammula, Veronica serpyllifolia, Galium palustre, G. trilobum, Hydrocotyle novae-zelandiae* sward with *Eleocharis gracilis* and *E. acuta* becoming more prominent toward the shallow margin of the almost permanently flooded central part of the wetland.

Barton's Lagoon and the Southern Wetland are, of course, important habitats for waterbirds. Airey *et al* (2000) lists 17 threatened fauna species recorded in Lake Wairarapa wetlands, but there has been no specific survey at Barton's Lagoon.

3.6 Threats

- The main hydrological threat is the potential for increasing abstraction of water between the Tauherenikau River and Lake Wairarapa and possible reduction in the lagoon water supply and its all-important flushing function.

- The Tauherenikau Seepage Drain is not a designated diversion of the Tauherenikau River, so the main water supply to Barton's could be subject to significant change in the future (e.g. in the event of increased ground instability, increased severity of droughts etc). The lagoon does seem to cope well with droughts at the moment, but only because it has a stable, high-volume inflow and effective flushing.

- Peat shrinkage (affected by farming intensity and lowering of the water table) could change the functional boundary between wetland and pasture along the northern boundary of the lagoon.

- Intensification of farming on adjacent land, and its resultant run-off, could cause increased nutrient inputs and reduction of biodiversity in the wetland through growth of aggressive vascular plant species and algae. Of particular concern would be any increase in phosphorus concentrations, as nitrogen is already well within the eutrophic range. This threat would be further exacerbated by a reduction in volume inflow through greater irrigation takes or reduction in seepage rates from the Tauherenikau River. Maintaining a high throughflow in Barton's Lagoon is the best protection against algal blooms.

- There is still evidence of significant stock intrusion along the southeastern and northern-eastern boundaries of the Reserve. At the southern end, stock have damaged a planting programme, as well as caused some heavy pugging and even grazed the raupo and flax. Stock effluent is a source of additional nutrients to Lake Wairarapa which is already classed as supertrophic (highly eutrophic).

- Ogle *et al* (1990) record over 100 adventive plant species in the Lake Wairarapa wetlands and Airey *et al* (2000) draws attention to 40 which need special vigilance. Of these, Mercer grass and hornwort are of particular concern at Barton's Lagoon and the Southern Wetland. Neither were seen during the present study, but hornwort at least has been recorded in the lake Domain.

3.7 Conclusions/recommendations

- Barton's Lagoon wetlands and the Southern Wetland, considered either separately or together, have significant conservation values, based upon their species diversity, their diversity of habitats and upon their geomorphological and hydrological features. Most of the plant species are exotics, but that should not automatically relegate these wetlands to a low ranking. Adventives are an important component now of the 'natural character' of many of New Zealand's wetlands and we need to get used to this fact and include exotics as community components, not weeds *per se*, unless they are behaving in an aggressive fashion and obviously eliminating other species. In fact, *Typha* and *Isolepis prolifer* can be almost as much of a threat to biodiversity as some adventive species when excess nutrients occur.

  Predominantly adventive communities can also act as sanctuaries for some New Zealand species: as, for instance, the turfs of the Southern Wetland, where stock grazing pressure maintains ecological niches in which small native turf species of genera such as *Galium, Gunnera, Pratia* and *Ranunculus* may well co-exist. Predominantly adventive assemblages can also be useful wetland community types in their own right: not for their species composition but for their landscape or wildlife value, or simply for water conservation.

  Low nutrient status is also a factor that reduces the competitiveness of faster-growing or higher-stature adventive species. Increased phosphorus levels would therefore have a deleterious effects as fast-growing, weedy species would be favoured.

- A full flora and fauna survey is needed for Barton's Lagoon and the Southern Wetland. Particular note should be taken of aggressive exotics.

- Supporting Barton's Lagoon wetland values depends primarily upon maintaining the present high-volume water supply that it currently enjoys. The present character of the Southern Wetland depends on maintaining its present hydrological relationship with the

Tauherenikau Wetland Reserve and, of course, on maintaining at least some limited stock grazing. Too many stock would increase phosphorus levels.

If stock grazing were removed from the Southern Wetland, the seasonally-flooded area would be likely to see domination by tall plant species (tall fescue, for instance), shading out the turf species. Localised trials with stock-exclusion blocks may be worth trying.

- If more water were abstracted from the Tauherenikau Seepage Drain, Barton's Lagoon would be likely to develop more seasonal wetlands, and possibly more exotic weed problems. In addition, both willows and raupo would advance further into the open water areas, as they are only limited at present from doing so by water depth. Constructing an outlet weir to maintain the lake level with a lower groundwater supply would not necessarily maintain the present wetland characteristics, because a weir would only maintain the water depth – it would not restore the high rate of throughput, so the threat of algal blooms would remain.

- Both the Tauherenikau Seepage Drain and the Simmonds Lagoon outflow are gauged by GWRC from time to time, but there would be benefits in having a continuous record of water levels in the lagoon: perhaps a capacitance probe in the open water at the southern end. Together with occasional flow-gauging and the rainfall record, a seasonal hydrograph would pick up any long term trends and feed into management planning for the wetland system.

- Farming to the north and northeast of Simmonds Lagoon is intensifying and irrigation needs, together with increased nutrient loadings, particularly nitrogen and phosphorus, could affect the wetland through the expansion of raupo and willow coverage and the shrinkage of open water, or through increased dominance of adventive species and algal blooms.

- There is considerable potential for restoration work, but the recently planted area on the southeastern shore of the lake (P, Fig. 3.1) is still being browsed by stock, with considerable damage to plantings. There would be benefits in restricting stock to land beyond a substantial buffer zone around the mean winter high water level in the lagoon. A buffer of 30-40m is preferable, but it may be difficult to secure more than 20m along parts of the eastern and northeastern margins.

- Three farm drains run into the eastern and northeastern margin of the lagoon. Time did not permit a detailed study of them, but it would be preferable if these discharged across land at least 20-40m from the lagoon or, even into constructed treatment wetlands. If they have not been monitored for nutrient loading (particularly phosphorus), it would be useful to obtain such data as part of a nutrient budget study.

- Total nitrogen levels leaving the wetland are quite high and, since flow rates are also high, nitrogen mass flow is very significant. It would be useful to know where all this nitrogen is coming from (perhaps employing a nitrogen isotope study). The nigh nitrite found in the present study needs further investigation. A two-year programme of water quality monitoring would be instructive regarding discharges to Lake Wairarapa.

3.8 Barton's Photographs

Photo 3.8.1: Lake, looking north from southern shore. This margin has been cleared of willow and alder and replaced with native planting. Unfortunately fence does not exclude stock, and much of the planting has been damaged and the raupo grazed.

Photo 3.8.2: Tauherenikau Seepage Drain near its source from under the river stopbank. Barton's Lagoon ca 2km far left. Note extensive use of irrigation.

Photo 3.8.3: Tauherenikau Seepage Drain entering Barton's Lagoon. High flow rate year-round. Photo taken from stopbank separating drain from Southern Wetland.

Photo 3.8.: Outflow from Barton's Lagoon. Dense raupo centre and willow beyond. Alder left centre on drier ground. Much of the rough grazing to the north and northeast of the Lagoon (i.e. to the left and beyond) is waterlogged most of the year.

Photo 3.8.5: Very little of the ground flora in the willow and alder blocks is native. Much is willow-weed, water celery and watercress. The substrate at the above location is 80cm of organic silt (lake peat).

Photo 3.8.6: Southern wetland from stopbank. Although dominated by *Isolepis prolifer* sedge here, wetland vegetation is more diverse towards the shallow lake beyond and, particularly, in the more seasonally flooded areas closer to the Tauherenikau Seepage Drain stopbank off the picture to the left. Willows in the distance have been sprayed. Fish & Game mai-mai in distance right.

4. MANGAROA PEATLAND
Hutt Valley

4.1 Introduction

Mangaroa Peatland is located in Whiteman's Valley, to the east of Wallaceville, and there is a good overview of the peatland as the Wallaceville Road drops down into the valley of the Mangaroa River. The wetland is in multiple private ownership and there is no public access. On 31 March 2010, access was facilitated by John Hill from his property on Katherine Mansfield Drive, and a ground inspection was made into the Grant Munro block.

4.2 Topography & Stratigraphy

Fuller (1993) and Harris (1984) describe Mangaroa Peatland as a bog and it does have the appearance of a classic valley bog. If that is the case then, like all lowland bogs, the surface would originally have been domed (higher in the centre than around the edges), but the 2004 GWRC LiDAR data overlay of the peat-covered area now shows the surface in the centre of the peatland to be practically level at RL 145m, with an eastward 2m rise through block M (Fig. 4.1) towards Katherine Mansfield Drive and a 2m downward slope across the western edge of the peat towards Black Creek. The blue line on Figure 4.1 does not delimit the extent of the peat: it is merely the GWRC Wetlands Database boundary and it has no practical significance on the ground.

The area now occupied by the peatland may have originally been a lake. This would have infilled with alluvial sediment, leading to swamp development maintained by groundwater flow from the western hills (and possibly the Mangaroa River) and the subsequent accumulation of up to 10metres (Harris, 1984) of peat. When the groundwater supply was not sufficient to regularly flood the swamp, it would have become a transition bog (see Section 1.4.3, wetland definitions) as rainfall contributed a greater proportion of the water supply. The present Black Creek is now an engineered drain, but it would formerly have been a stream draining the high ground to the west and the peatland to the east.

Figure 4.1 indicates 'gulley peats' to the west of the Mangaroa peatland. This is now a historical label, as the swamp peats which would have existed here, and for a short distance up the western gulleys, are no longer significant.

According to John Hill, there has been farming on the Mangaroa peat since the natural peat-forming vegetation was cleared in the late 1880s, and the area visited during the present study was part of the Waipango Farm in the early1900s. Further clearance operations by Dalmatians in the 1930s had the objective of harvesting flax crops, but ignorance of wetland processes resulted in heavy compaction of the surface peat and the flax cultivation enterprise failed (Fuller, 1993). Since then, much of the peatland

Figure 4.1 MANGAROA PEATLAND

S1	water chemistry sample from drain
M	manuka
C	recently cleared agricultural land
A1	intensive agriculture
A2	low-intensity grazing

has been burned over at least twice and part of it used as marginal pasture. Some areas (eg around C, Fig. 4.1) have been cleared, then allowed to revert, several times. The level of the peat surface will therefore have fallen significantly during the past 100+ years, due to the burning and the peat dewatering and oxidation.

4.3 Hydrology

There are two hydrosystems in the Mangaroa Valley: rain-fed and groundwater-fed. The groundwater system is drained by the Mangaroa River to the east and Black Creek, which runs along the base of the western hills to join the Mangaroa River to the north.

The two-metre rise from the floodplain of Black Creek to the surface of the Mangaroa peatland strongly suggests that the Mangaroa peatland is not part of the groundwater system and supports the contention that it is a bog or a transition bog.

SKM Consulting has recently (2007) modelled the hydrology of the Mangaroa River and its floodplain. The Q20 (20-year return period) flooding event model predicts possible waterlogging (but not deep flooding) in part of the north-eastern dairy farming area to the west of Whiteman's Valley Road, but deep flooding only in a small area near the Gun Club.

However, the SKM Q100 model (see Figure 4.2) predicts extensive flooding in the northeast sector and also up Black Creek. The model does confirm the elevation of the peatland above the floodplain and also the sharp cut-off along the northeastern edge of the peat, where intensive farming has lowered the peat level compared with the less intensive land-use to the west.

Local landowners contest the veracity of the SKM modelling, because flooding has never been observed in the northeastern peat-soil farmland. They confirm, however, that the area near the Gun Club is flooding-prone, and point out that the twin box culverts under the Wallaceville Road are probably too small for flood flow and an old bridge also remains in the channel of the creek. The landowners also question the reliability of the SKM model because, they note from the GWRC website, that the verification and calibration for the model was done well downstream, at Te Marua, where the Mangaroa River joins the Upper Hutt River. Landowners are in fact of the opinion that flooding frequency may have declined over the past 30 years (John Hill & Grant Munro, *pers. comm.*).

The floodplain modelling, whether realistic or not, obviously still raises concerns about future shrinkage of the peat under the more intensive farming that dairying and cropping bring. Both Figures 4.1 and 4.2 show that more-intensive farming is spreading into the blocks of remaining semi-natural vegetation. It has not been possible in the present study to carry out a full peat depth survey, but it is recommended that this be done and the floodplain models revised to take account of any expected future peat soil shrinkage rates. A 20-25mm per year peat shrinkage rate would be expected under intensive farming, but could be more, depending on the land use management practices employed and the peat type – but it would be less where the organic content of the soil is low.

Artesian water supplies originating beneath the peat deposits cannot be discounted, as they occur frequently in valley peatlands, but there is no direct evidence for this.

The main drains of the unimproved blocks of the peatland run NW-SE, usually 200-300m apart. Some exceed 1.5m depth. Drains on improved land are at 80-100m intervals.

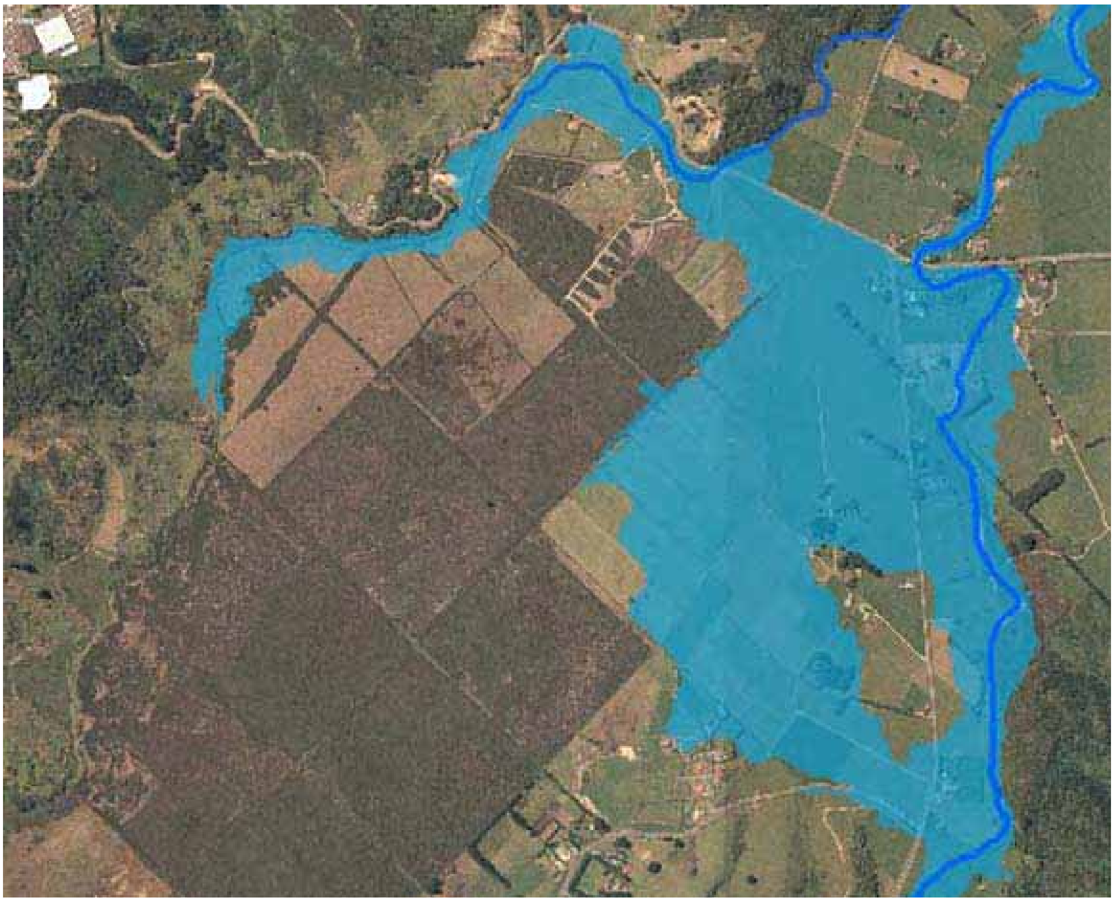


Figure 4.2: 100 Year Flooding Extent around the Wallaceville Hill Road and the Whitemans Valley Road. [After Fig. 5-29, SKM Consulting 2007]

4.4 Chemistry

A water sample was taken from a NW-SE drain in the centre of the peatland. Conductivity and pH values (Tab 4.1) are not indicative of bog peats, which would more typically be less than 8.0 mS/m and under pH5.0.

Bicarbonate, sodium and chloride levels also suggest that the drainwater originates outside the peatland. The relatively high sodium and chloride, in particular, are likely to be indicators of groundwater, although total dissolved solids are not particularly high, so an unconfined surface aquifer is most likely. As would be expected, nutrient concentrations are low.

Sampling was carried out in late summer and the drain water was over 1.5 metres below the peat surface and not flowing. From surface contours it is likely that normal flow direction is towards the Black Creek drain (SE-NW).

Further water quality sampling is needed to confirm the nature of the Mangaroa peatland and the source of the drain waters.

TEST	Site	Mangaroa
	Material	Water
	Lab nos	780739.1
	Location	Drain
	Date	31.03.10
	Sample	S1
WATER	**UNITS**	
1. total nitrogen TN (3+4+5)	g/m^3	0.98
2. ammoniacal nitrogen (NH_4_N+NH_3_N)	g/m^3	0.042
3. Kjeldahl nitrogen TKN (2+organic N)	g/m^3	0.92
4. nitrite (NO_2_N)	$g/_m3$	0.0047
5. nitrate (NO3_N)	g/m^3	0.051
6. nitrite+nitrate (NO_2+NO_3)	g/m^3	0.056
7. total phosphorus (all organic P+8)	g/m^3	0.026
8. dissolved reactive phosphorus DRP	g/m^3	0.0049
9. sum anions (HCO_3+CO_3+Cl+SO_4)	Meq/L	1.64
10. sum cations (K+Na+Ca+Cl)	Meq/L	1.66
11. pH Laboratory	pH	6.4
12. pH Field	pH	5.8
13. electrical conductivity (EC) Lab	mS/m	18.0
14. electrical conductivity (EC) Field	mS/m	23.0
15. total alkalinity (as $CaCO_3$)	g/m^3	24
16. bicarbonate (HCO_3)	g/m^3	29
17. total hardness (Ca+Mg as $CaCO_3$)	g/m^3	35
18. dissolved calcium (Ca)	g/m^3	6.7
19. dissolved magnesium (Mg)	g/m^3	4.5
20.dissolved potassium (K)	g/m^3	4.7
21. dissolved sodium (Na)	g/m^3	19.2
22. dissolved chloride (Cl)	g/m^3	38.0
23. dissolved sulphate (SO_4)	g/m^3	3.4

Table 4.1: Mangaroa peatland water quality data

4.5 Ecology and land use

Mangaroa is a deep valley peatland. – most likely either a bog or a transition bog. On the present visit, the peatland was cored to over 3 metres and both *Gleichenia* tangle fern and sphagnum moss macro-subfossils were identified in the profile, both of which are bog indicators.

The Mangaroa peatland is a unique geomorphological structure in the Wellington region and its peat type is probably also unique among remaining peat deposits.

Time did not permit visiting the ‘gulley swamps’ along the toe of the western hills, but Fuller (1993) reproduces, with reference to Harris (1985) and Druce (1957), what he considers to be a reconstruction of the vegetation profile from the upper rata/beech forest of the western hills, through kahikatea/pukatea/maire swamp forest to manuka/flax/sedge transition bog to the main body of a manuka/tangle fern/sphagnum bog. This reconstruction has yet to be verified by a more detailed study of the macro-remains in the peat profile, but it is an entirely plausible scenario.

In terms of natural vegetation, Mangaroa Peatland is now highly degraded. Even in 1993, Fuller noted that two-thirds of the the area was manuka scrub and gorse, and the remainder marginal pasture with *Juncus* rushes. In 2010 there are no significant natural vegetation communities remaining. Dense manuka covers several of the blocks, and suggests that the most recent burning would have been over 20 years ago. There is virtually no understorey in the manuka – a few *Dianella* (turutu) and the occasional wheki tree fern, some *Drosera* (sundew) on the drain sides – very little else. The low species diversity suggests low-nutrient, acid peats, but in any case the low water table and summer drought are not conducive to developing a permanent wetland at present.

In 2010, pasture in some of the areas visited was colonised by low-fertility grasses (*Agrostis, Cynosurus, Dactylis,* etc.) and was limed but not fertilized. Whereas this type of management regime will minimise peat shrinkage, the sustainable stocking rate is low. Most blocks are now cleared of gorse and are under fertilizer regimes to raise pasture production.

Fuller (1993) notes: *The perception that this land has limited value for development is reflected in the District Plan where the valley is classified 'Rural D: limited to low intensity development'. From an ecosystem perspective, the lack of 'value' for development represents an opportunity for enhancing wetland 'value'.*

It is almost certainly too late for that, as there is now an intensive dairying operation along the northeast margins of the peatland and land improvement is taking place for pastoral or cropping elsewhere. The peatland has also been in private ownership for a long time.

4.6 Threats

- The Mangaroa Peatland will continue to shrink under present management practices, although the unimproved blocks will have low shrinkage rates. Deep drains may increase shrinkage rates, and if the peat deposits are layered they increase the risk of a perched water table developing..

- The more intensive drainage regimes needed for intensive pastoral farming or cropping, together with much increased applications of fertiliser, also accelerate peat consolidation. This can rapidly create a height differential along the interface with unimproved peatland and may result in conflicts between adjacent properties with different intensities of land use. This has occurred in the Waikato, for instance.

  There is a threat to the role of the Mangaroa peatland as a hydrological buffer. Increased intensity of land use on peat soils may increase flooding risk from the Mangaroa River and Black Creek.

- Fire is a constant threat on dry peat, especially with large stands of manuka. Deep peat fires are a particularly serious threat, as they are difficult to extinguish (they may burn for several weeks) and can damage up to even two metres depth of peat over considerable areas. However, manuka clearance has been under way for a number of years, and the fire threat is therefore declining. In fact, there have been no significant fires in the last 30 years (John Hill, *pers. comm.*)

4.7 Conclusions and recommendations

- There are no obvious natural ecological values remaining at Mangaroa, as all natural vegetation has been removed. However, as a geomorphological feature – a large valley peatland – it is not only rare regionally, but also throughout the lower North Island. There is no District or Regional Plan protection and Council requires only that 'flows be maintained in waterways'.

  On the other hand, the value of the peatland as a farming resource and as a hydrological buffer are both high within the region. Unfortunately these two values are in potential conflict.

- Farming on peat is basically unsustainable in the longer term, because farming practices inevitably cause on-going shrinkage (dewatering and oxidation) of the peat. Unimproved, unfertilised peatland will have the lowest shrinkage rates, so in terms of soil sustainability, low intensity farming methods are the most appropriate. However, improved peats make very productive soils for farming purposes, but realising their full potential diminishes the lifetime of the soil resource, as well (perhaps) as the effectiveness of the flood buffer.

  In addition to drainage effects, different nutrient loadings (through fertilisers, stocking rates, cultivation, etc) also influence peat shrinkage rates, so that adjacent properties can potentially develop different surface levels.

- Because peat is not (when drained) a sustainable soil, where there is multiple ownership of a contiguous peat resource, there is a strong case for a monitoring programme to track ground levels and drainage configurations over time, because what happens on one property can affect activities on another.

  In the Waikato Region, for instance, drainage consents are required within 200 metres of a listed wetland. 'Listing' (in the Regional Plan) is usually based upon ecological/biodiversity values, but this is not an option for private wetlands like Mangaroa, due to their low ecological value. There is, however, a case for some sort of listing for Mangaroa Peatland based upon flood hazard, because reliable information on peat shrinkage rates could improve predictive models (e.g. SKM Consulting, 2007) for flood events. A survey of peat depths and extent would be needed, at least in the northern section.

- Surface level monitoring could in theory be done remotely by LiDAR, but the GWRC 2004 LiDAR survey used 2.5m contours, which is far too coarse for on-going surface monitoring. If LiDAR surveys could discriminate levels down to, say, 20-50cm then shrinkage could be monitored remotely over a period of, say, 10 years. Perhaps better discrimination could be extracted from the raw ground strike data used to generate the LiDAR contours.

- There is realistically little or no potential for restoration of natural wetland communities at Mangaroa Wetland. The hydrology of the peatland has been heavily modified through drainage and the removal of the original wetland vegetation. Wetland vegetation could not be re-established without re-wetting of the peat through significant year-round raising of the groundwater table and, even if there were a will to do this, it would be extremely difficult, if not impossible to achieve. And, in any case, the plant species that would have formed the peats no longer occur at the site and would therefore need to be re-introduced in any restoration plan.

- The water supply of the Mangaroa Wetland basin is derived from runoff from the hills (surface flow and, possibly, artesian), rainfall and the Mangaroa River.The general drainage direction is towards the north-east. There is insufficient information to speculate on possible interactions with deep, confined aquifers within the basin itself (some artesian input perhaps), or on whether the large number of properties along Katherine Mansfield Drive influence in some way the hydrology of the adjacent Mangaroa peatland.

- Harris's (1985) palynological investigation was the history of vegetation development in the area, so his limited number of peat cores did not shed much light of the three-dimensional structure of the Mangaroa peat deposit. A survey of the extent and depth of the Mangaroa peat would provide valuable baseline data for improving understanding of the hydrology of the basin, for predicting future surface contours and for deciding whether the flooding models need to be revised. Further chemical sampling is needed to confirm the relationship of the peatland with marginal drainage waters. Considering the rarity of this wetland type in the region, a stratigraphic study would also have significant scientific value.

4.8 Mangaroa photographs

Photo 4.8.1: Mangaroa peatland from the Wallaceville Road. Peat paddocks with manuka-vegetated drains, recently-cleared blocks beyond and remaining dense manuka stands in distance.

Photo 4.8.2: Three ages of manuka on deep peat: sub-fossil stumps of manuka exposed by consolidating peat, dense 15-25 year-old manuka stand beyond and regenerating manuka middle distance.

Photo 4.8.3: Subfossil kahikatea stumps exposed by consolidating shallow peat on southwestern margin of peatland. Dense manuka block middle right. Western hills with drainage gulleys in distance.

5. FOREMANS LAGOON
Wairarapa

5.1 Introduction

Foremans Lagoon is located adjacent to State Highway 2, six kilometres north of Carterton. It is a private wetland, owned by John Foreman, protected by a QEII Open Space Covenant and managed by Ducks Unlimited. Access is from a private road, past a property leased by Gordon Clode, a 40-year resident.

Foremans Lagoon was visited on 22 April 2010.

5.2 Topography and stratigraphy

The wetland comprises about 4ha of open water and marginal swamp. It is bounded to the north by the scarp of the Carterton fault-line, which rises 2-3 metres steeply from the lake to farmland with a thin, stony soil. The western end of the wetland is bunded by the main road, which is elevated well above surrounding land. Land surface slope, and drainage flow, is towards the south.

In its present form, the wetland has been created by excavation: deepening of the central open water area and construction of two islands with the excavated material. Most of the island material derives from a deep ditch dug just below the fault escarpment. Drainage is mainly via a stream exiting from the southern margin.

The fault is active, so little sediment has accumulated in deeper water but, at the shallower eastern end, 20-30cm of swamp peat has accumulated over a pebbly substrate. On the Google satellite image, there are braided flow-lines clearly visible in adjacent farmland, which explain the pebbly base material of the wetland: this area was formerly (and relatively recently) a river terrace, broken at this point by the fault-line. In fact, there is a suggestion from the aerial image that the flow-lines from the north converge on the wetland and then diverge again to the south. Unfortunately, these flowlines do not show up on the GWRC image, so the directions of the historical flow-lines have been indicated on Figure 5.1 with arrows.

5.3 Hydrology

Foremans Lagoon surface (rainfall) catchment is now only a small area of farmed terrace to the north (A, Fig. 5.1), and runoff from SH2 (I2, Fig. 5.1), which is banked toward Foremans on a curve. Most of the wetland's water supply (exiting at I1, Fig.5.1) appears to issue from almost a single point from under the fault esscarpment into the central lake area. The converging surface flow-lines from the north may, perhaps, explain the localised nature of the underground seepage input. The Masterton faultline at Waingawa Wetland and the Carterton faultline at Allen-Lowes Wetland also have localised spring seeps.

There are two outlets from Foremans. The main outflow is an adjustable board-weir halfway along the southern margin of the lake (O1, Fig. 5.1). There are no significant earthworks bunding the southern margin, so the weir installation in the 80cm deep outflow channel maintains the current depth of ponding. There is no provision for fish passage.

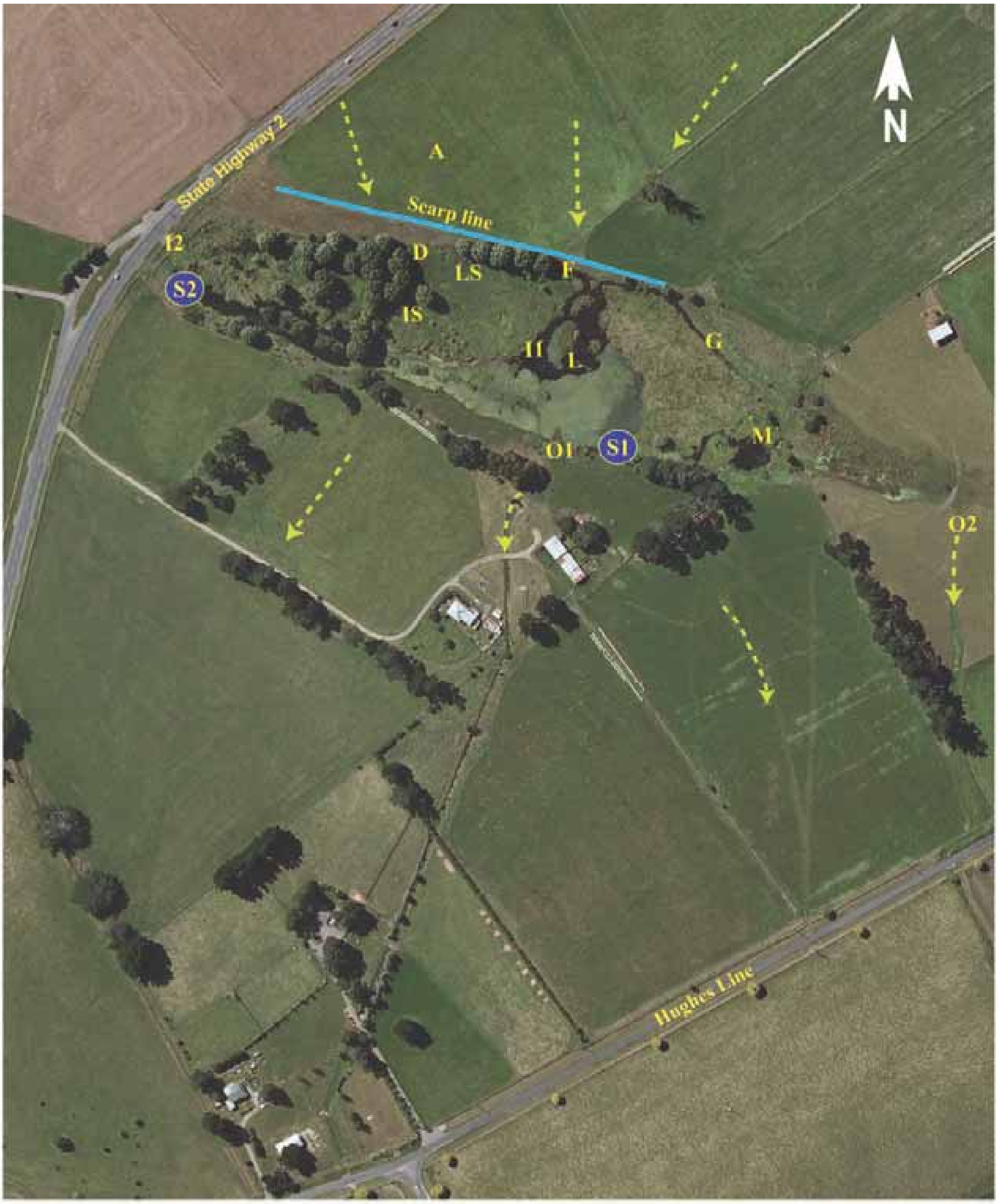


Figure 5.1 FOREMANS LAGOON

I1	main inflow from faultlines	IS	one of three constructed islands
I2	occasional stormwater flow from inroad	F	fault scarp (N–S downthrow)
O1	main outflow (adjustable structure)	LS	large sedge sward
O2	minor surface outflow	G	grass/small sedge sward
S1 S2	samples for water chemistry	D	deep excavated ditch below fault scarp
A	low intensity farming	L	open-water lake
- - ->	direction of terrace flow-lines	M	shallow lake margin community

The second outflow (O2, Fig. 5.1), a slow sheet- flow exits to the east, then turns south down a farm drain. Either the two outflows have exactly the same elevation, or O2 is higher and there is additional seepage from the fault scarp to the east of the Foremans lake which feeds O2.

Historically, there would certainly have been a natural wetland here, since the fault is clearly responsible for providing the water source. The faulting brings the water table in the northern terrace to the surface, effectively creating a north-south hydraulic gradient along the faultline. There was probably always an open water-body in the faultline debris depression, although it would have been smaller than it is now. However, water inflow could well have been greater in the past, so swamp and shallow seasonal marsh could have been more extensive to the south and east. The main historical outflow would either have been to the east, or else near the present location.

Most of the water supply is likely to be from a superficial, unconfined aquifer, with hydrological links to deeper, confined, aquifers unlikely or only minor. The sodium/chloride signature is not pronounced enough (it is similar to that of Barton's Lagoon) for a significant contribution from a deeper aquifer

5.4 Water chemistry

Sample 1 (S1, Fig.5.1), was taken from the open water area in the centre of the wetland, close to the southern outflow. Sample 2 (S2, Fig. 5.1) was taken from the western edge of the wetland, below the road. The concentrations of the major ions in the two samples are very similar, confirming that they have a common water source.

The relative balance of the major ions is broadly similar to shallow subsurface waters elsewhere in the Carterton Fault zone, but the closest chemical comparison in this study is with Barton's Lagoon and the Tauherenikau River. Since the nearest river to Foremans Lagoon is the Waingawa, this may suggest a more widespread similarity between waters ultimately derived from the Rimutaka and Tararua ranges, as well as across surface materials of the Wairarapa terraces. This point is picked up again in the General Conclusions (Ch. 12).

Total nitrogen levels are high and, in the S1 sample, most of it is nitrate, which suggests that much of it is likely to be leached nitrogen from pastoral land use in the catchment entering the shallow subsurface aquifer. Although the immediate catchment supports only low-intensity farming, there is both cropping and dairying further to the north.

S2 contains over twice (5.1g/m^3) the total nitrogen of S1, but the higher TKN (1.87g/m^3) suggests that the additional nitrogen is generated within the wetland by decomposition and bird activity. Algal growth is also more prominent at S2, and it is possible that some nitrogen derives from State Highway 2 stormwater runoff, as nitrogen oxides (NO_x) are dissolved in rainwater to form nitric acid. There is, for instance, a fertiliser store just down the road which despatches regular truck deliveries. Further speculation needs more detailed sampling.

Comparing phosphorus concentrations, S1 total phosphorus (0.052g/m^3) is similar to several other Wairarapa wetlands, but S2 has five times as much phosphorus (0.27g/m^3). Both are largely organic-P, so with 0.05g/m^3 being an approximate regional norm, the additional phosphorus in S2 appears to be indicative of either local generation within the wetland (e.g. bird-imported), or of runoff from the highway.

TEST	Site	Foremans	Foremans
	Material	Water	Water
	Lab nos	786392.1	786392.2
	Location	Lake	Lake
	Date	22.04.10	22.04.10
	Sample	S1	S2
WATER	**UNITS**		
1. total nitrogen TN (3+4+5)	g/m^3	2.0	5.1
2. ammoniacal nitrogen (NH_4_N+NH_3_N)	g/m^3	0.126	0.0185
3. Kjeldahl nitrogen TKN (2+organic N)	g/m^3	0.73	1.87
4. nitrite (NO_2_N)	$g/_m3$	0.025	0.0033
5. nitrate (NO3_N)	g/m^3	1.25	3.2
6. nitrite+nitrate (NO_2+NO_3)	g/m^3	1.27	3.2
7. total phosphorus (all organic P+8)	g/m^3	0.052	0.27
8. dissolved reactive phosphorus DRP	g/m^3	<0.004	0.055
9. sum anions (HCO_3+CO_3+Cl+SO_4)	Meq/L	1.24	1.5
10. sum cations (K+Na+Ca+Cl)	Meq/L	1.12	1.29
11. pH Laboratory	pH	6.9	6.8
12. pH Field	pH	6.5	6.3
13. electrical conductivity (EC) Lab	mS/m	13.2	14.4
14. electrical conductivity (EC) Field	mS/m	14.2	15.0
15. total alkalinity (as $CaCO_3$)	g/m^3	26	30
16. bicarbonate (HCO_3)	g/m^3	31	37
17. total hardness (Ca+Mg as $CaCO_3$)	g/m^3	32	38
18. dissolved calcium (Ca)	g/m^3	7.5	8.8
19. dissolved magnesium (Mg)	g/m^3	3.3	4.0
20.dissolved potassium (K)	g/m^3	1.73	1.77
21. dissolved sodium (Na)	g/m^3	9.7	11.0
22. dissolved chloride (Cl)	g/m^3	13.9	14.1
23. dissolved sulphate (SO_4)	g/m^3	11.3	12.4

Table 5.1: Foremans Lagoon water quality data.

Both petrol and diesel engines have high NO_x outputs and the nitric acid they form during rain events could produce organic nitrogen compounds within the wetland. Petroleum-based petrol and diesel fuels do not contain large amounts of phosphorus and, although bio-oil based diesel does, it is not yet used extensively in New Zealand. However, phosphorus compounds (thiophosphonates, zinc dithiophosphates) are extensively added to vehicle lubrication oils as anti-oxidants, corrosion inhibitors, anti-wear agents and detergents (del Rio, 2008), in amounts of up to several thousand parts per million.

Considering the large discrepancy between the phosphorus concentrations at S1 and S2, runoff from the highway should at least be considered a possibility as a significant nutrient source for the wetland. However, the arguments presented here in support of this suggestion are entirely speculative at this stage and would need to be verified by more detailed chemical sampling. For instance, samples in the present study were not analysed for heavy metals, but zinc and copper would almost certainly be present in sample S2 if there is traffic-derived phosphate. Similarly, a significant presence of PAHs (polycyclic aromatic hydrocarbons, such as benzene and toluene) would support a proposal for the road being a significant source of nitrogen.

Sulphur concentrations too are higher than in all other wetlands in the present study except for the coastal wetlands of Kathihiku and Haruatai, so road sources (vehicle tyres and exhaust fumes) are again possible. However, Foremans Lagoon used to be the site of a tannery/fellmongery, so there is also the possibility of residues still remaining in the lagoon sediments from the use of sulphides and sulphites during the de-hairing process. Once again, further analyses are needed to explain the sulphur concentrations here – they may simply be a feature of the particular aquifer supplying the Foremans'water.

5.5 Ecology and land use

Foremans Lagoon is largely a lacustrine wetland, but with some palustrine components around the eastern margin. It is not a particularly significant wetland in terms of naturalness and ecological representativeness, but it is still a good example of a wetland based upon a shallow water body with extensive shallow margins. It has moderate plant species diversity, high landscape diversity values and moderate values for its wildlife (predominantly wildfowl) habitat. Values are limited mainly by the reserve's small size and by its relatively low diversity of native plant species.

Most of the plant species in Foremans Lagoon are exotic. There are five main plant communities. Taxa listed below are indicative only:

- **Aquatic community**: *Rorippa, Azolla, Potamogeton, Spirodela, Schoenoplectus, Potamogeton crispus*
- **Shallow lake margin**: *Myriophyllum propinquum, Isolepis, Polygonum, Carex secta, Eleocharis gracilis, Juncus articulatus, Veronica serpyllifolia, Myosotis, Cotula* etc
- **Tall sedge community**: *Carex geminata, tall fescue,*
- **Wet grass community**: *Holcus, Agrostis, Glyceria declinata, Juncus*
- **Islands and steep margins**: Manuka, tree lucerne, alder, *Cordyline, Salix babylonica,* flax, tall fescue, *Dactylis.*

The lake margins have the greatest total species diversity, with a good mix of natives and exotics. There has been extensive planting on the islands, but this is, after all, primarily a wetland developed to optimise waterfowl habitat, many of which nest in the wetland.

Although the control structure on the outflow stream at O1 (Fig. 5.1) restricts fish access, it is possible that they could still enter the wetland from the eastern drain.

5.6 Threats

- The wetland is critically dependent on the faultline water supply, which may be less predictable than a race or a river. However, little can be done to protect against possible fault movement and settlement, as there is no alternative water source. The depth of the water source below the visible escarpment is not known but, from its chemical signature, it is presumably (entirely or predominantly) an unconfined subsurface aquifer.

- A reduction in water throughput would be of concern with present levels of nutrients (and especially if phosphorus supply were to increase relative to nitrogen), because of the risk of algal blooms with increased water residence time.

- Stormwater from the road is potentially a source of contaminants – a possible source of not only nitrogen and phosphorus, but also of heavy metals (particularly copper, lead and zinc) and PAHs. Extra nitrogen could promote the growth of aggressive plant species, PAHs can be toxic to invertebrates at least, and heavy metals can be accumulated in food chains. Heavy metals are chelated by humic acids, so there may be accumulation of these in the wetland's organic sediments – even from the bygone days of leaded-petrol.

- Raised nutrient status could result in expansion of coverage by of aggressive plant species at the expense of overall species diversity. *Azolla* floating fern, *Glyceria* grass, and native raupo, the tall sedge *Carex geminata,* and the mat-forming sedge *Isolepis prolifer* all respond well to plentiful nutrients. Algae too, of course, but the risk of blue-green algal blooms at the moment is low as the N/P ratio is low. However, increased bird numbers and reduced summer flow rates could change this.

- The further intensification of agriculture is always a threat to small wetlands. The thin, porous, stony soils north of Foremans lagoon would be particularly susceptible to nutrient infiltration under more intensive land-use practices, such as irrigation).

5.7 Conclusions/recommendations

- Foremans Lagoon is a small lacustrine wetland fed by spring water along a faultline and ponded by a board-weir. It has only moderate ecological values, but provides valuable waterfowl habitat. Since birds are breeding in the wetland, a pest control programme (stoats and rats) is likely to be a component of its current management plan.

- The wetland is not ideal mudfish habitat, but it may be worth conducting a survey to check for fish presence.

- Because of its small size, Foremans Lagoon will only be ecologically stable if the water throughput (turnover rate) remains high. There is scope for enhancing the native wetland flora (eg by increasing sedge diversity), but this is not likely to be a priority for Ducks Unlimited unless it can add significantly to wildlife habitat.

- A biannual water sampling programme would be useful to check for eutrophication trends. It should include, at least initially, sediment analyses, particularly for phosphorus and sulphur. The control structure could be modified (with a V-notch weir and capacitance probe) to monitor flow rates. As a small wetland, hydrological models will have fewer variables. The role of the eastern outflow needs further research.

- The threat from road runoff contaminants is unknown, but Foremans is uniquely placed for a research study into this, because the roading discharge is so clearly definable at this location and conclusions could have applications in the many other places that roading potentially impacts conservation reserves. 'First flush' events (initial rain runoff after a long dry period) discharging directly into the wetland would be the most (potentially) harmful. Such events could carry nutrients such as nitrogen, sulphur and phosphorus, as well as a range of potentially toxic chemicals.

  A student ecotoxicology study would probably be the best approach. If toxins in stormwater runoff do prove to be a significant ecological threat and/or if nutrient additions have the potential to change the wetland character, perhaps the roading authority could be approached to fund construction of a settling/treatment pond with a discharge to a stormwater drain isolated from the Lagoon.

5.8 Foremans photographs

Photo 5.8.1: An aesthetically attractive recreational wetland with high landscape amenity value, but largely comprising exotic species. In this view, native flax and *Juncus sarophorus* mix with dominant exotic trees and grasses, willow-weed and watercress.

Photo 5.8.2: Lake looking southwest, with secondary outflow to immediate left.

Photo 5.8.3: Deep ditch below fault escarpment (behind camera). Large sedge/grass sward and lake beyond.

Photo 5.8.4: Eastern margin of wetland, looking towards secondary outlet (red colour is water fern). Sward is tussocks of adventive *Juncus* rushes and creeping bent grass (left); native *Isolepis prolifer* sedge right.

Photo 5.8.5: Metalled shoulder of State Highway 2 channelling road runoff through culvert to wetland.

6. TE HAPUA WETLAND COMPLEX
Kapiti Coast

6.1 Introduction

Te Hapua boasts the broadest range of coastal wetlands on the Kapiti Coast and also comprises a large proportion of the district's remaining 1% of its formerly extensive palustrine swamps (Aussiel, *et al*, 2008). Even so, most of the Te Hapua wetlands have been heavily modified by drainage, grazing, roading and property development. But during the past 10 years, several wetlands have been constructed, rehabilitated or artificially enhanced to re-establish some of the former landscape character of the area and, collectively, the Te Hapua wetlands now represent a valuable conservation and recreational resource. Some are protected by QEII Open Space Covenants.

Te Hapua wetlands are accessed from Te Hapua Road, off SH1 between Waikanae and Otaki, and they are all privately owned. Four wetlands were visited on 19 and 21 April 2010: Trotters, Jill and Joys, Pateke and Shovelers.

Valuable insight into the structure and functioning of the Te Hapua wetlands can be found in Craig Allen's MSc study (Allen, 2010).

6.2 Topography and Stratigraphy

The Kapiti Coastal Zone is underlain by gravels, sands and silts to a considerable depth. The maximum post-glacial sea level is marked by a wave-cut platform to the west of State Highway 1 and sand dune formation, with inter-dune swamps, commenced as the sea receded about 6500BCE.

The Te Hapua wetlands were formed from this time as dune slacks and ephemeral dune lakes, some developing later into seasonal swamps. Peat-depositing fens predominate closer to the wave-cut platform, where water levels are more seasonally stable due to springs issuing from the nearby higher ground, but as seasonal fluctuations in groundwater increase to the west, wetlands of the dunefields become increasingly ephemeral.

Wetlands are common in older dunes, because iron and humic compounds bind sand grains together to make impermeable layers. Sometimes the impermeable layer is provided by a silt band. Deeper in the profile, confined aquifers are separated by aquicludes (impermeable layers) of silts or peats. One of the main wetland management issues is whether, and to what extent, Te Hapua wetlands may be interconnected with a deeper aquifer.

All of the wetlands visited during the present study possess organic soils of 10-24% carbon content around their peripheries. In fact, at about 45% organic content (24% carbon), the soil of the swampy eastern margin of Pateke Lake is a peat.

6.3 Hydrology

Te Hapua wetlands are supplied with water from rainfall, from short-term (seasonal) groundwater storage in adjacent dunes (and possibly from transfer of surface groundwaters from adjacent basins), from surface drainage, or maybe even the Mangaone Stream or, during

Figure 6.1 TE HAPUA WETLANDS

S1 S2 Water quality sampling points

flood peaks, from artificial drainage channels such as the Puruka Drain (sometimes called the Te Horo Drain) from the north . All of the main wetland aquifers are unconfined and may lose or gain water from adjacent surface systems, depending on the permeability of intervening material. Transmissivity can be quite high in the unconfined surface aquifers of sand dunes.

Hydrology and water chemistry studies carried out to date (Jones & Gyopari, 2005; Tidswell, 2009; Allen, 2010 and *pers. comm.)* suggest that the three deep confined aquifers (35-56m, 65-110m, 164-172m) are unlikely to significantly recharge the wetlands. However, all of these studies have still left the possibility of hydrological connections between confined and unconfined aquifers open. Several of the deep bores in the coastal zone have significant piezometric heads (vertical hydraulic pressure gradients), impermeable layers vary in thickness and are often discontinuous, so artesian inputs to some wetlands cannot be ruled out, except by monitoring for chemical signatures.

However, precisely because deeper bores have positive piezometric heads, it is highly unlikely that any wetlands are being significantly drained into a lower aquifer. Nevertheless, although the deeper aquifers are apparently under-allocated in terms of borehole abstraction, and pump-tests show good recovery, it is still not unlikely that, in dry summers, piezometric heads in lower aquifers could be reduced with drawdown effects on the surface unconfined aquifer.

Indeed, Allen (2010) has noted that deep bores closer to the sea, such as R25/5100 (a 48m bore), show greater seasonal fluctuations than those closer to the Tararuas, so the potential vulnerability of unconfined aquifers increases seawards. Nine subdivisions are planned for west of the Shoveler Wetland and these are likely to tap the 90m aquifer. In fact, the high-take consented bores in the Te Hapua area all tap aquifers in the 50-90m depth range, whereas shallow bores drawing from the unconfined surface aquifer are only used for small takes, such as stock watering (Allen, *pers. comm.*).

Whilst it is good to keep water abstraction well away from higher aquifers which are more likely to directly affect the wetlands, it cannot be assumed that abstraction will have no effect at all on confined aquifers and some monitoring would be wise. Similarly, with small, unconsented takes, it is not the size of individual surface takes that matters, but the cumulative take.

Allen (2010) has distinguished between three distinct hydrological types of wetland:

- Upper catchment fens fed by year-round groundwater flows from springs in the wave-cut platform.
- 'Recharge wetlands' in dune hollows (eg Jill & Joy's, Shoveler). These were formerly dune slack wetlands, ephemeral, but with elevated seasonal aquifers in the flanking dunes maintaining surface water in the dune hollows at least well into the summer.
- 'Discharge wetlands' on relatively flat land (eg Pateke, Trotters), in which the water table is elevated above groundwater levels in adjacent land for at least part of the year.

Discharge wetlands are the most vulnerable of the non-fen Te Hapua wetlands, because they are usually dependent on either rainfall, or perhaps artesian, water to see them through the warmer part of the year. Another possibility is that some discharge wetlands, such as Pateke, may simply have higher throughflows (or, at least, inputs) during the summer than recharge wetlands, so that the open water areas maintain their water levels as riparian zone levels decline though evaporation – two wetlands occupying different places on a hydrological continuum. And, of course, if recharge and discharge wetlands are different hydrologically, they will almost certainly be distinguishable chemically in some way as well.

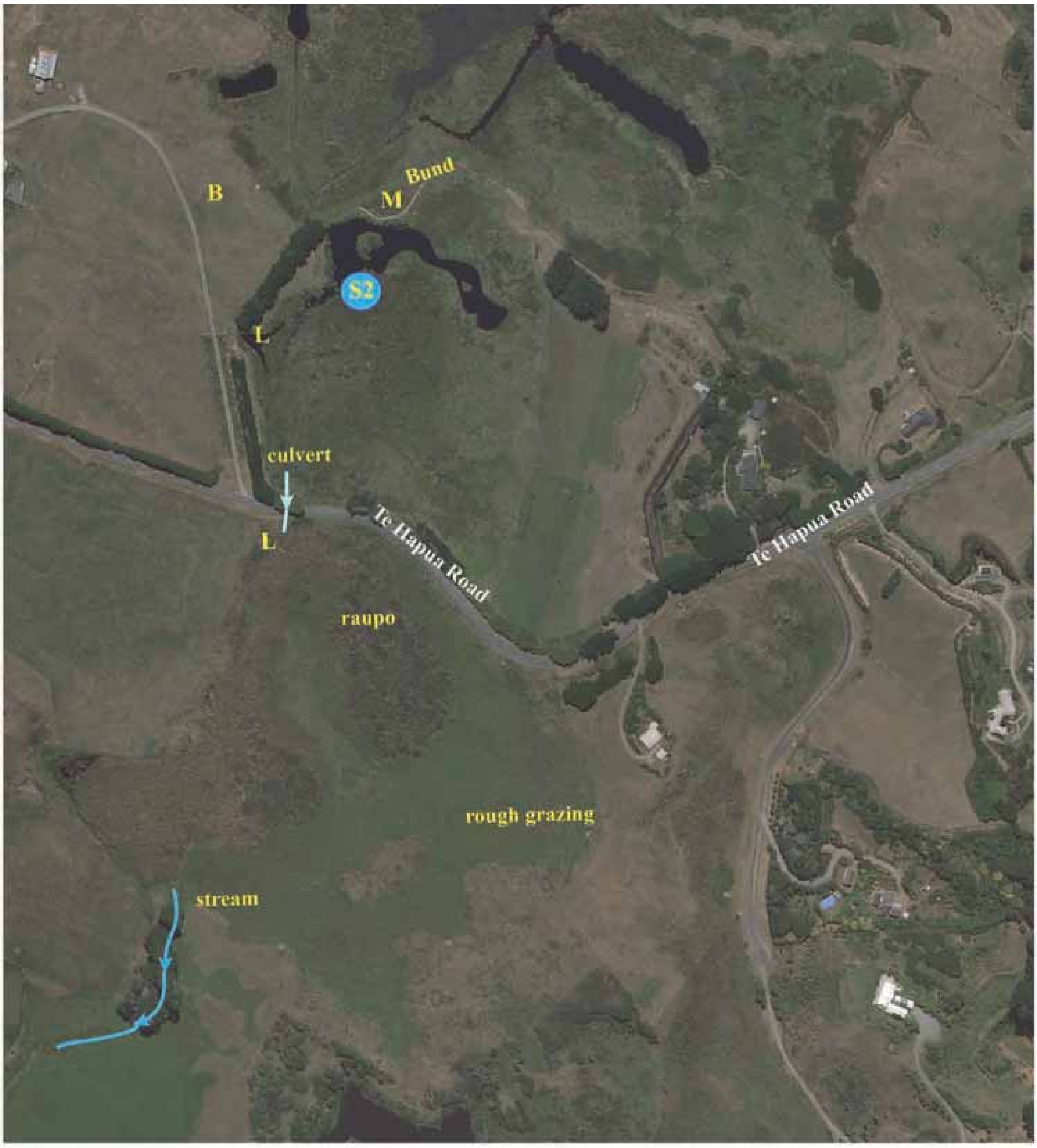


Figure 6.1 A JILL & JOY / TROTTERS WETLANDS

L Water level recorders

B Bore R25.5111 (O' Malley bore)

M Liverwort 'mini' wetland

S2 Water quality sample

Culvert

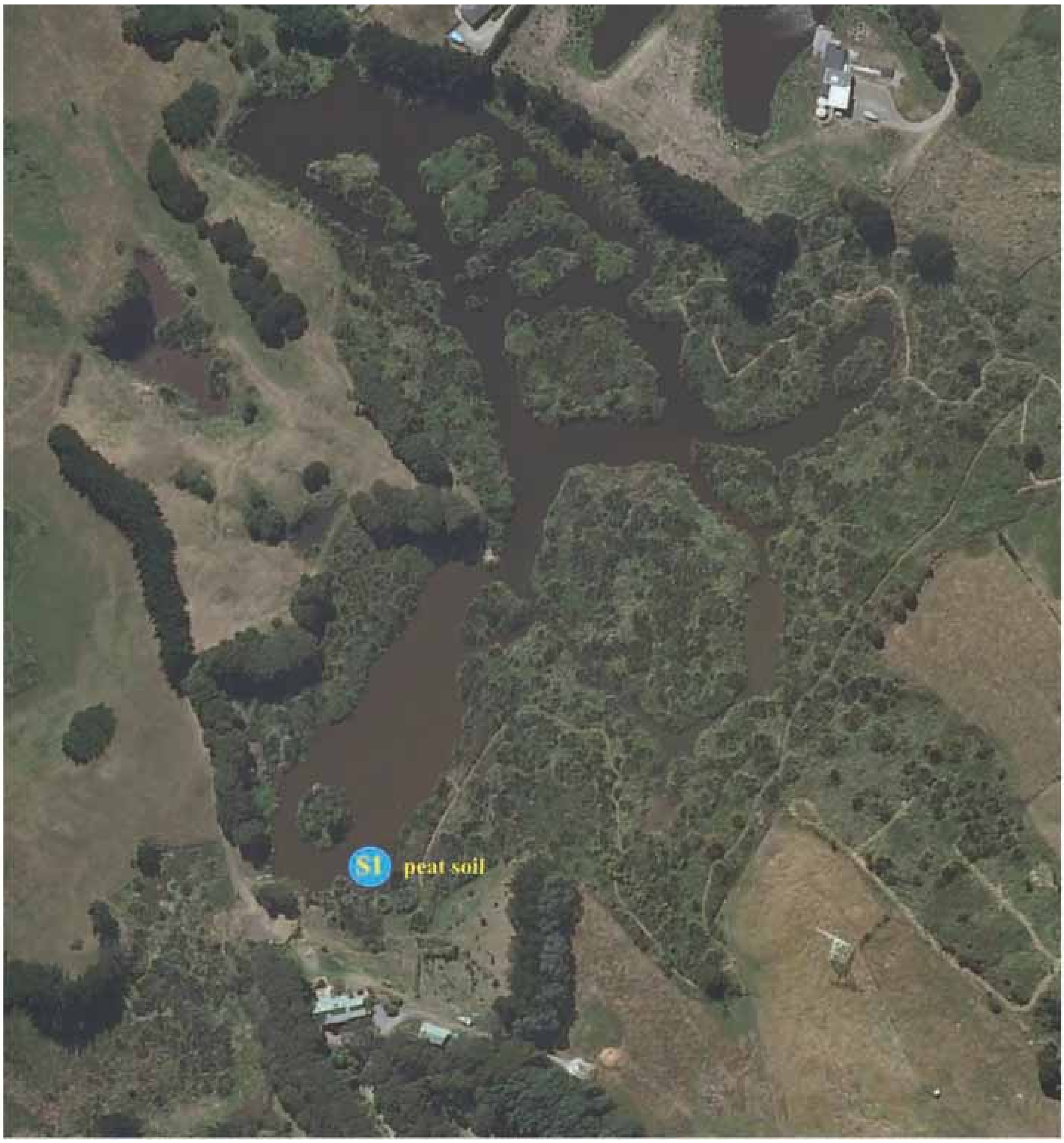


Figure 6.1 B PATEKE WETLAND

S1 Water quality and soil samples

NOTE: Compare colour of algal bloom in lake below centre, compared with clear humic-stained waters towards top.

Figure 6.1 C SHOVELERS WETLAND

B Location of bore and rain gauge

L Water level recorder

A Note floating water fern carpet (compare darker fern-free water in Shovelers)

Over 95% of the original wetlands in the coastal zone have been drained or altered and most of the Te Hapua lakes have been created by shallow excavation to expose the surface aquifer. Since lakes were not formerly a common feature of these dune wetlands, there can be no assumption that the (artificial or modified) wetlands of today will be sustainable simply because the original wetlands were. Lakes almost always have higher evaporation rates than vegetated wetlands, particularly when they are as shallow as the Te Hapua ones and have relatively low albedos. They are therefore prone to summer heating and high evaporation losses.

The automated water-level monitoring equipment already installed in Trotter's (recharge wetland) and Jill and Joy's (discharge wetland)will be very valuable in identifying trends and developing hydrological models for the two wetlands, but will be unlikely to detect any deep aquifer contributions unless they are fairly substantial. Also, care must be taken to cover all major parameters if these models are to be reliably predictive. An important management parameter, for instance, is (water) turnover rate, especially since groundwater input/output rates are probably quite low. For instance, the stream running under the road from Jill & Joy's to Trotters does not usually flow during the summer. The raupo swamp in Trotters Wetland is fed by shallow, unconfined groundwater from the west, but this water flow is supported by a weir on the stream exiting the raupo to the south. This provides enough water to keep the species-rich rough grazing area south-east of the raupo supplied with summer moisture

Ecological processes and trends are usually slow and weather conditions vary from year to year, so long-term data are usually required to validate models. Even then, there are episodic 'threshold events' - extreme situations which can 'flip', or reset, ecology and hydrology into new stable patterns. For instance, Allen (2010) suggests that the 1.6m sustained drop in the R25/5111 bore may well have all occurred during the dry summer of 1997-98. Moreover, he does not believe that the primary cause of this significant change was weather conditions, because this was the only bore log that showed a sudden change of that magnitude. Allen believes that some anthropogenic influence is more likely to be responsible.

There are more 'stresses' on the Te Hapua wetland than there used to be in pre-development times – even with the wetland creation and re-vegetation programmes in place (and maybe partly *because* of these programmes) – so the occasional threshold event can be expected to impose itself on longer-term hydrological trends.

Activities outside the Te Hapua wetland complex may also be having an impact on the hydrology. Shoveler lake, for instance, was excavated in 1990 by removing about one metre of peat/organic soil down to the sand base. The northern margin of Shoveler has been stopbanked since the land was subdivided, but a deep, unlined drain, Puruka Drain, starting only metres north of the stopbank extends, unbroken, as far as the Mangaone Stream to the north.

This drain contributes to agricultural intensification adjacent to, and beyond, the Te Hapua wetlands and has the potential to bring about longer-term hydrological changes within the wetlands area. In fact, landowner Ian Jensen believes the Puruka drain is already having a major hydrological effect on Shoveler, where he is monitoring both surface water levels and the effects of a 10metre deep bore. Minor stopbanks almost always leak, unless they are very well keyed into the substrate – and the substrate here is coarse sand. The drain has, for most of the growing season, a significantly lower water level than the Shoveler wetland to its immediate south and this increased hydraulic head could well be drawing water from the Shoveler Wetland. The 10m bore, of course, will also be accessing the unconfined wetland aquifer, so its effect will need to be accounted for before any effect of the Puruka Drain is factored into the equation.

In times of flood, though, the Puruka Drain is a conduit for bringing agricultural runoff south, to the very boundary of the Te Hapua lower wetlands. Any water quality sampling programme for Te Hapua should consider monitoring for any significant nutrient transfer effect.

The Puruka drain may also be impacting on the QEII covenanted Housiaux block to the east of the drain. The Housiaux wetland is higher than the drain, so will not receive nutrients from it but, by intercepting the groundwater table the drain is not only increasing the hydraulic head between the Housiaux wetland and the drain, but also rapidly removing water drained into it. This enhanced drainage effect warrants further study.

Several of the concerns discussed above were also expressed by Jones & Gyopari (2005), who recommended 150m buffer zones around wetlands and springs, with all abstraction controlled within these zones. The Waikato Regional Council has such a restriction which applies to wetlands specified in the Regional Plan. Jones and Gyopari also recommend surface and shallow water monitoring, as well as additional monitoring of wetland levels and springs.

6.4 Chemistry

Sample S1 was taken from Pateke and S2 from Jill & Joy's. The major ions clearly show, for both wetlands, the sand-dune signature of high values for pH, Ca and carbonate/bicarbonate. The Pateke discharge wetland has higher levels of these ions, suggesting a different water supply. Other ions, particularly sulphate, also point to
water supply differences. The high sodium and chloride concentrations are most likely to derive from residual coastal sediments in the adjacent dunes, or from aerosol deposition by on-shore winds and during sea frets. Different catchment characteristics could account for different sodium/chloride concentrations in Pateke and Jill & Joy's and, of course, one is a discharge wetland and the other a recharge one, so differences in major ion concentrations would be expected of two wetlands at different points on a hydrological continuum.

On the basis of several differences between major ions in S1 and S2, a contribution from a deeper aquifer, probably to Pateke, cannot be ruled out, but water quality analyses from selected boreholes and from more widespread surface sampling in different wetlands would be needed before water sources could be confirmed with confidence. Heavy metal analyses may also provide useful indicators.

Total Kjeldahl nitrogen (TKN) and total phosphorus concentrations are both high, particularly in Jill and Joy's, and oxidised forms of nitrogen and phosphorus are very low. Dissolved oxygen concentrations are therefore expected to be low, and the heavily humic-stained water does suggest this. At least some of this organic nitrogen probably derives from atmospheric nitrogen fixation by the high cyanobacterial and water-fern populations in these lakes, although there will also be a contribution from lake detritus breakdown during the summer.

It is also possible that there is some nitrogen and phosphorus input from outside the permanent wetland to Jill and Joy's and some particularly vigorous raupo stands in this wetland would be worth checking for point-source surface nutrient runoff or artesian supply. The nitrogen concentration in Jill and Joy's does seem to be too high to be solely internally generated, although disturbance caused by the recent removal of willows may have resulted in a temporary nutrient release.

TEST	Site	Te Hapua	Te Hapua
	Material	Water	Water
	Lab nos	785164.1	785164.2
	Location	Pateke	Jill & Joy's
	Date	19.04.10	19.04.10
	Sample	S1	S2
WATER	**UNITS**		
1. total nitrogen TN (3+4+5)	g/m^3	1.14	5.8
2. ammoniacal nitrogen (NH_4_N+NH_3_N)	g/m^3	<0.010	<0.010
3. Kjeldahl nitrogen TKN (2+organic N)	g/m^3	1.13	5.8
4. nitrite (NO_2_N)	$g/_m3$	<0.002	0.0034
5. nitrate (NO3_N)	g/m^3	0.0126	0.022
6. nitrite+nitrate (NO_2+NO_3)	g/m^3	0.0127	0.026
7. total phosphorus (all organic P+8)	g/m^3	0.174	0.34
8. dissolved reactive phosphorus DRP	g/m^3	<0.004	0.030
8a. nitrogen/phosphorus ratio.	-	6.6	17.0
9. sum anions (HCO_3+CO_3+Cl+SO_4)	Meq/L	2.9	2.7
10. sum cations (K+Na+Ca+Cl)	Meq/L	2.8	2.4
11. pH Laboratory	pH	7.4	7.4
12. pH Field	pH	7.7	8.6
13. electrical conductivity (EC) Lab	mS/m	31.4	30.6
14. electrical conductivity (EC) Field	mS/m	27.5	28.6
15. total alkalinity (as $CaCO_3$)	g/m^3	70	46
16. bicarbonate (HCO_3)	g/m^3	85	56
17. total hardness (Ca+Mg as $CaCO_3$)	g/m^3	72	49
18. dissolved calcium (Ca)	g/m^3	15.8	11.0
19. dissolved magnesium (Mg)	g/m^3	7.9	5.3
20.dissolved potassium (K)	g/m^3	5.3	3.7
21. dissolved sodium (Na)	g/m^3	29	31
22. dissolved chloride (Cl)	g/m^3	50	62
23. dissolved sulphate (SO_4)	g/m^3	5.1	0.85
SOIL	Lab	785222.1	
	Location	Pateke	
	Date	20.04.10	
24. Total carbon (C) as dry weight	%DW	24.0	
25. Total recoverable phosphorus (P)	mg/kg DW	1452	
26. total nitrogen (N) as dry weight	%DW	1.54	
27. bulk density (volume weight)	g/mL	0.37	

Table 6.1: Te Hapua Wetlands water and soil chemistry data.

An additional an obvious nutrient supply to the Te Hapua lakes is birds. Pateke, in particular, has a high waterbird population, because there is plenty lakeside grassy areas for loafing. Many shallow lakes around the country have become hyper-eutrophic through excessive bird numbers (and this also increases the threat of avian botulism).

The much higher pH values measured on-site reflected the photosynthesis contribution from the substantial algal communities in the lakes. Chlorophyll analysis (as an indicator of biomass) would have been useful to help check the amount of nutrients locked up in algae, and lake sediment analysis would indicate the amount of phosphorus being stored in the system. The total nitrogen/total phosphorus ratios are very low, so that Pateke lake, in particular (N/P ratio only 6.6), is very susceptible to algal and cyanobacterial blooms (Fig. 6.1B) and water fern explosions (Fig. 6.1C). Because these water bodies have slow rates of water turnover during the summer, algae and cyanobacteria are less likely to be flushed out before they can build up their populations.

The predominance of vigorous raupo stands suggests either high nutrient concentrations or else high groundwater flow rates. Flowing water maintains root oxygenation and continuously renews nutrient supplies to the roots. Thus, the particularly lush stand of raupo in the northern corner of Trotters owes its vigour to a spring (or artesian supply) at that point.

An opportunity did not arise to take water samples from Shoveler Wetland, but it would make a useful chemical comparison to do so as it is closer to the sea than those wetlands which have been sampled on this occasion. It is also lower than the other wetlands, as well as being adjacent to the Puruka drain (see above).

The nitrogen content of the organic soils around the Pateke lake margin (Tab. 6.1) is quite high, and seasonal decomposition in these soils will be a partial source of the nitrogen to the lake, although the actual contribution cannot be quantified as the peat decomposition/accretion balance is not known. It will very likely be net decomposition and therefore a significant source of nitrogen.

6.5 Ecology and land use

The Te Hapua wetlands are a complex of lacustrine and palustrine systems, of dune slacks, fens, reedland/flaxland and dune lakes, and of both ephemeral and permanent wetlands.

Over 95% of the indigenous vegetation has been removed from the dune swamps of Kapiti Coast (Allen, 2010; Preece, 1995), and the modified Te Hapua wetlands have far more shallow lake habitat than was present in the original wetlands. Indeed it could be argued that Te Hapua Wetlands do not have any 'true' lakes at all, because they have all been constructed. All the lakes are shallow and humic stained, so summer heating will be a problem for fauna and flora. However the Te Hapua wetlands still retain many of the original features of 'true' wetlands (such as lacustrine characteristics and hydrological responses) and they do, of course, contain wetland habitat, albeit considerably modified from it original state. Restoration has been a huge private undertaking on several properties, involving tens of thousands of plantings.

The least physically modified wetland of those seen was Trotters. Much of the reedland community south of Jill and Joy's lake is, whilst unexcavated, more monospecifically raupo than it formerly was. Stock do have access to much of Trotter's Wetland, so its proportion of exotic plant species is higher, but grazing stock do to some extent help to maintain the high overall biodiversity of the sward around the raupo block, by preventing domination of vigorous exotics. The flora includes: *Coprosma propinqua, Juncus sarophorus, J. pallidus, J. articulatus, Baumea articulata, Schoenoplectus, Carex virgata, C. geminata, Eleocharis gracilis, E. acuta, Galium palustre, Veronica serpyllifolia, Oenanthe aquatica, Bidens pilosa, Myriophyllum propinquum, Agrostis stolonifera, Isolepis prolifer,* etc. The aggressively weed *Carex ovalis* is also common in this community and the hemiparasite *Parentucellia viscosa* is fairly widespread.

A small (only about 10m x 10m), area of shallowly flooded mud between Jill & Joy's Wetland and the western property boundary fence has significant ecological value and should be preserved if possible. It is dominated by the relatively uncommon native thalloid liverworts *Ricciocarpus natans, Asterella tenera* and *Gonocarpus micranthus*, together with the native aquatic fern *Azolla filiculoides*, the small, creeping native aquatic angiosperm *Myriophyllum propinquum* and the small native sedge *Eleocharis gracilis.* It is relatively rare now to find a native freshwater 'turf' community outside the alpine zone or very oligotrophic waters at lower altitudes.

This little 'bonsai'wetland was visited again in February 2012 and, unfortunately, the liverworts were being over-run by the *Myriophyllum,* and *Cotula* (batchelor's button) and *Eleocharis* was also spreading.

6.6 Threats

- Extensive modification of the Te Hapua wetlands, particularly the considerable increase in open-water area by shallow excavation, is likely to have increased evaporative losses from the wetland complex compared with the original dune wetlands. Linked water bodies can also move water more rapidly through the system than would have been the case historically, thus reducing storage. However, compared with the uncontrolled drainage of the fully developed system of 20 years ago, water storage will almost certainly have been enhanced.

- Small, unconsented bores from the unconfined surface aquifer may have a significant combined take compared with summer groundwater flows and dune storage. Since summer groundwater flows are so low, even individual shallow bores could be a threat to specific wetlands.

- Declining groundwater flows in the unconfined surface aquifers, or interference with connectivity, through construction or development, can result in gradual changes to wetland dynamics. Wetlands are in a more delicate balance – more vulnerable – when water inputs are small. It is normal for dune wetlands to have fluctuating water levels or to be of an ephemeral nature, but if the amplitude and duration of extreme events increases they can be damaged – their structure will change, either gradually or even dramatically.

- Lakes such as those at Te Hapua, with low turnover rates, are particularly susceptible to developing the low nitrogen/phosphorus ratios that promote cyanobacterial blooms. Waterbirds can often provide the P input for this to happen. Shallow water and low albedo will cause the summer heating which favours algal blooms. The same conditions also accelerate deoxygenation, promoting phosphorus regeneration from sediments and increasing the likelihood of cyanobacterial blooms.

- The Puruka Drain and any intensification of farming between the Mangaone Stream and Te Hapua may have gradual influences on some of the Te Hapua wetlands. To understand nitrogen sources and transmission rates, Tidswell's (2009) proposal for monitoring nitrogen isotopes is a good one.

- In ecological terms, lake excavation and wetland enhancement at Te Hapua took place relatively recently and young wetlands take time to stabilise. Meanwhile, cross-boundary effects, such as drainage, abstraction, land-use intensification, etc, make it more difficult to create stable, sustainable wetland systems.

6.7 Conclusions and recommendations

- The Te Hapua wetlands complex is an important biodiversity resource in a coastal zone which is now almost fully developed. Because the wetlands are in private ownership, management is an administrative challenge as much as a scientific one. Because many of the wetlands have hydrological links (eg through a shared dune aquifer), a conservation management plan ideally needs to be inclusive, rather than site-specific. Te Hapua is a good place to develop the sort of planning provisions and land/water use rules (eg hydrological buffer zones) that wetlands will need in order to be sustainable. The unconfined surface aquifer is a finite resource which ultimately sets a limit on both development and wetland creation.

- Three chemical signatures could be extracted from water quality data:
  (a) A dune signature of high calcium and carbonate/bicarbonate.
  (b) High sodium and chloride, which is most likely also derived from the dunes and from aerosols. This can also be a signature of a deeper confined aquifer, but evidence for this is speculative.
  (c) the signature of disturbed, eutrophic systems with high nutrient levels.

  More extensive, and seasonal, water quality sampling is needed to help better explain water sources and hydrological processes. For instance, do any discharge wetlands (eg Trotters) have artesian water supplies? Also, particularly vigorous stands of raupo rising well above the bulk of the reedland has to indicate something different hydrologically or chemically at that particular location. Lake sediment should be analysed for phosphorus storage. Heavy metal analyses, calibrated using bore waters, may be an approach to distinguishing confined and unconfined aquifers from dune-sourced waters.

- The Te Hapua wetlands will certainly be much more eutrophic than they were before subdivision and this poses a challenge for maintaining species diversity. The unconfined aquifers supplying the wetlands are also under greater pressure due to increased evaporative losses and increased water abstraction since land development. Eutrophic systems are difficult to manage when turnover rates are low, as they seem to be at Te Hapua. If there were ways of increasing throughflow it would be helpful, but there probably isn't enough water to be able to do that.

- One or two suitably located deep bores, or one shallow (less than 35m) and one at about 90m, should be monitored for longer-term hydrological trends. Allen (2010) recommends that the O'Malley bore (on the O'Malley property) be used for this purpose and pump tests (drawdown and recovery) be conducted occasionally.

- Shoveler is one of the lowest lakes in the Te Hapua wetlands complex. If possible, water quality monitoring should be added to the GWRC monitoring network. Shoveler is also close to the Te Puruka Drain, which may possibly be having a hydrological or chemical impact on at least part of the Te Hapua complex.

- Trotter's wetland has potential for restoration as a high-biodiversity system although, if nutrient levels remain high, light grazing or artificial mowing may have to be part of the management regime.

- The wetland turf community linked to Jill & Joy's is well worth preserving but as with all turf communities, it will only survive without help if the nutrient levels are low. Failing the ability to establish a suitable nutrient regime, it will need regular weeding to prevent the faster growing vascular plants, such as *Myriophyllum*, from overgrowing the liverworts. Aggressive exotic plant species are also likely to establish unless vigilance is applied.

6.8 Te Hapua photographs

Photo 6.8.1: Jill & Joy's shallow rehabilitated dune wetland and marginal plantings. Nutrient levels are higher than Pateke, but water is darker and clear, perhaps indicating higher rate of turnover here. Much of the former dune hollow raupo swamp still adjoins the lake.

Photo 6.8.2: Trotter's wetland, hydrologically linked to Jill & Joy's, still has economic value as rough grazing, but much is still waterlogged ground with blocks of flax and raupo, linked by swards of grass, sedge and rush, with grazing pressure maintaining a fairly high species diversity. Note clumps of native *Muellenbeckia complexa* dune shrub on drier land.

Photo 6.8.3: Pateke Wetland looking east. Vigorous raupo and flax are indicative of high nutrient levels, and surface algal bloom is noticable from light brown colouration, perhaps suggesting slow turnover (compare darker Jill & Joy's, 6.1 above).

Photo 6.8.4: Shovelers', a recharge wetland in a dune hollow, rehabilitated 20 years ago. These dunes were all originally forested.

Phot 6.8.5: This collecting drain (Puruka Drain) runs from the Shovelers' stopbank (foreground) several hundred metres towards Te Horo and appears to be having a significant drying effect on surrounding land. Nutrient status is high, as indicated by the water fern mat.

7. HARUATAI FORESTED WETLAND
Otaki, Kapiti Coast

7.1 Introduction

Swamp forest is rare in the Foxton Ecological District, and dune swamp forest rarer still, so this 6 hectares of Unprotected Maori Land is a particularly important remnant of the now very depleted Kapiti Coast wetlands. The swamp forest is currently bounded to the east and south by non-dairy pastoral farming, and to the north by dairying.

The forest can be entered from the Haruatai Park sports ground in Otaki, but there is no defined access point and a fence must be scaled. The wetland is fully fenced, but the quality of protection is suspect in places along the western margin. Two visits were made on 21 and 22 April 2010, during which the wetland was circumnavigated and two internal transects evaluated.

7.2 Topography and Stratigraphy

The land to the east, west and south of Haruatai swamp forest is an ancient dunefield, rising 10-12 metres above the forest floor. GWRC LiDAR data (2004) indicates that most of the forest floor is practically level at between 15-17.5 metres above sea level although more accurate levelling (the LiDAR contours are only 2.5m) would probably reduce this range to one metre. Raised dunes (with non-swamp forest cover) protrude into the reserve from the north and west/northwest.

Throughout most of the forest there is only a shallow litter layer lying on sand, but there are localised depressions where shallow organic soils have developed.

7.3 Hydrology

There are no stream inflows or outflows and no obvious signs of springs or artesian water supplies. There is a single drain connecting the forest with a tributary of the Waitohu Stream about 500 metres to the north. So it can be assumed that, for at least part of the winter period, this drain is an outflow from the forest block. However, the volume of outflow is probably very low, because the drain is small and LiDAR contours indicate that its fall is no more than 1:1000 for at least a kilometre to the north. There was no flow in the drain during the April 2010 visits and significant flow would have been unlikely to occur without a groundwater level rise of at least 400-500mm (above those experienced on the present visit). The tree-trunk ‘lichen line’ is close to ground level, which indicates that the swamp forest does not undergo long periods of flooding.

There was probably never a well-defined outflow from Haruatai. The drain serves, or was intended to serve, a farming function and does not necessarily follow the line of a natural drainage channel. Indeed occasional north – south backflows are not unlikely during some rainfall events. An extension of the drain (B, Fig. 7.1) around part of the northern boundary of the reserve is stopbanked and this further suggests a farming purpose – to ensure that any accumulation of water within the swamp forest is contained there, and channelled away by, the drain.

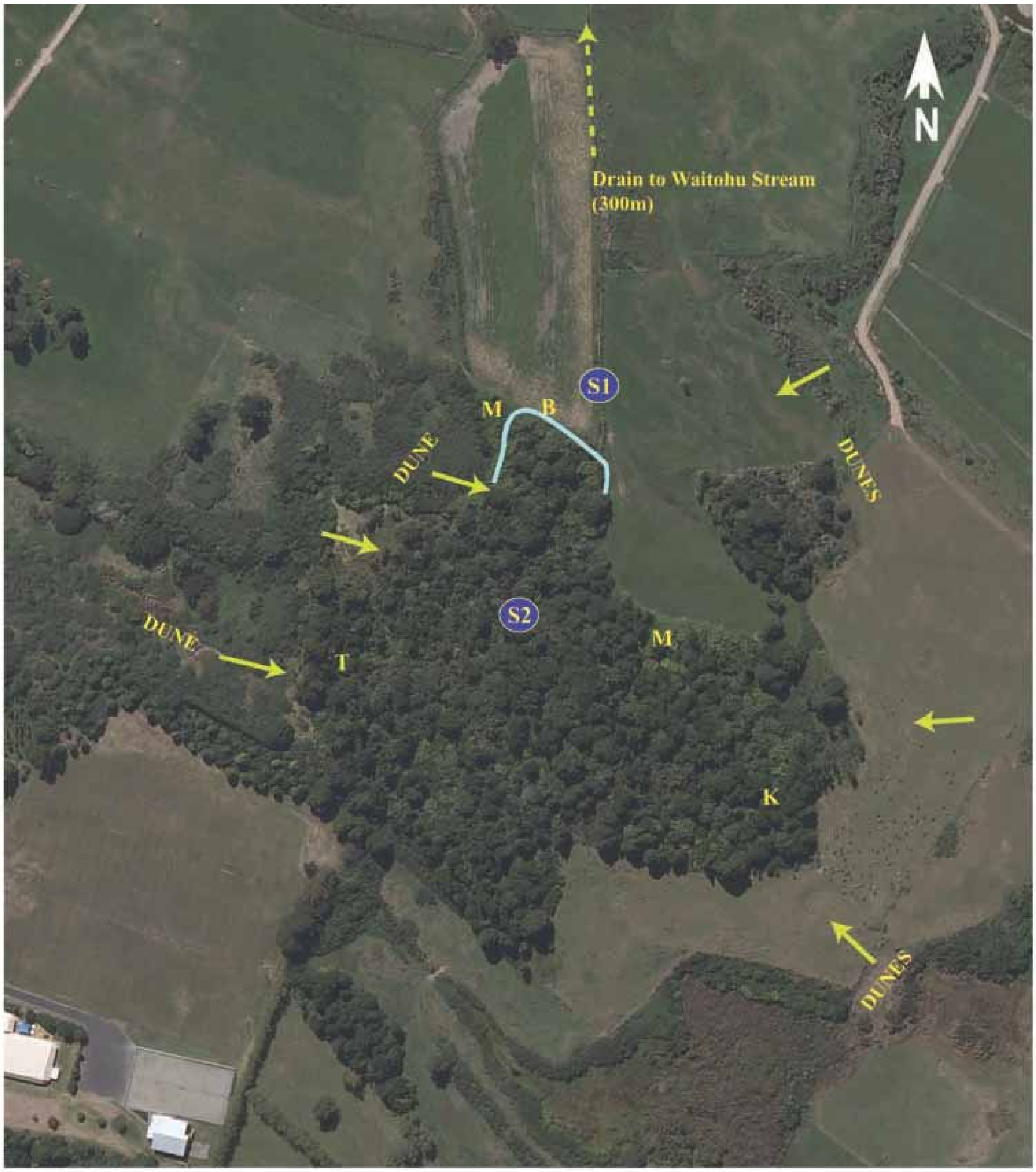


Figure 7.1 HARUATAI FORESTED WETLAND

In other words, Haruatai appears to be, using Allen (2010) terminology, a 'recharge dune wetland' – a hydrological 'sink', supplied with water stored in shallow unconfined aquifers in the adjacent dunes. A mature forest of this size will represent a very significant evaporative demand but, during the visit (well into autumn), the groundwater table was no-where lower than 500mm below ground and, at the toe of the eastern and western dunes, it was at or close to the surface.

However, the forest may not be entirely dependent on recharge from surface storage.. There are no obvious indicators (eg plants responding to upward seepage of artesian water (see e.g. Ch. 11), but there may be evidence of recharge from a deeper aquifer in the water quality data (Tab. 7.1). A water balance study will be needed to establish water sources with more certainty.

7.4 Chemistry

Water sample S1 was collected from the northern drain; Sample S2 from a shallow augur hole 60m inside the forest and halfway along the northeastern forest boundary.

The ion balance in the two samples is broadly similar, with S1 being, more or less, a diluted version of S2, but with the noteable exceptions of the higher calcium, carbonate/bicarbonate and sulphate concentrations in the S1 sample. These may be attributable to runoff (lime and fertiliser) from tilled land to the north, adjacent to the drain, but calcium and bicarbonate levels are only 50% higher than S2, so there is probably a 'dune signature' in both samples, supplemented by a farming contribution in S1. The sodium and chloride concentrations in S2, and even the

TEST	**Site**	**Haruatai**	**Haruatai**
	Material	**Water**	**Water**
	Lab nos	**785947.1**	**785947.2**
	Location	**Drain**	**Bore (20cm)**
	Date	**21.04.10**	**21.04.10**
	Sample	**S1**	**S2**
WATER	**UNITS**		
1. total nitrogen TN (3+4+5)	g/m^3	1.33	10.6
2. ammoniacal nitrogen (NH_4_N+NH_3_N)	g/m^3	0.046	0.043
3. Kjeldahl nitrogen TKN (2+organic N)	g/m^3	1.31	10.5
4. nitrite (NO_2_N)	$g/_m3$	0.0021	0.0086
5. nitrate (NO3_N)	g/m^3	0.0159	0.108
6. nitrite+nitrate (NO_2+NO_3)	g/m^3	0.0180	0.117
7. total phosphorus (all organic P+8)	g/m^3	0.35	4.3
8. dissolved reactive phosphorus DRP	g/m^3	0.077	0.0082
9. sum anions (HCO_3+CO_3+Cl+SO_4)	Meq/L	3.7	4.9
10. sum cations (K+Na+Ca+Cl)	Meq/L	3.5	4.9
11. pH Laboratory	pH	6.8	6.3
12. pH Field	pH	6.4	6.1
13. electrical conductivity (EC) Lab	mS/m	38.1	57.6
14. electrical conductivity (EC) Field	mS/m	36.8	56.2
15. total alkalinity (as $CaCO_3$)	g/m^3	74	48
16. bicarbonate (HCO_3)	g/m^3	90	58
17. total hardness (Ca+Mg as $CaCO_3$)	g/m^3	97	67
18. dissolved calcium (Ca)	g/m^3	23	11.3
19. dissolved magnesium (Mg)	g/m^3	9.6	9.3
20.dissolved potassium (K)	g/m^3	5.3	9.3
21. dissolved sodium (Na)	g/m^3	32	77
22. dissolved chloride (Cl)	g/m^3	54	127
23. dissolved sulphate (SO_4)	g/m^3	32	14.6

Table 7.1: Haruatai forested wetland water quality data.

carbonate/bicarbonate levels, are so high that a deep aquifer input is a distinct possibility (see, for instance, the Allen-Lowe S3 chemistry in Table 10.1), although a contribution from residual salt in the dune sand still cannot be ruled out – the sodium/chloride ratio is consistent with this possibility.

If the drain were receiving an almost continuous discharge from the wetland, it would be expected that the higher sodium, chloride and sulphate levels of S1 would be also be more elevated in the S2 water sample. Similarly, if the drain flowed south, into the forest block for any significant proportion of the year, S2 calcium concentrations would be higher at S2 than they are. This issue can only be resolved with more extensive water quality sampling, including evidence from bore waters.

Haruatai S2 has high total nitrogen, but very little of this is mineralised. Living plant material is 1-2% N, so TKN values of $10g/m^3$, derived from decomposition processes, are not surprising in a high-biomass wetland with a very low groundwater throughput. Interestingly, Katihiku (Ch. 8) also shows this in the present study. The groundwater in swamp forests is usually anaerobic below ground and dissolved organic carbon can be as high as $500g/m^3$, so mineralised nitrogen will be largely ammonium, but since mature forests have 'ammonium economies', rather than nitrate ones (it is metabolically more efficient for plants to take up nitrogen in its ammoniacal form), free ammonium ions are readily absorbed by tree roots (note that only $0.043g/m^3$ of ammoniacal nitrogen is present in S2). Nitrogen from agriculture cannot explain the higher concentrations in the swamp forest, as the drain nitrogen levels (S1) are only 12% of those in S2.

Most of the very high phosphorus concentration in Haruatai S2 is also organic, and this would need to have a biological origin anyway.

7.5 Ecology and land use

Haruatai is a good example of a mature swamp forest in terms of the abundance of type species (kahikatea and pukatea), the variety of tree age classes (demonstrates a self-sustaining community), and also in terms of the variety of associated species (total species diversity).

Unfortunately, several aggressive weed species are well established throughout the swamp forest, including *Crocosmia* (montbretia), *Cyperus eragrostis, Tradescantia fluminensis, Ligustrum lucidum & sinensis, Selaginella kraussiana, Clematis vitalba, Asparagus scandens, Lonicera japonica.* Blackberry, gorse and barberry thickets are frequent along margins. Massive swards of tradescantia and montbretia dominate the adjacent derelict hospital site and are spreading from there. Alder is also expanding its range: it is waterlogging and flooding tolerant, but as it is light demanding it is only establishing along the eastern boundary in any quantity.

Some parts of the forest floor are wetter (lower) than others (although there was no standing water in April 2010) and this is usually indicated by the tree cover, with kahikatea (plus *Carpodetus, Coprosma tenuicaulis, Laurelia, Cordyline, Dicksonia squarrosa,* etc) more prominent in lower-lying areas and where water seeps out of the nearby ancient dunes. A ground flora of species such as *Isachne, Carex lessoniana, C. dissita, Isolepis* spp*, Rorippa* and bryophyte swards also characterise wetter areas. Lichen lines on tree boles are good indicators of seasonal mean highwater levels, and these are nowhere more than about 250mm above the soil litter layer.

In drier places, and on slightly more elevated ground, there is a shift to matai, titoki, mamaku, mapou, mahoe, totara, tawa, kohekohe, etc. There are also indications, from the distributions of younger trees and seedlings, that titoki and tawa are becoming more common so that in some places the forest composition may be moving away from a swamp type towards one with a drier and more mesophytic character. A 5-year ecological survey would be a useful check on any successional trends which may be occurring.

Two stands of mamaku tree ferns indicate regenerating areas.

The area of forest at Haruatai which is true swamp forest coincides more closely with the Kapiti Coast District Council's Ecosites delimitation on the site map, than it does with the area outlined in the current GWRC Wetlands Database. Much of the privately owned area to the west of the wetland forest, some of which was formerly seasonal wetland, has recently been cleared for stock grazing, and there has also been some intensification of farming to the north or the swamp forest.

7.6 Threats

- Any further intensification of agriculture within the Haruatai Forested Wetland catchment area, whether through stock grazing (compaction/over-grazing and increased runoff, reduced infiltration, enhanced evaporation) or cropping (increased evaporation) may eventually alter the balance between swamp and non-swamp tree species. There may be indications (mainly vegetation succession trends) that the water table has already been declining for some time within the wetland.

- Since the main threat to the swamp forest is reduction in water supply, boreholes, particularly shallow ones, should be discouraged or controlled where they may affect dune storage. Reducing pressure gradients within deep bores in the region cannot be ruled out as a threat until more is known about groundwater flows in the Waitohu zone. Of course, as Haruatai is privately owned, most management measures can only be enacted with owner consent.

- The total dissolved solids levels indicated by a conductivity of 57.6mS/m, with sodium and chloride as the dominant cation and anion, is getting towards the high side osmotically. I have seen kahikatea develop epicormic shoots (a widely recognised indication of stress) in swamp waters with EC values of 80.0mS/m, although no stress indicators were seen on the present short visit.

- Without any controls, some aggressive weeds (particularly tradescantia, selaginella and clematis) will start to suppress plant performance and seedling establishment.

7.7 Conclusions and recommendations

- High nitrogen concentrations were found near the forest centre by Tidswell (*pers. comm.*), and confirmed further to the east by the present study. There are three possible explanations:
  1. Agricultural supply. It is difficult to see how this could account for such high nutrient concentrations at S2, when they are lower at S1.
  2. Deep aquifer supply. Almost all the nitrogen is in the organic form and this is unlikely to come from a deep aquifer in this form; root zone transformation from nitrate to organic nitrogen is possible, but only if the rate of supply is low. High phosphorus levels will not have originated from a deep aquifer anyway.

3. Forest decomposition processes. Dissolved organic nitrogen (DON) concentrations of up to at least 30g/cu m are common in soils of mature forest during summer (eg McDowell *et al*, 1998). The 10.6g/cu m found in S2 at Haruatai, together with 4.3g/cu m total phosphorus, are not unexpected equilibrium concentrations for a swamp forest soil at this time of year. They will be less in spring, and this would be worth checking.

- Seasonal water quality sampling is needed at about five locations to check variations in nutrient levels and attempt to trace water inputs. Heavy metal analyses could be useful for identifying any deep aquifer involvement. Even an early summer survey of groundwater conductivities could provide useful insights into water sources. If necessary a nitrogen isotope survey could be employed to confirm the hydrology of the system.

- The present study does not identify firm evidence for a deep aquifer playing a major role in the Haruatai hydrology, although there are indications that this might be the case. If dune storage alone provides all the water needed, it would have to supply about 250-400m^3/day during the summer period. A more thorough hydrological study, utilising water level recorders and supplemented by water quality data, would be needed to build a good hydrological model. It would need to incorporate abstraction volumes from any boreholes likely to influence the water supply.

- If the owners are agreeable to, say, a covenant agreement over the wetland, a management plan should be prepared, so that there are documented goals and management tasks for the owners, lessees, adjacent landowners and the Regional and District Councils.

- *Selaginella* and *Tradescantia* are weeds which are very time consuming to control, but a start must be made sooner rather than later, or the task will rapidly become very much more difficult. Several other aggressive weeds are present (Japanese honeysuckle, for instance) which are easier to control. A weed control survey would be an appropriate first step. Perhaps encouragement and support could be given to an Otaki based community care group to organise weed control (if the owners are agreeable).

7.8 Haruatai photographs

Photo 7.8.1: Haruatai swamp forest has an abrupt northern boundary with intensive farming. The small drain (foreground) is the sole outflow and functions winter/spring only. It curves round just inside the forest and is stopbanked on the inside.

8. KATIHIKU WETLAND
Otaki, Kapiti Coast

8.1 Introduction

Almost all of the coastal land between Te Hapua and the Otaki River is now pastoral farming. Kathihiku Wetland is the only significant natural wetland still remaining in this block north of Te Hapua.

Katihiku Wetland is included within the Kapiti Coast District Council (KCDC) Otaki River Estuary Ecosite, and it is owned by the Kathihiku X Trust and leased to a farmer.

The site was visited on 30 March 2010.

8.2 Topography and stratigraphy

The wetland is bounded on the north and west by a major stopbank, constructed in the mid-1970s at a point which used to be a ferry crossing over the Otaki River estuary to the Otaki township. To the south and southeast of the wetland, an extensive drainage network supports agricultural development, some cropping, but mainly sheep and beef at present, although conversions to dairy are spreading. Farm drainage waters are channelled into a collecting drain, running down the eastern margin of the wetland, from where it is discharged through a flapgate into the estuary at low tide.

Before conversion to agriculture, the area south of the stopbank would have been backwater estuarine swamps of the Otaki River, some of them brackish and some freshwater. The stopbank and flapgate has prevented brackish incursion and also provided a primary control over water levels in the area.

In the Katihiku Wetland, the upper 30cm of the substrate is an organic soil but, as the carbon content of the soil is very low (Table 8.1), the wetland is clearly not currently accumulating organic material and the surface soils may therefore be largely mineralised material deposited before construction of the stopbank. Below the soil is a 40cm layer of coarse sand, underlain by a fine organic silt (gyttja) of unknown depth, presumably deposited in a former estuarine lagoon.

8.3 Hydrology

Much of the Katihiku Wetland and its surrounding area is affected directly, or indirectly, by the Otaki River. Directly through artesian inputs at various places, such as near the Kathihiku marae, where over two metres of peat have accumulated around a spring; and indirectly by maintaining a back-pressure from the north of the stopbank, which helps to maintain groundwater levels to the south. The former estuarine swamp water levels would have responded only slowly to rainfall and evaporation, because vegetation slows down drainage responses, but artificial drainage networks accelerate water movement through the system, in order to enable agricultural use of the soils. This reduces storage, so the result of an unregulated drainage network is that it increases the amplitude of groundwater fluctuations because water levels start off lower at the beginning of rain-free periods than they did before drains were installed, in order to take away flooding quickly. Natural wetlands, on the other hand, are adapted to tolerate flooding.

Figure 8.1 KATHIHIKU WETLAND

S1 S2 Chemistry sampling points

F Discharge through flapgate to estuary – note humic-stained water

G Tall fescue swards

R Raupo stands along western margin

K Cabbage tree, flax, baumea, carex

Direction of

So it is with the Katihiku Wetland. The drainage systems to the south and east of the wetland feed into two collecting streams, which converge near the wetland. The dark brown, peaty colour of these streams shows that drainage in their catchments is releasing humic acids as groundwater levels in former wetlands are lowered to support agriculture, but exposing organic soils to disturbance and decomposition in the process.

The merged streams discharge into a collecting basin, or lagoon, ponded by the stopbank to the north and the wetland on the west. Because the southern drainage network removes floodwaters and directs them around the wetland's southern perimeter into the lagoon, this deprives the wetland of water which could otherwise have been used to maintain its character and suppress weeds such as blackberry. The eastern stream may also have formerly fed into the wetland.

In addition, the drainage lagoon has been excavated in order to provide good drainage fall (hydraulic head) and therefore make the most of gravity in clearing the drainage network in the agricultural land. This means that, even though the drainage water is ponded (in the lagoon) adjacent to the wetland, the wetland surface is elevated above it so seepage recharge is not able to fully re-wet surface layers of the wetland. In any case, the lagoon level fluctuates semi-diurnally as water is discharged through the flapgate at low tide, so the effective lagoon level is an average.

A groundwater level fluctuating semi-diurnally by up to two metres immediately adjacent to a freshwater wetland must impose some constraints on species performance and chemical processing within at least part of the wetland. The present study can only pose questions, but the issue does need more detailed study.

In January 2010, heavy rain resulted in the drainage network being overwhelmed and the surface of the wetland was flooded. However this had quickly receded and, by the time of the present visit, 30 March 2010, the groundwater table in the wetland had been up to 70cm below the ground surface for several weeks. 70cm is below the sand layer, and coarse sand does not support a high capillary rise. Moreover, although no surveying data are available on relative levels, the groundwater table in the wetland would almost certainly have been higher than the mean level in the lagoon, and this negative head would have drawn water out of the wetland soil.

The problem, then, is that the drainage system in the block of which the Katihuku Wetland is a part, is designed to remove floodwaters quickly and to maintain a groundwater regime which is agriculture-friendly. The Katihiku Wetland, on the other hand, needs a different water regime: it need drainage water fed into it, not channelled around it. Possibly between 5-10 000 m^3/hr discharges from the flapgate; there is certainly 'spare' water for the wetland, but whether it can be gravity-fed is doubtful, because dewatering soil for agriculture results in shrinkage (note the reference above to decomposition of organic soils in the area covered by the drainage network) and water levels in drains will be lower than the optimal level for maintaining the character of Kathihiku Wetland.

There is a possibility of one or more artesian inputs to the wetland, but if there are any they are not likely to be large or they would be distinguishable on the Google Earth image as vegetation anomalies. Time did not permit a detailed search of the wetland for evidence of wetter areas.

8.4 Chemistry

As there appeared to be no surface water on the wetland at the time of the present field visit, both samples for chemical analysis had to be taken from groundwater, accessed by 100mm augur, at about 70cm depth. Sample S1 was located on the northeastern margin of the wetland, 15m from the drainage lagoon. S2 was 50m inside the southern boundary of the wetland and was difficult to filter because of the fine organic particulates.

TEST	**Site**	**Kathihiku**	**Kathihiku**
	Material	**water**	**water**
	Lab nos	**779951.1**	**779951.2**
	Location	**borehole**	**borehole**
	Date	**30.03.10**	**30.03.10**
	Site	**S1**	**S2**
WATER	**UNITS**		
1. total nitrogen TN (3+4+5)	g/m^3	1.33	99.0
2. ammoniacal nitrogen (NH_4_N+NH_3_N)	g/m^3	0.035	0.049
3. Kjeldahl nitrogen TKN (2+organic N)	g/m^3	0.36	99
4. nitrite (NO_2_N)	$g/_m3$	0.0086	0.0043
5. nitrate (NO3_N)	g/m^3	0.96	0.0152
6. nitrite+nitrate (NO_2+NO_3)	g/m^3	0.97	0.0195
7. total phosphorus (all organic P+8)	g/m^3	0.034	17.8
8. dissolved reactive phosphorus DRP	g/m^3	0.0142	0.030
9. sum anions (HCO_3+CO_3+Cl+SO_4)	Meq/L	2.4	2.5
10. sum cations (K+Na+Ca+Cl)	Meq/L	2.1	2.9
11. pH Laboratory	pH	7.1	6.1
12. pH Field	pH	6.1	5.8
13. electrical conductivity (EC) Lab	mS/m	25.5	32.6
14. electrical conductivity (EC) Field	mS/m	23.6	30.9
15. total alkalinity (as $CaCO_3$)	g/m^3	35	16.1
16. bicarbonate (HCO_3)	g/m^3	42	19.6
17. total hardness (Ca+Mg as $CaCO_3$)	g/m^3	53	43
18. dissolved calcium (Ca)	g/m^3	11.7	4.5
19. dissolved magnesium (Mg)	g/m^3	5.8	7.7
20.dissolved potassium (K)	g/m^3	2.3	6.7
21. dissolved sodium (Na)	g/m^3	22	44
22. dissolved chloride (Cl)	g/m^3	38	71
23. dissolved sulphate (SO_4)	g/m^3	25	6.9
SOIL	**Lab**	**779951.3**	**779951.4**
	Location	**S2 Surface**	**S1 Surface**
	Date	**30.03.10**	**30.03.10**
24. Total carbon (C) as dry weight	%DW	3.7	6.1
25. Total recoverable phosphorus (P)	mg/kg DW	830	990
26. total nitrogen (N) as dry weight	%DW	0.41	0.52

Table 8.1: Kathihiku Wetland water quality and soil chemistry data.

The chemistry of the wetland water certainly has a freshwater signature, as would be expected from its vegetation characteristics. However, the chemistry of both water samples is heavily modified by internal soil processes and interpretation is difficult without a broader study of water quality in the Kathihiku catchment (drainage network, western raupo swamp, marae spring, etc) that was ruled out by time constraints. There are still some useful conclusions to be drawn from analyses at S1 and S2.

The high sodium and chloride concentrations, for instance, could be a marine signature, from aerosols or residual substrate estuarine salt. However, there are significant differences between S1 and S2. The higher carbonate/bicarbonate in S1 could reflect the water quality of the nearby lagoon, whereas the higher sulphate in S2 can only be influenced by the occasional surface flooding from the south and west. Sulphate can also be attributable to residual estuarine sediments. Neither of the water samples can provide any evidence for artesian water sources.

The high total nitrogen and total phosphorus values ($99 g/m^3$ and $17.8 g/m^3$) for S2 are almost entirely attributable to organic forms of these nutrients. As in the Haruatai borehole sample (S2), water from the subsurface aquifer of an organic soil is anaerobic most of the time, thus restricting mineralisation of the nutrients in the organic matter.

The organic silt from which the S2 sample was taken has a naturally high nutrient content, and it is this material that is responsible for the extremely high nitrogen and phosphorus concentrations here, mainly because of incomplete filtering. The S1 borehole only penetrated sand to 70cm, so there was no organic silt at this location. If the organic silt layer is exposed by agricultural development south of Kathihiku, it would raise nutrient levels in drainage waters reaching the lagoon.

The soil samples for the present study were taken from surface soils (above the sand layer) at the two water sampling locations. The soils are very low in carbon for awetland soil, and this suggests that organic material is not currently accumulating. This is not unexpected, considering the low water table level in the wetland.

8.5 Ecology and land use

Kathihiku Wetland is a largely seasonal, freshwater palustrine wetland. It is characterised mainly by flax with cabbage tree (ti kouka) emergents and a tall sedge (*Carex geminata*) understorey. The flax averages 40-50% cover throughout the interior of the wetland, but is denser nearer to the stopbank. Tall sedge swards are admixed with scattered tall fescue over the remainder of the wetland. *Coprosma robusta* and *C. propinqua* shrubs are sparsely scattered throughout and there are isolated patches of *Baumea rubiginosa, Eleocharis sphacelata* and *Gleichenia dicarpa* (tangle fern). There are also patches of raupo, particularly along the western boundary, but all of the raupo is of short stature, indicating low nutrient availability and slow groundwater flow rate.

The wetland margins are dominated by blackberry, blue morning glory, pampas and gorse, with occasional tussocks of the rushes *Juncus sarophorus* and *J. effusus.*

Because Katihiku Wetland is so close to the estuary, much of the land which is now protected by the stopbank would have formerly been brackish swamp, with islands of freshwater swamp. The ti kouka/harakeke swamp could therefore be a quite recent development. *Baumea* and tangle fern would formerly have been much more prominent, and would be again if the wetland groundwater table could be brought up further during the summer. The survival of the spike sedge (*Eleocharis*) in the present wetland community is a good indicator of the considerable changes that have taken place over the past years, because this plant’s optimal habitat is permanent shallow water.

Introducing more water to the wetland would not only favour species such as the sedges *Baumea and Eleocharis,* but would also be the best way to control most of the weedy exotic species

8.6 Threats

- The Wetland already shows obvious signs of drying out, from the weed incursions to the low water table and the low organic content of the surface soils. Steps need to be taken to halt what appears to be a decline in biodiversity and ecological quality. However, there needs to be a reasonable assurance that it is, or can be made to be, a sustainable system before seeking formal conservation status for the Kathihiku Wetland. Any measures taken to improve the hydrology of the wetland and achieve the most appropriate species balance will also carry risks if the tolerance limits of the existing ecologically desirable swamp species are exceeded.

- There is irrigation on at least one dairying operation south of the wetland. Since water is a limited resource, intensification of agricultural landuse could diminish the amount of drainage water arriving at the stopbank, and therefore the amount potentially available for improving the condition the wetland.

- It is very likely that all of the water in the drainage system south of the Katihiku Wetland is derived from the former Otaki River fan, but if it only surfaces as a limited number of discrete artesian sources, these could be easily over-exploited for agricultural purposes.

- Increased seepage under the stopbank could favour saltmarsh species at the expense of freshwater wetland plants, although there are no indications that this is happening at the moment. On the other hand, the rising and falling of the level in the drainage lagoon may have unusual ‘pumping' effects.

- Aggressive weeds, such as blackberry and pampas, are likely to be spreading inwards from the margins and true wetland plants, such as raupo, baumea and carex, are becoming scarcer.

- Pests such as cats, rats and stoats will restrict native birds and lizards. Stock graze along the southern margin of the wetland, which is bounded only by temporary electric fencing.

8.7 Conclusions and recommendations

- Katihiku Wetland is one of very few remnants of once widespread swamps on the Kapiti Coast. It is well worth putting effort into restoring and conserving it, but establishing a sustainable hydrological regime will not be straightforward. It was not fully explored during the present visit but, at most, it will have only pockets of swampy ground during the summer, such as the raupo stands to the west. It is approaching the status of a seasonal freshwater marsh, with insufficient permanence of waterlogging to accumulate organic material as peat.

  The main recommendation, therefore, is that, first of all, a feasibility study needs to be carried out and management plan prepared. Some of the issues that need to be addressed in this respect are listed below in the proposal below (S. 8.8).

- The wetland does need a more consistent hydrological regime, and the only practical means of providing this is by re-directing water from the drainage network. A pumped supply may be needed, so the differential between drain water levels and the water levels needed in the wetland must be established. Decomposition of organic material in soils developed for agriculture will be progressively lowering ground levels (and drain invert levels) within the wetland's catchment, so allowance will have to be made for this. A continuous record of groundwater levels in the wetland would be essential base level information for conservation management planning.

- There were significant differences between the chemical features of the two water samples, so there can be no clear understanding yet of the characteristics of the wetland's water supply and how it influences the chemistry of its groundwaters. In order to achieve this, further sampling will be needed, probably spring and summer, from the raupo swamp on the western margin of the wetland, from a couple of locations in the drainage network to the south (including the main stream), from the drainage lagoon and also from the Otaki River. The artesian spring near the marae should also be analysed, since there may be other artesian water sources near Kathihiku Wetland.

  Further sampling is needed to establish the extent of the high nitrogen and phosphorus concentrations at S2. Also the very unusual hydrology adjacent to the northern section of Kathihiku Wetland, a semi-diurnally fluctuating water level - a 'pumping' effect, can be expected to result in unusual substrate chemistry and further studies are needed to assess this in detail, before a management plan can be prepared.

- *Baumea* patches are usually an indication of a wetter substrate. Further investigation is needed to establish if these patches occur in surface depressions, maybe with artesian supply, or it they are relict (and shrinking) from former times when the wetland water level; was consistently higher.

8.8 Proposed Wetland Management Plan: some issues

The Kathihiku X Trust is already taking steps to retain and restore Kathihiku Wetland, so this section highlights a number of issues which need to be addressed during restoration and feasibility planning.

- Describe biodiversity values (fauna and flora) and confirm local importance as a rare or uncommon regional wetland type. This it almost certainly is, but the pre-1970s history of the wetland should be researched using, for instance, aerial photographs. Knowing as much a possible about the history of the wetland is important in planning its restoration.

- The most important factor in wetland management is hydrology (well ahead of water quality), so any sustainability model needs to establish long-term water availability in adequate amounts to maintain the type of wetland under consideration.

- It may be enough initially to compile a simple visual record (using stage boards) of water level fluctuations in relation to rainfall and river level, but subsurface water levels also need to be monitored in the wetland and, for this, piezometer tubes (dip wells) would be needed for manual measurements. However, if restoration is seriously contemplated, real-time digital water level recorders would be adviseable to obtain a more detailed picture of the hydrodynamics of the system. There would need to be at least one in the wetland and one in the lagoon, but probably also one in the western collecting drain. River level records will presumably already be available. Levels will also need to be surveyed to relate recording probes to the local survey datum.

- Check the extent of borehole abstraction, whether there are further artesian sources, the spread of irrigation usage and land-use intensification potential within the catchment area of the drainage network – and whether any of these activities may impact yet further on water availability to the wetland in the future. Much of the land immediately south of the wetland is owned by the Kathihiku X Trust, so there may be opportunity here for developing a land-use plan which integrates sustainable wetland conservation with good productive farming.

- Investigate feasibility of introducing more water into the wetland, by diverting drainage, or even by raising the level of the lagoon. Plans will be needed to detail how water levels will be controlled.

- Survey water quality in the drainage system outside the wetland, so that all possible water sources are identified. Compare water chemistry in the Otaki River fan with the impact of agriculture. For instance, Tidswell (2009, Figure 3.1) records several sewage and animal waste discharge sites which may be operating within the area covered by the drainage network leading to Kathihiku.

- Conduct a risk assessment of proposed rehabilitation measures comparing, for instance, the impact of a net rise in wetland groundwater level under a rehabilitation regime with the continuing effects of the current net decline resulting from agricultural priorities. Thus, if the mean wetland water level were to rise too much (say, 500mm), or too quickly, there could be a cabbage tree dieback, although stature and incidence of raupo would increase and baumea swards would spread.

  If the hydrological regime in the wetland stays as it is, or there is a further net fall in the groundwater level, there will be continued spread of blackberry and pampas, a decline in the performance and presence of raupo, spike sedge and baumea, and replacement of carex with fescue. It may then be worth choosing between a pumped water supply, or else conversion to a swamp forest with a planting programme.

  An assessment of the risk of salinisation should also be included and, since farming intensification will most probably lead to increasing nutrient concentrations in drainage waters, implications of this for the balance between plant species in the wetland need to be considered. Raupo, for instance, could be difficult to contain if nutrient levels increase.

- Some fencing is needed to exclude stock grazing when water levels are raised, and a pest (cats, rats, stoats) and weed management plan will be needed.

8.9 Kathihiku photographs

Photo 8.9.1: Wetland looking south from the stopbank, which appears to be critical in maintaining a reasonable wetland hydrology. Flax foreground and cabbage trees beyond suggest a high water table, but the tall fescue community extreme left suggests considerable seasonality.

Photo 8.9.2: Drainage lagoon levels fluctuate semi-diurnally and pictured is the highest level on 30 March 2010. Low-growing marginal vegetation indicates **mean** highest levels reached. Tall fescue (light brown) is an indicator of seasonal waterlogging only, suggesting that wetland water supply does not depend upon the lagoon. Turf vegetation of lagoon margin is mostly *Cotula*.

Photo 8.9.3: Inside wetland at sampling Site S2. Cabbage trees/flax are mixed with tall fescue/tall sedge – species are all tolerant of seasonal waterlogging. Substrate is low in organic matter, also an indicator of considerable seasonality in water availability.

Photo 8.9.4: Tall fescue, gorse and willow fringing the southern margin of Kathihiku – all indicators of marked seasonality in groundwater supply.

Photo 8.9.5: Deep drain (western collecting drain, Fig. 8.1) routing drainage water around Kathihiku Wetland instead of into it.

Photo 8.6: Confluence of the two collecting streams from the southern drainage network. Water flows into the drainage lagoon beyond. Note considerable rise to the wetland on the left.

9. TAUMATA TERRACE WETLAND
Wairarapa

9.1 Introduction

Two Taumata wetland areas are recorded on the GWRC Wetlands Database: Taumata Island Wetland and Taumata Terrace Wetland. Taumata Island is not covered by the present report.

Taumata Terrace Wetland is located on land owned by the Murray Edward Taylor Estate and access is from the Taumata Island Road and the property of Selwyn Taylor.

The field visit was on 23 March 2010.

9.2 Topography and Stratigraphy

The area is flat and comprises former river terraces incised by channels (former braids) and oxbow lakes. The designated GWRC Database wetland (Taumata Wetland) is a braid channel linked structurally to the Parkvale Stream (Fig. 9.1), but a quick field survey established that it has no biodiversity values, or restoration potential, and it was not considered suitable for further study.

However, one kilometre to the west (at GPS location E2723314/N6009724) a remnant of former (presumably) widespread floodplain forest is considered worthy of recording in the GWRC significant wetlands database. The stand of trees at this location is bounded to its north by a flooded channel, a former oxbow, but now cut off at the western end and fed (during flood events) by a swale running from farmland to the east.

The stratigraphy is river gravels extending to about 20 metres depth. This is underlain by impermeable mudstones at about 25 metres (Doug McAllister *pers. comm.*), so the surface water aquifer is effectively defined by this aquiclude. The gravels are not well sorted and there are many lenses, so this could locally affect groundwater flows.

Surface soils on the terrace are mixed fine and coarse material, with no accumulation of organic material and distinct gleying (ferric iron precipitation in the profile – see Section 1.5.3) to at least 1200mm depth.

GWRC LiDAR data (2004) shows the land surface to be practically level around Taumata Terrace Wetland, although braid patterning has a general northeast-southwest trend (indicated on Fig. 9.1).

9.3 Hydrology

Groundwater levels are highly seasonal. The GWRC gauge record for 2003-09 from the Parkvale Stream at Renall's Weir shows a seasonal variation of less than 0.5m^3/s for 6-9 months in the year, although flows peak for brief periods at 5-10m^3/s during the winter, when they result in extensive surface flooding of the terraces. Occasionally floods occur during summer, as in early 2004 and again in early 2010 (Selwyn Taylor, *pers. comm.*).

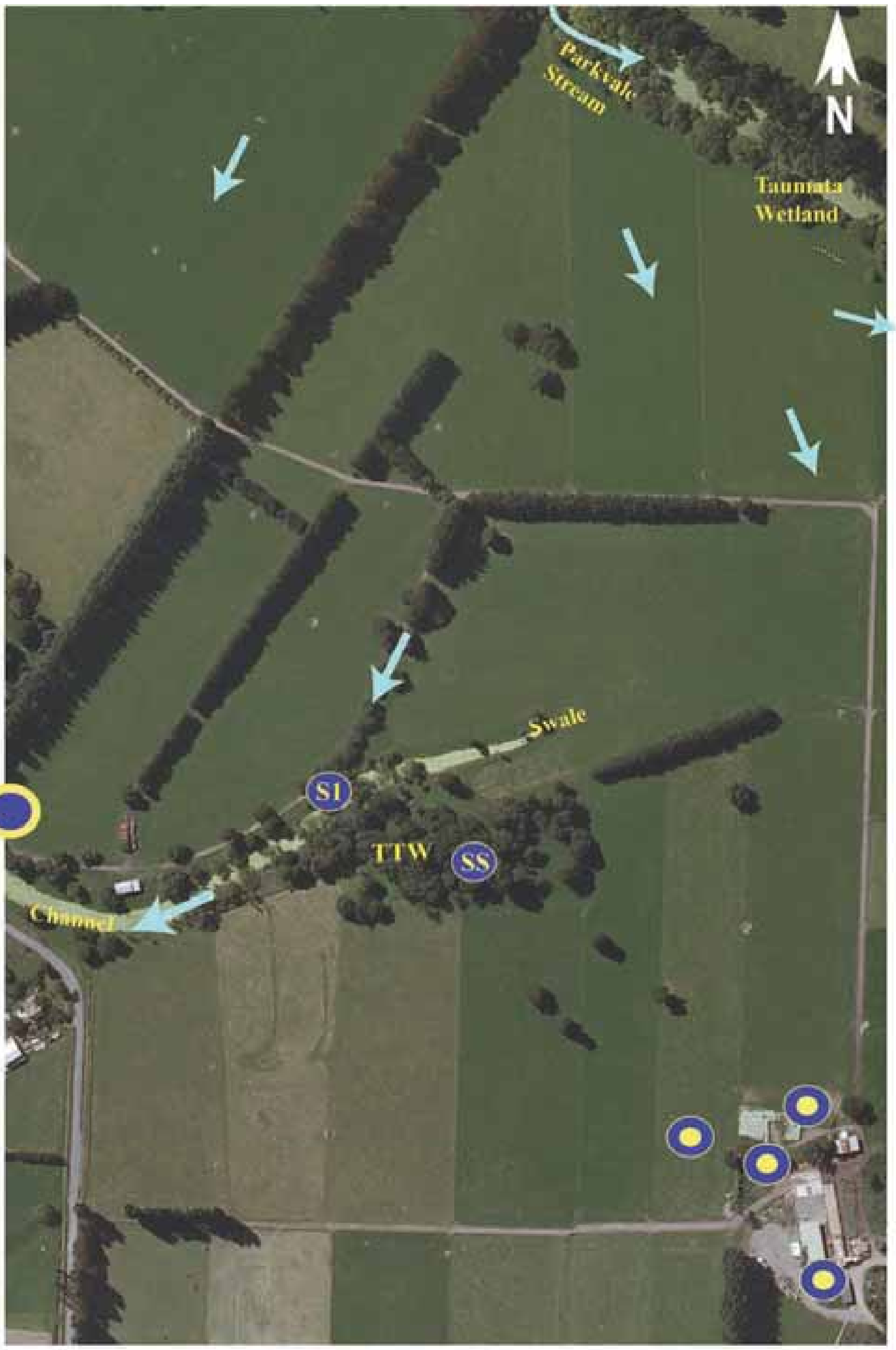
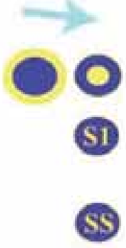


Figure 9.1 TAUMATA TERRACE WETLAND



Direction of groundwater flow

Large and small borehole takes

Water chemistry sampling points
Open water stage installed at this point

Soil sampling point

TTW Taumata Terrace Wetland

Groundwater flow directions are generally NE-SW, with the Parkvale Stream and its seasonal tributaries joining the Ruamahanga River to the south. A grassed swale leads to the Taumata channel, where water was about 30cm deep at the time of the field visit, although it often dries up during the summer. There was no visible flow in this braid channel, but when the level is higher the channel discharges through Novaflo piping to a drain running to the south.

The strong gleying and low soil organic content indicate that there is no year-round water supply and therefore unlikely to be significant supplements to the surface aquifer from deeper ones. As the surface gradient is very low, groundwater flows will be slow, especially considering the heterogeneous nature of the substrate through which the superficial aquifer moves. Since the natural vegetation of the terraces was removed during agricultural development, there will have been compaction due to summer drying, and this will have reduced soil porosity still further.

Groundwater depth on the terrace was well below the hand-augur depth of 1200mm at the time of the visit. The landowner confirmed that this is normal throughout the summer period, but that groundwater levels rise during the winter and surface flooding is seasonally common. The January 2010 flood was up to a metre deep on the terrace.

There are three consented bores in the vicinity:

1. Bore name	2. Code	3. Bore depth *metres*	4. Duration of monitoring	5. Annual amplitude *metres (av)*	6. Summer decline *metres (av)*
Morrison	S27/0248	8	1984-1998-2009	1.2-1.5-2.0	0.5-1.0-1.5
Stevenson	S26/0756	19	1998-2009	1.2-2.3	0.8-1.5
Blundell	S26/0749	10	1998-2009	1.3-2.4	0.7-1.5

Table 9.1: Bores in the vicinity of Taumata Terrace Wetland.
Bore S27 has been monitored continuously since 1984; the S26 bores since 1998. Column 5. shows the annual average range of groundwater levels for years around the three dates in Column 4. Column 6. tracks the progressive decline of summer groundwater levels compared with average December levels for the years around the three dates in Column 4. (*Data taken from graphed GWRC borelogs*).

All of these bores operate well within (Column 3) the unconfined surface aquifer. Bore logs show that levels rise steeply to winter peaks in July/August, then decline with early season drainage, then spring evaporation. Pumping, usually from December, greatly increases the rate of bore level decline and February/March lows are currently about 1.5m below December levels – down from 1m in 1998 and 0.5m in 1984 (Column 6, Table).

The average water depth of the bores has remained constant over the past 10-20 years, but the seasonal amplitudes (summer/winter ranges) have all increased (Column 5), and the greatest changes have been in summer declines.

The logs suggest either that more water is being pumped now than was the case a few years ago, or that the field capacity of the soils (the amount of water a soil can hold against gravity) has declined. In addition, the apparent increase in winter highs could be caused by changes in land use, less effective drainage, or else rainfall trends. Whatever the explanations, continued trends of this nature – less water in the summer - could be of concern for the terrace wetland's longer-term sustainability (e.g. tree health and regeneration).

The closest logged bore to the wetland is 300 metres away (Stevenson), although there are at least 8 other bores in the 0.01-2.0L/s category within half a kilometre. Collectively these could be drawing up to 200 m^3/day. Two bores to the northwest and one to the northeast, in the 10-30L/s category are all within about one kilometre of Taumata Terrace Wetland, and could be collectively be drawing about 1500m^3/day (equivalent to the summer evaporative losses from about 50ha of land) over the summer. Whether these volumes are significant in terms of the hydrological balance of the area in question would need more modelling, but landowner Taylor has noticed that pumping activity in the surface aquifer during the summer does noticeably lower groundwater levels in the vicinity of the wetland.

There is no hydrological evidence for inputs from a deep confined aquifer, and the underlying mudstones would appear to preclude this, unless they have discontinuities of course. Similarly, there is no good reason to suspect drainage losses from the surface aquifer to a lower level. Bore logs indicate rapid recovery from flooding, and this is likely to be cleared by surface drainage, as the slope of the land is too slight for subsurface flow to make much impression on floods. For most of the year, the majority of the losses from the surface unconfined aquifer are likely to be by evaporation, as is the case at Haruatai.

9.4 Chemistry

Groundwater could not be accessed on the terrace, but the sample taken from the braid channel is likely to have similar major-ion chemistry, as the water table had been fairly stable for several weeks and interchange between the channel and the terrace groundwater would have occurred.

The extensive soil gleying confirms the seasonal nature of waterlogging and the lack of substrate oxygen when the groundwater table is high. Heavy gleying also suggests high iron concentrations in local groundwaters and landowner Taylor confirms that this is indeed the case. The iron is presumably derived from the superficial terrace material, but the element was not analysed in the present study, so deeper origins are still possible.

Nitrogen concentrations in the channel are high, but it is all organic or ammoniacal and the extremely low (0.18g/m^3) oxygen concentration explains this. Phosphorus levels are high too, and half of it is organic. This is not unexpected, as the swale and channel are sinks for surface runoff of stock wastewaters during the summer. The standing water in the channel was very high in suspended solids accumulated during flooding and from dust.

The soils under trees on the terrace above the channel are almost devoid of carbon (0.73g/m^3) and have low nitrogen and phosphorus contents. Stock have access to the treed area, but do not appear to make extensive grazing use of it.

Water from the Taumata channel has very high dissolved solids (EC 50mS/m), with carbonate/bicarbonate and chloride dominating the anions and calcium/sodium the cations. Together with very low sulphur, this unusual chemistry either labels the terrace as an 'evaporite' system, or else the braid channel where the water sample was collected is a sink for runoff from farming. The high nutrients in the channel will certainly be farm runoff, but since the channel water level is presumably the groundwater level in the terrace, the major ion concentrations in the

TEST	Site	Taumata
	Material	**Water**
	Lab nos	**779412.1**
	Location	**channel**
	Date	**29.03.10**
	Sample	**S1**
WATER	**UNITS**	
1. total nitrogen TN (3+4+5)	g/m^3	6.0
2. ammoniacal nitrogen (NH_4_N+NH_3_N)	g/m^3	1.04
3. Kjeldahl nitrogen TKN (2+organic N)	g/m^3	6.0
4. nitrite (NO_2_N)	$g/_m3$	<0.002
5. nitrate (NO3_N)	g/m^3	0.0044
6. nitrite+nitrate (NO_2+NO_3)	g/m^3	0.0050
7. total phosphorus (all organic P+8)	g/m^3	1.14
8. dissolved reactive phosphorus DRP	g/m^3	0.74
9. sum anions (HCO_3+CO_3+Cl+SO_4)	Meq/L	4.8
10. sum cations (K+Na+Ca+Cl)	Meq/L	4.4
11. pH Laboratory	pH	6.7
12. pH Field	pH	6.5
13. electrical conductivity (EC) Lab	mS/m	47.0
14. electrical conductivity (EC) Field	mS/m	50.0
15. total alkalinity (as $CaCO_3$)	g/m^3	142
16. bicarbonate (HCO_3)	g/m^3	173
17. total hardness (Ca+Mg as $CaCO_3$)	g/m^3	133
18. dissolved calcium (Ca)	g/m^3	36.0
19. dissolved magnesium (Mg)	g/m^3	10.6
20.dissolved potassium (K)	g/m^3	13.1
21. dissolved sodium (Na)	g/m^3	31
22. dissolved chloride (Cl)	g/m^3	66
23. dissolved sulphate (SO_4)	g/m^3	<0.5
SOIL	**Lab**	**779951.5**
	Location	**terrace**
	Date	**29.03.10**
24. Total carbon (C) as dry weight	%DW	0.73
25. Total recoverable phosphorus (P)	Mg/kg DW	580
26. total nitrogen (N) as dry weight	%DW	0.114

Table 9.2: Taumata terrace wetland water quality and soil chemistry data.

channel would be expected also to reflect the chemistry of the subsurface groundwaters under the terrace wetland. This water chemistry is probably consistent with what would be expected of an unconfined surface aquifer flowing very slowly through unsorted terrace sediments and accumulating salts through evaporation over the summer period. The possibility of the high salts content of the channel water deriving from a deeper confined aquifer has already been discounted due to the prevalence of gleying, but the evaporite explanation would also need to be eliminated before a deep aquifer involvement would be needed to explain the water chemistry.

Drainage and conversion to pasture will have resulted in some consolidation and compaction of the substrate, and accumulation of evaporites would have reduced porosity and possible increased flood peaks. Compaction will in any case reduce annual flushing of salts from the soil – this often occurs in heavily-stocked and irrigated dairy pastures. Landowner Taylor is of the opinion that flooding and waterlogging is taking longer to clear after major weather events, and substrate changes could account for such changes.

More comprehensive seasonal water quality sampling is needed to explain the water chemistry, which can then be used to improve understanding of the hydrology. Analysis of bore waters would also be valuable. If the system has indeed accumulated evaporites, it would obviously be important to know if this process is still occurring and what the implications might be for the Taumata wetland remnant – and also for farming.

9.5 Ecology and land use

Taumata Terrace Wetland is a 1.5ha remnant of a formerly widespread forest type that used to dominate the seasonally-flooded terraces above the permanent wetlands of the oxbow lakes and braid hollows – a seasonal semi-swamp floodplain forest, now isolated in a landscape of pastoral development, mainly dairying.

The remnant is dominated (about 50%) by totara, with smaller proportions of kahikatea, small-leaved milk tree, kowhai and titoki. Totara is characteristic of seasonally waterlogged ground, and kahikatea of seasonal surface flooding. Titoki, kowhai and milk tree are all tolerant of seasonally high water tables.

It seems that the former forest community that this remnant represents was intermediate between typical totara habitat and dry-end kahikatea floodplain swamp. A single old 'stagshead' kahikatea remains, although there are a few others in another small remnant block about 300 metres to the northeast. These older trees will have been around for at least 300 years, thus supporting the assumptions made regarding the former vegetation type of these terraces.

It is the mixture of species – the intermediate nature of the seasonal swamp forest - that confers biodiversity value to this site. The milk tree is becoming regionally very uncommon, so its presence here adds further to the value of this remnant of a now scarce forest type. Of course the site is certainly much drier than it used to be before agricultural development, and this is borne out by the presence, probably increasing, of tawa and ribbonwood.

Most of the vines have been cut out of the canopy, although some rata, passion vine and pohuehue remain. Stock use the forest block for shelter and ground cover is now almost entirely exotic: pasture grasses, solanum, inkweed, etc. Along the braid channel edge, there are some cabbage trees and both twisted and crack willows.

9.6 Threats

- If the groundwater flow really is slow within the terraces, then there is likely to be a drying trend at the surface. Resulting compaction could extend the duration of surface flooding during winter and spring, but higher evaporation rates during summer, due to removal of the natural vegetation, will be favouring non-swamp-forest species. In addition, evaporation will be creating an upward trend in the accumulation of salts: soil permeability will have declined and annual flushing of accumulated salts will not be as effective as it once was.

Tree stress could therefore occur through either increased flooding duration or increasing drought – or both. If salts are indeed continuing to accumulate in the soils (say, to above EC 60mS/m), this could also become a stress factor for the trees (this issue is also mentioned in Section 7.5 of the Haruatai chapter).

- Pumping from boreholes may already be affecting plant growth. The logs for the three consented bores show that recharge rates are not rapid, so refilling is very likely lateral from within the surface aquifer and not from a lower confined aquifer. The logs also suggest that pumping has intensified in recent years and any significant increase in bore number may cause a more widespread decline in water tables.

- Any retirement through fencing will need monitoring and managing for inevitable weed growth.

9.7 Conclusions and recommendations

- There are two components to the Taumata Terrace Wetland: the channel/braid semi-permanent wetland and the seasonal semi-swamp forest on the terrace. At present there are no current significant biodiversity values in the channel wetland, because it is no longer permanently flooded. The terrace community, on the other hand, is a now a very uncommon remnant of a once widespread seasonal wetland type.

- On the basis of current information, hydrology and water chemistry can be explained without invoking water input to the surface aquifer from a lower confined aquifer in any significant quantity. However, a more detailed water quality survey, including bore waters, may detect chemical indicators of links (iron?).
- If the terrace wetland remnant is considered worthy of conservation management, the first restoration priority would be to enhance, or at least stabilise, water availability during the summer period. One option could be to instal a control structure (some sort of weir) in the channel outlet stream. It would not, though, be a straightforward exercise, because:
  (a) Raising the height/duration of the water table too much/too quickly could damage the trees. They would need 'adaptation time'.
  (b) Because the terrace is prone to flooding, the weir would need to be easily adjustable between winter and summer settings.
  (c) The storage volume of the braid channel would not be large in comparison with the summer evaporative losses of the forest remnant, so a bore supply may be needed to achieve objectives.
  (d) The present summer water balance would need to be modelled before any hydrological manipulation could be attempted. Records from one or two capacitance probes would enhance the modelling.
  (e) If enough water is available, the control structure could transform the braid channel into a permanent eutrophic water body, and the swale into a wetland, but there would need to be controlled plantings to help control the growth of aggressive weed species.

- Seasonal water quality monitoring is recommended (particularly groundwaters and borewaters), partly to confirm nutrient patterns and partly because if total dissolved solids rise much above present levels, there could be adverse effects on some tree species, and even on crops.

- Pumping from the surface aquifer would need to be minimised in the vicinity of the terrace wetland, until drawdown effects of existing bores have been further studied and compared with estimates of evaporative losses.

- Existing stock access would need to be restricted, to protect any planting programme to re-establish a largely native groundflora and a more typical balance between woody species. The landowner is willing to cooperate with a fencing programme, but the present canopy cover is a valuable stock refuge, so an appropriate compromise would need to be reached.

9.8 Taumata photographs

Photo 9.8.1: Listed as 'Taumata Wetland' on the GWRC wetlands database, this former oxbow or braid channel of the Ruamahanga River flows only seasonally, is dominated by willows and has no conservation values.

Photo 9.8.2: On the other hand, the nearby seasonal swamp forest wetland on the terrace above a braid channel has significant value as a rare remnant of a former widespread wetland type. It is dominated by totara, but there are also several good specimens of the regionally uncommon small-leaved milk-tree, kahikatea and titoki. There is restoration potential.

Photo 9.8.3: Large small-leaved milk tree with totara and titoki. Understorey is used for stock grazing and shelter.

Photo 9.8.4: Grassed swale leading to channel. Seasonal flooding depth can be a metre. Groundwater table depths have not been monitored.

10. ALLEN-LOWES BUSH
Wairarapa

10.1 Introduction

Lowes Bush Scenic Reserve is one of two substantially forested wetland reserves in the Masterton District. It is accessed from Perry's Road South via a short easement through land owned by David Lowes. All other access routes require landowner consent.

Beadel *et al* (2002) describes Allen/Lowes Bush as "…the largest and most intact area of kahikatea swamp forest distinctive for its size, maturity, ecological diversity and condition within Wellington Conservancy, if not the entire North Island…" and "…the best representative of the once extensive podocarp swamp forest of the Wairarapa Plains…".

In 2002 Lowes Bush was still privately owned, but now it has been acquired as the 42ha Lowes Bush Scenic Reserve, and it is contiguous with a 7.5ha still-private bush area of similar type, owned by Keith Allen.

Visits were made on 12th (with Tony Silbery, Department of Conservation) and 16th April. Time did not permit a survey of the Allen block.

10.2 Topography and Stratigraphy

The wetland has formed on the immediate upside (and to the north) of the Carterton fault but, as the fault is rather jumbled, the faultline is only clear where the forested southeastern margin of the Reserve is elevated above the pastoral land to the south and the herbaceous raupo swamp that dominates the central part of the Reserve.

The northern part of the wetland has not accumulated more than 300mm of organic silt, but there are places around the southwestern spring which have built up over a metre of peat. The central basin was not examined for soil type.

The directions of the two inflow races, as well as the distinct braided flow-lines on aerial photographs, demonstrate the north-northeast – south-southwest slope of the terraces. Nearby bore logs 3I/53 and 3I/109 describe underlying poorly-sorted gravels and other alluvial deposits. Details of borehole RS45 (Fig. 10.1) has not been researched.

10.3 Hydrology

The Lowe Reserve comprises a mix of permanent and seasonal wetlands. Much of the northern margin is only seasonally flooded and the northwestern and southeastern spring zones, and the central raupo-dominated community, at least, are permanent wetlands, with the water table at or above the ground surface year-round. Because of its jumbled nature, the Carterton faultline provides both a physical impediment to water flow in some places and a substantial supplement to the water supply in others.

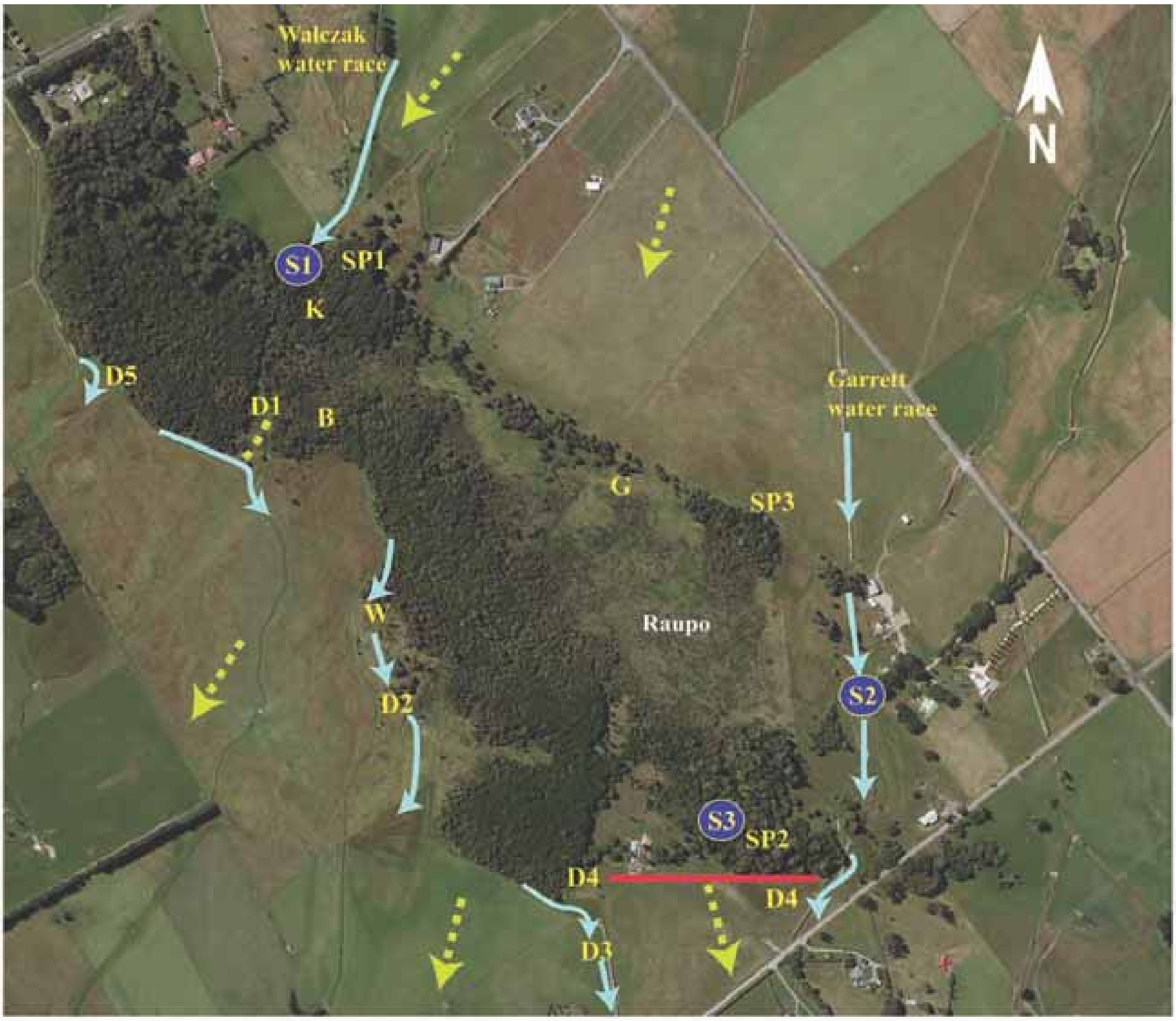


Figure 10.1 ALLEN-LOWES BUSH WETLAND

S1 S2 S3	Water chemistry sampling points
D1, D2, D3, D5	Drainage lines
D4	Drainage seeps
SP1	Wylie-Morgan spring
SP2	South-eastern spring
SP3	Garrett Spring
W	Weir
B	Borehole RS45
K	Kahikatea stand
G	Carex / tall fescue sward
(blue arrow)	Drain flow direction
(yellow dashed arrow)	Groundwater flow direction
(red line)	Faultline

There are two strongly-flowing water races feeding the wetland: one enters the northwest corner of the wetland, from the Walczak property, and the other skirts the southeastern corner on the Garrett property, before heading south under Perry's Road South. Both races are tributaries of the Parkvale Stream, and derive their water ultimately from the Waingawa Stream and the Waingawa River to the north of the Waingawa Wetland.

There are at least two springs associated with this wetland. The northwestern spring, just outside the Reserve on the Wylie/Morgan boundary, fluctuates seasonally, and the one in the southeastern corner of the Reserve is year-round, but difficult to gauge because it exits over a broad zone of (predominantly) kahikatea forest, directly over the faultline. In addition, there are several groundwater seepage zones along the northeastern boundary of the Reserve, particularly SP3, and some of the water from the Garrett race leaks into the eastern end of the Reserve.

Much of the Walczak race water disperses into secondary flow channels inside the Reserve where it is joined by the Wylie-Morgan spring waters. It first supplies a vigorous young kahikatea stand (K) and then mostly flows through swamp forest along the southern side of the Reserve before exiting mainly into drains D2 and D3. A proportion of Walczak race water exits the wetland at D1, directly opposite the entry point at S1. D2, as the major outflow, has a small gauging weir (W).

It would appear, from flowlines above and below the wetland, that most of the wetland is fed by the Walczak race, the Wylie-Morgan spring, and seepage inputs along the northern boundary. The southeastern spring has a substantial local influence, but its limits of influence need checking with an electrical conductivity survey. Substantial drainage seeps (D4) issue from the faultline scarp below the southeastern spring.

Although the Walczak race is fully allocated for water abstraction, there appears to be potential for farming intensification both north and south of the wetland. This could have a negative effect on the wetland if irrigation or borehole abstraction increases.

10.4 Chemistry

Samples were collected from the Walczak race, where it enters the wetland (S1), from the Garratt race, where it approaches within 20m of the wetland (S2), and from the southeastern spring (S3). The two races have almost identical major-ion chemistry and they may well also contribute to seeps along the northern wetland boundary, although probably not to the Wylie/Morgan spring.

Spring SP1 and Drain D2 were not sampled, but checking their chemistry should indicate whether or not known inputs along the northern boundary have been mixed with artesian waters within the wetland.

Because of the elevation of the faultline and the known groundwater flow directions, farming activity can only influence water chemistry on the northern side of the Reserve. Thus the higher nitrate concentration in the Garrett race (S2), compared with S1 from the Wolczak race, will be an upstream agricultural land-use effect.

The southeastern spring (S3) has over twice the dissolved solids concentration and clearly therefore a quite different provenance. The sodium and chloride levels are too high for an unconfined surface aquifer remote from coastal influences, and carbonate/bicarbonate levels are also high. The chemical signature is similar to that of Carters S2, and both are more than likely to be drawing water from deeper confined aquifers.

The flowrate of Allen-Lowes S3 could not be estimated and the depth of the lower aquifer has not been identified. However, the seepage losses to the south (D4) are substantial (visual assessment only). Dissolved nitrogen and phosphorus components are largely organic, as the sample was collected from water seeping through a deep litter and organic soil under kahikatea/pukatea forest.

TEST	Site	Allen-Lowe	Allen-Lowe	Allen-Lowe
	Material	water	water	water
	Lab nos	783025.1	784597.1	784597.2
	Location	race	race	forest seep
	Date	12.04.10	16.04.10	16.04.10
	Sample	S1	S2	S3
WATER	**UNITS**			
1. total nitrogen TN (3+4+5)	g/m^3	0.24	0.84	1.33
2. ammoniacal nitrogen (NH_4_N+NH_3_N)	g/m^3	<0.010	>0.010	0.0120
3. Kjeldahl nitrogen TKN (2+organic N)	g/m^3	0.24	0.27	1.32
4. nitrite (NO_2_N)	$g/_m3$	<0.002	0.0024	<0.002
5. nitrate (NO3_N)	g/m^3	0.0033	0.57	0.0120
6. nitrite+nitrate (NO_2+NO_3)	g/m^3	0.0052	0.58	0.0138
7. total phosphorus (all organic P+8)	g/m^3	0.026	0.028	0.094
8. dissolved reactive phosphorus DRP	g/m^3	<0.004	0.0054	0.030
9. sum anions (HCO_3+CO_3+Cl+SO_4)	Meq/L	0.76	0.84	1.97
10. sum cations (K+Na+Ca+Cl)	Meq/L	0.78	0.74	2.1
11. pH Laboratory	pH	6.4	7.5	6.8
12. pH Field	pH	5.8	6.9	6.4
13. electrical conductivity (EC) Lab	mS/m	8.0	8.2	19.8
14. electrical conductivity (EC) Field	mS/m	8.0	8.1	18.8
15. total alkalinity (as $CaCO_3$)	g/m^3	22	22	66
16. bicarbonate (HCO_3)	g/m^3	27	27	80
17. total hardness (Ca+Mg as $CaCO_3$)	g/m^3	22	21	36
18. dissolved calcium (Ca)	g/m^3	5.9	5.5	8.1
19. dissolved magnesium (Mg)	g/m^3	1.82	1.69	4.0
20.dissolved potassium (K)	g/m^3	0.65	1.34	0.59
21. dissolved sodium (Na)	g/m^3	7.3	6.6	31
22. dissolved chloride (Cl)	g/m^3	7.3	8.1	21
23. dissolved sulphate (SO_4)	g/m^3	5.2	6.0	3.5

Table 10.1: Allen-Lowes Bush wetland water quality data.

10.5 Ecology and land use.

The Allen-Lowes Bush wetland is probably the best remaining example of kahikatea swamp forest in the lower North Island, and it includes both young and mature stands as well as floodplain and spring-fed types. There is also extensive sedgeland, reedland and shrubland.

Prior to agricultural development, which involved channelising the surface water into races to the north, and drainage channels to the south, there would have been seasonal surface flows in braided channels and year-round seeps from the north into the shallow depression that is now the Allen/Lowes Bush. Few places would have been deep enough to accumulate any depth of peat, except where springs emerged along the faultline (compare Waingawa, Ch. 2). Raupo/flax/sedge communities and kahikatea/pukatea would have dominated. The wetland has been improving its condition since the area was fenced and retired from rough grazing only some ten years ago.

Various individuals, and members of the Wellington Botanical Society, compiled, between 1988 and 2005, a vascular plant flora for Lowes Bush (Rebergen *et al*, 1999-2005, updated by Enright, 2009) and Allen's Bush (Ogle *et al*, 1988-1999). These are impressive inventories of over 200 indigenous, and over 50 adventive species. At least as important as the high species tally is the diverse range of vegetation types, although the lists do not provide ecological information.

The high species diversity is due largely to high habitat diversity. There are seasonal herbaceous and shrub wetlands, and permanent wetlands which range from ponded waters, such as low-stature raupo swamp, to tall spring-fed stands of vigorous raupo, flax and tall sedges. Swamp forest ranges from dense young pole stands developing in former grazed areas (particularly where the Walczak race enters the Reserve) to large, mature kahikatea and pukatea in the wetter hollows and around the southeastern spring. Swamp maire is present along the southern margin and tawa/matai stands occur in the drier places. An extensive area of shrubland is characterised by *Olearia virgata*.

The relatively high quality water supply (particularly its medium/low nutrient status), also contributes to this diversity, by enabling slower-growing species to co-exist with more aggressive (often exotic) species which benefit most from high nutrient levels.

The area around the southeastern spring has particularly high species diversity. The spring site itself is within 30m of the Reserve boundary fence, but has dense young and old kahikatea/pukatea and cabbage trees. The forest understorey is characterised by titoki, mahoe and coprosmas. Closer to the fenced boundary, artesian water in peaty hollows supports tall dense stands of raupo, *Carex lessoniana, C. secta* and *Isolepis prolifer*, kiokio ferns and, where starwort and sweetgrass form mats, the uncommon *Ranunculus amphitrichus* occurs. Pools are fringed by bushes of tauhinu and small-leaved mahoe, lacebark, tarata, hangehange, and coprosmas.

This southeastern part of the Reserve also supports a thriving population of brown mudfish (*Neochanna apoda*), which has been monitored for some years. Mudfish are very likely to be more widespread in the seasonally-inundated hollows which are a feature of Lowes Bush, but access problems have restricted the area over which detailed studies can be done.

The herbaceous swamps of Allen-Lowes are mosaics of raupo and various sedges where water is permanent but, where water is more seasonal and there is no canopy cover, *Carex geminata* and tall fescue compete for dominance.

Several quite uncommon wetland species have been recorded from Lowes Bush, such as the dwarf musk, *Mazus novae-zelandiae*, although its much commoner, but adventive, close relative, *Mimulus guttatus* also forms swards here, particularly where the Wylie/Morgan spring enters the Reserve. The small leaved shrub community in the southeastern corner of the Reserve (bounded by the Garrett and Lowe properties) is important for it's diversity of species and it is being enhanced with plantings of species such as *Olearia gardneri* – one of a suite of threatened shrub species planted here as insurance against catastrophe at their other sites in the region.

In general, adventives appear to be well balanced with indigenous species, but this could change if the water supply to the wetland becomes more seasonal, or richer in nutrients. Japanese honeysuckle is currently widespread in the central raupo area and, together with tradescantia, has -

the potential to spread regardless of groundwater levels, but *Cyperus eragrostis,* native umbrella sedge and selaginella could also spread rapidly in drier conditions.

10.6 Threats

- There is potential for both hydrology and water quality to be negatively impacted by farming intensification. The Walczak race is fully allocated, but there may still be demand for increased bore abstraction, either from the surface aquifer or from a deeper one.

- The southeastern spring has clearly been stable for a long time (there are some quite old kahikatea – one at least could be 400-500 years), but any increased abstraction from the aquifer that feeds it could diminish supply. The swamp forest and herbaceous swamps fed by this spring may be elevated above the rest of the wetland, so continuity of water supply is important.

- Greater seasonality in water supply would be likely to change the vegetation pattern, with increasing dominance of tall fescue, umbrella sedges, jointed rush and blackberry, and with a reduction in the vigour of raupo. The exotic liane *Cobaea scandens* is known to be present and old man's beard has been recorded. *Tradescantia* and Japanese honeysuckle are significant current threats, as is the seemingly innocuous, but actually insidious, selaginella. Elderberry also needs vigilance in the drier bush margins. Beadel *et al* (2000) recorded sweet briar, but it is not listed by Enright (2006).

10.7 Conclusions and recommendations

- The Allen-Lowes Bush wetland is a major hotspot for wetland biodiversity and every reasonable effort should be made to ensure its sustainability. Its water supplies appear to be good and stable, but there needs to be vigilance, because the wetland probably needs all the water it receives at present and any reduction in supply would be likely to result in ecological changes. Water quality is good and any resource consents sought for farming intensification, subdivision, etc in the vicinity should be made subject to conditions which protect the wetland's hydrology and water quality. At present, farming to the immediate northeast of the wetland is either low or medium intensity, but this could change. Also the races, and the water which feeds them, have several kilometres of travel before they arrive at Allen/Lowes.

- In order to construct a model of the hydrodynamics of the wetland, both the Wolczak race and the Wylie-Morgan spring need to be gauged, and D1, D2 and D3 flows estimated. Rainfall needs to be added, of course, but there is still uncertainty over how much diffuse seepage flow enters the wetland along the northern boundary. The southeastern spring would be difficult to gauge and monitor as the flow is diffuse and in dense bush.

  Surface contours are also needed, particularly along the southern boundary and in the southeastern corner. LiDAR may be adequate if contours of less than one metre can be achieved.

  Most of the point-source surface outflow from the Lowes block is likely to be down D2 and D3 but, from the aerial photograph, it would appear from the lushness of pasture near the wetland that there is also a lot of diffuse water loss to the south from the central wetland section. A hydrological model may not therefore be very precise, but it could still be useful as baseline for future monitoring – perhaps with a capacitance probe providing a continuous record of water level somewhere in the central wetland. Gauging of the Walczak race would also provide valuable information for the model, and real-time data would be even better.

- An electrical conductivity survey would delimit the zone of influence of the southeastern spring and also check whether there are any other deep aquifer inputs to the wetland. Any EC anomalies can be followed up with chemical sampling.

- If D2 and D3 discharges are significant during the summer period, raising weirs in these drains (possibly also D1) could be a means of retaining more water in the wetland (should this be necessary at some stage). However, retaining too much water in the wetland could reduce seasonal swamp habitat.

- Quarterly water quality monitoring would help with hydrology modelling and spring/summer samples (inputs and outputs) would check for any nutrient trending, as well as any progressive changes in major ion concentrations which could point to changes in water sources.

- There are no weed infestations requiring immediate attention, except perhaps Japanese honeysuckle, willow and ivy. Tradescantia and selaginella should at least be monitored; they may take 20 years to become serious threats, but since only physical control is possible (in dense bush) with these species, the earlier containment operations are established the better.

- *Carex geminata* will restrict the spread of tall fescue if summer water levels are high, and *vice versa* if a wetland becomes more seasonal. These species are good biological indicators of hydrological change around swamp margins, as are blackberry, umbrella sedge and jointed rush.

- A study of aerial photographs for the last three decades may help to build up a history of recent wetland changes since stock were excluded from the area.

- The Enright (2009) plant species list is valuable, but it would be more useful as a management tool if the species were allocated to one or more ecological community and given simple frequency/abundance ratings. A vegetation-zone map along the lines of Figure 11.2 (Wassilieff, *et al*, 1986) would also provide a useful management tool.

10.8 Allen-Lowes photographs

Photo 10.8.1: Considered to be the best kahikatea swamp forest remnant in the southern North Island. This view over the central wetland towards S3 (Fig. 10.1) at Allen-Lowes depicts a *Carex geminata* sward (G) in the foreground, dense raupo beyond and both young and mature kahikatea along the southern section of the wetland.

Photo 10.8.2: Land rising to top of fault escarpment in the southeastern corner of the wetland, with two large mature kahikatea (probably about 300 years old) marking the edge of the spring seepage from a lower confined aquifer accessed by the fault.

Photo 10.8.3: A drier forest type about 80m west of the southeastern spring, but still on the fault escarpment. There is only the occasional kahikatea, but still frequent pukatea and titoki.

Photo 10.8.4: The Walczak race from the north is the only direct surface input to the wetland, but is clearly not enough without other seepage inflows to sustain the wetland. Nutrient inputs are low, despite the long travel of the race through farmland.

Photo 10.8.5: The Wylie/Morgan spring arises in the paddock, but appears to have considerable seasonal variation in flow rate. The exotic musk-flower sward bottom left indicates the region through which the spring flows into the Reserve.

11. CARTER'S SCENIC RESERVE
Wairarapa
Also known as Carter's Bush

11.1 Introduction

Carters was designated as a Reserve in 1921 and is now a Department of Conservation Scenic Reserve. In 1960, it was enlarged by 133ha to 386ha, but then reduced in 1973 to its current 31.5ha when a large area was converted to farming. Soon afterwards, the Department of Lands and Survey prepared a management plan for the Reserve (Turner, 1978).

Carters Reserve and the Waiouku Stream are recorded in the Greater Wellington Region 1999 Freshwater Plan, Policy 4.2.10 and Appendix 2 (Part B) as a "wetland of a high degree of natural character".

There is public vehicular access along a track from Gladstone Road to a carpark area. The public walkway through the centre of the wetland is boardwalked for a considerable distance, but there is also a loop track running through the southern block of the Reserve.

Darryl Squires 2006 MSc thesis is a useful source on information on water quality and hydrology.

Visits to Carters were made on 14 (with Tony Silbery, Department of Conservation) and on 16 April.

11.2 Topography and Stratigraphy

Much of Carters Reserve is located in a former braid channel (Squires, 2006, refers to it as an 'old oxbow') of the Ruamahanga River (Terrace A, Fig. 11.1A)). The northern boundary of the Reserve is elevated in two steps: a small ca 4m rise to a clay-capped plateau of about one hectare (Terrace B), then a much larger 10m rise to an extensive old river terrace (Terrace C). A and B could possibly be the same terrace, but they are referred to in the present account as two. The GWRC catchment map overlay does not make this distinction. Terrace D rises to the west above Terrace C. Both C and D are in pastoral agriculture.

The S26/0755 bore, located on the current Ruamahanga floodplain and less than a kilometre southwest of Carters, typifies the general terrace stratigraphy, with layers of silt, gravel and sand lying on impermeable blue clays, and underlain by mudstone at about 20m depth. Permeable silts, sands and gravels also underlie the Reserve, but Squires (2006) study shows that they are capped in the old river channel (Terrace A) by a thick, presumably impermeable, silty clay deposit, although this is apparently not present in the southern part of the Reserve.

The S26/0772 borelog from Terrace C, above the Reserve, includes a substantial peat deposit at about 13m below surface, indicating a backwater palustrine swamp at that time, but S26/0755, closer to the main river channel, has no peat layer, so has presumably been flushed or eroded by river flow for a long time.

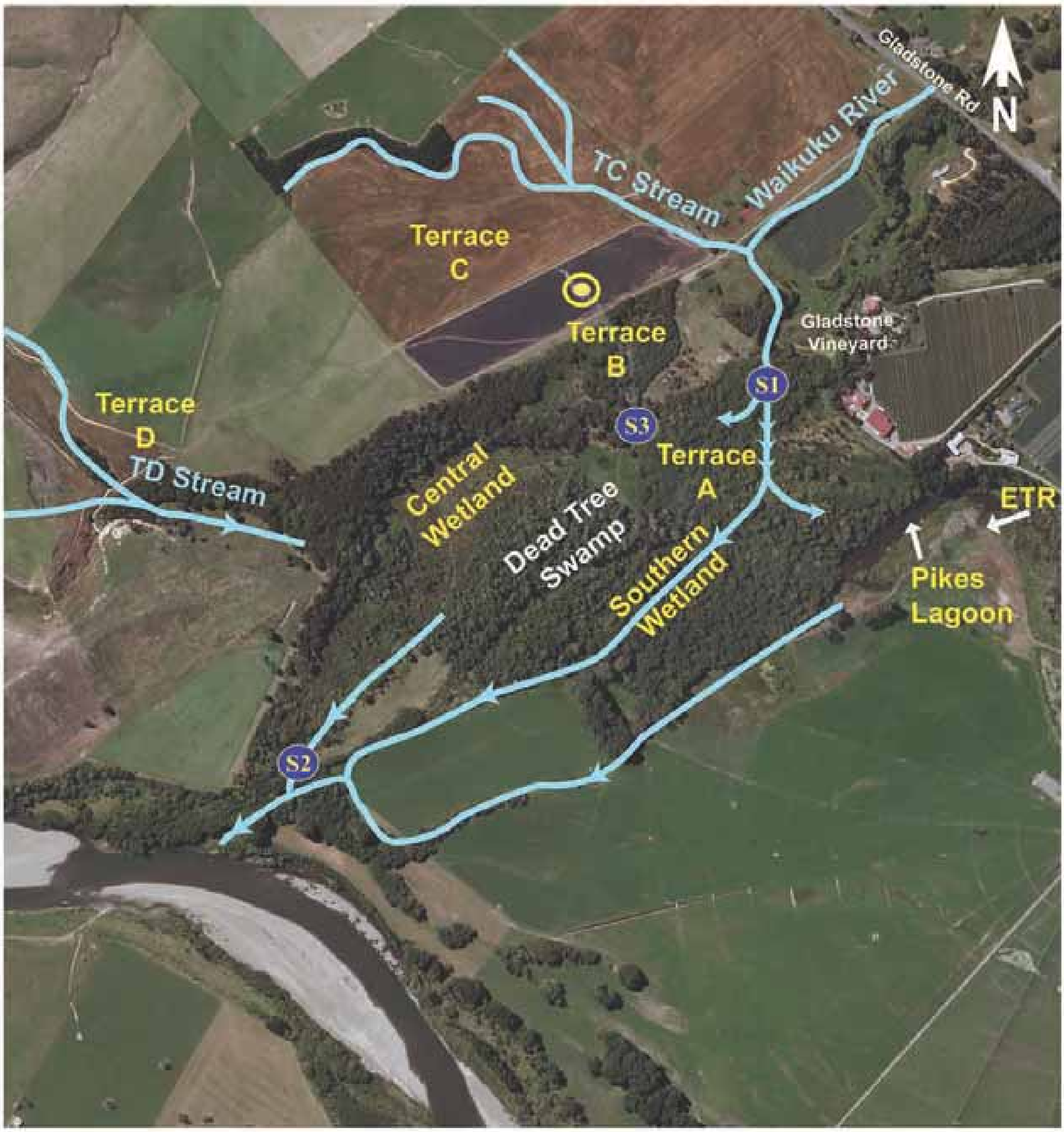


Figure 11.1A CARTERS BUSH - Hydrology & Geology

[legend symbol]	Water courses and flow directions
[legend symbol]	Majority flow of Waikuku River
TC/DC streams	Largely seasonal stream from Terrace C and Terrace D
ETR	East Taratahi Race enters here
[legend symbol]	S26/0772 borehole

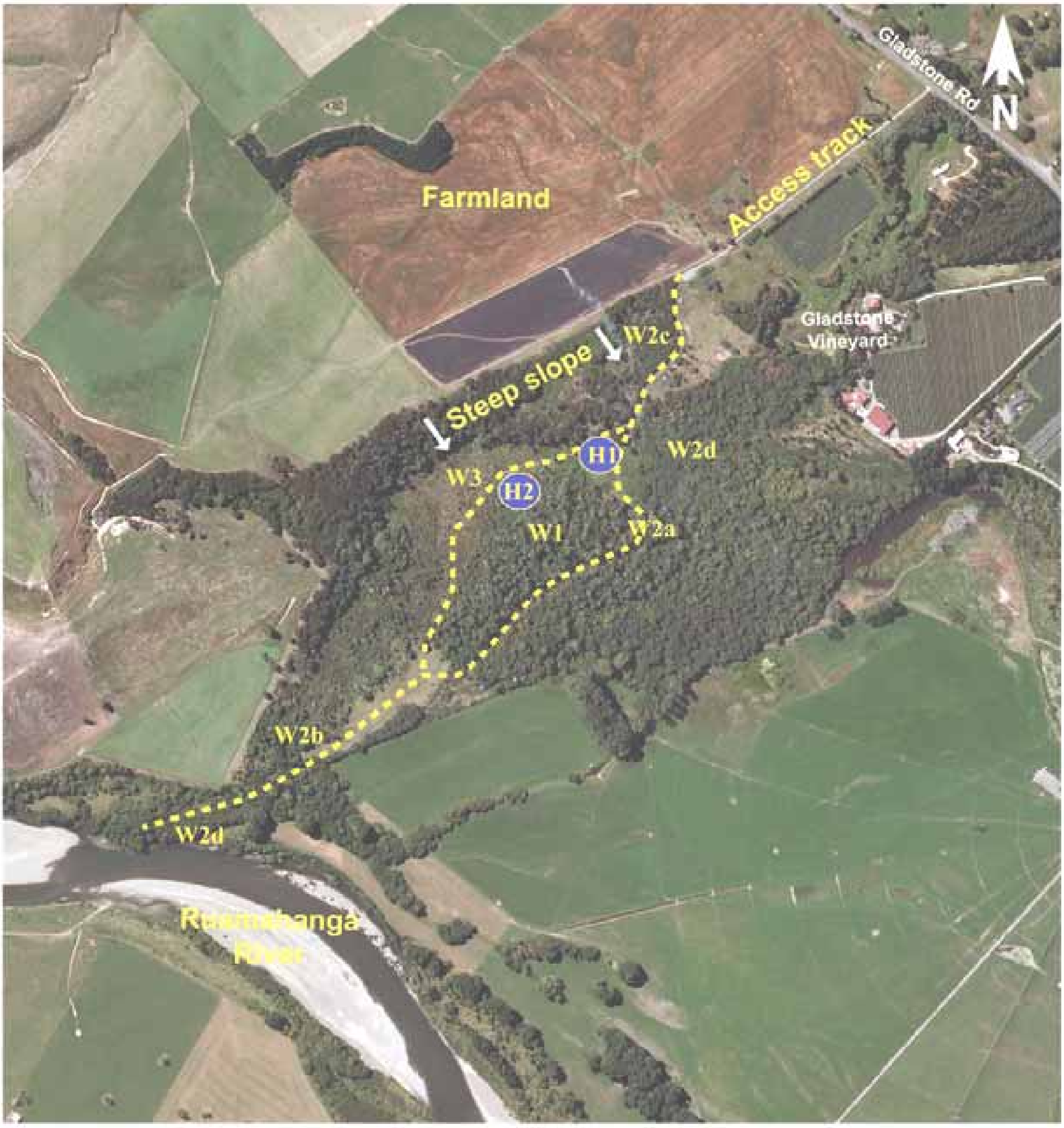


Figure 11.1B CARTERS BUSH - Vegetation Types

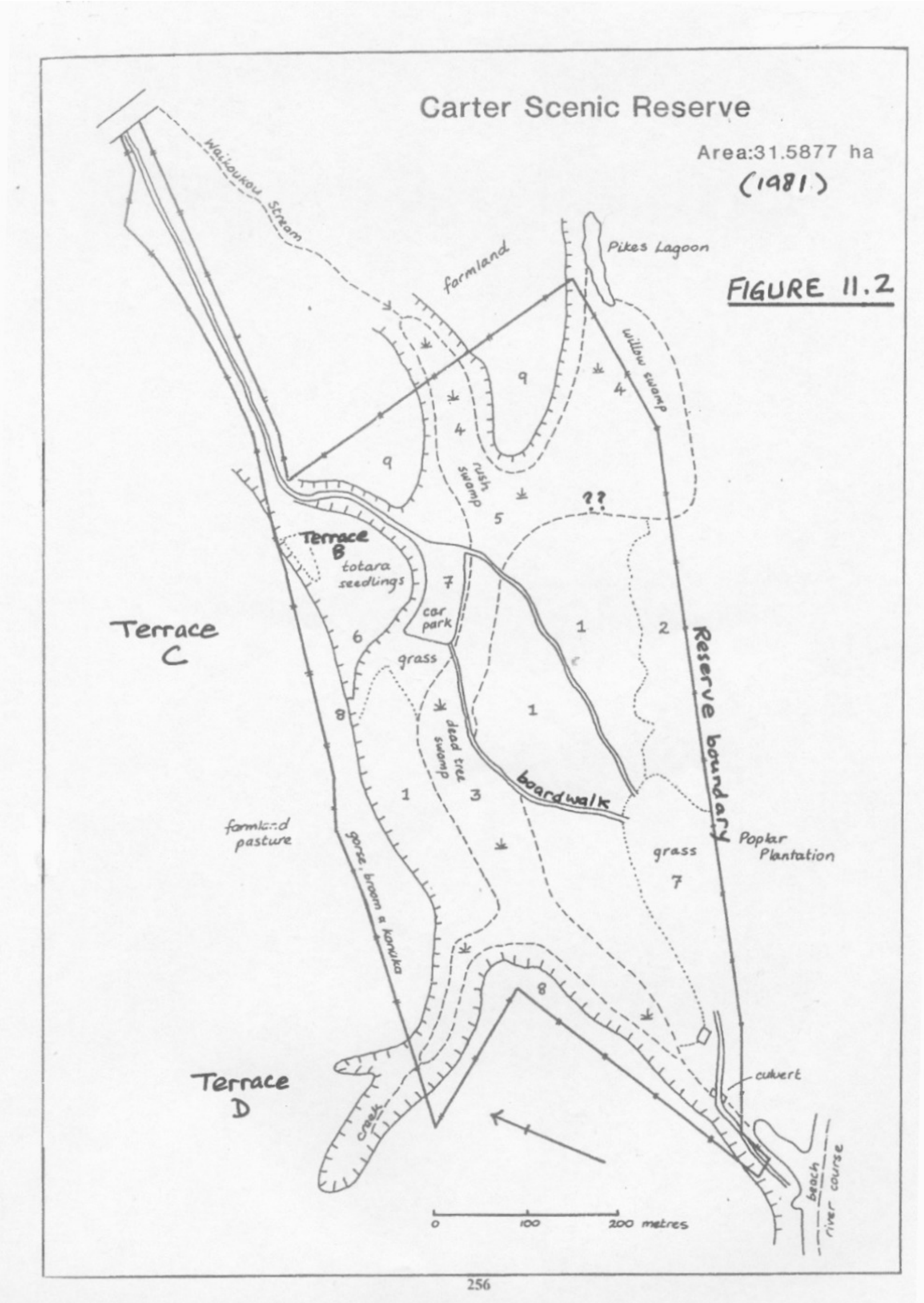


Figure 11.2: Sketch Map (1981) of Carters Bush (from Wassilieff *et al*, 1986)

1. Podocarp forest on alluvium of kahikatea-matai/titoki, with totara on well-drained terrace slopes.
2. Swampy bush and flax.
3. "Dead tree swamp" where flooding of kahikatea stand has left dead stumps in wet swamp with rushes, sedges and weeds.
4. Willow dominated swamp at eastern end of Reserve.
5. Eastern, central and western swamps of raupo, rushes and flax.

6. Grass and open scrub with kanuka and weeds, containing the collection of 8 *Coprosma* species. Totara were planted for protection after removal of pines.
7. Open grassed area at SW end, fringed by bush and periodically mown.
8. Gorse, broom and kanuka along NW and W boundary.
9. Pine plantation.

Notes:

- *Area 9 pine plantation has been felled and the carpark has now been moved into the northernmost block.*
- *The dashed lines indicating water flow lines may need some revision (eg at '??')*
- *Dead kahikateas are on both sides of the walking track (now a boardwalk).*
- *Terrace notation from the present report has been added to Fig. 11.2*

There are small areas only of very shallow peat deposits in Carters today. Presumably winter flushing by Ruamahanga floods maintain good substrate oxygenation as well as carrying away some of the recent litter.

11.3 Hydrology

Most of the surface water input to Carters Reserve derives from distributaries of the Waingawa River: specifically, the Waikoukou (=Waikuku) River from the north and the East Taratahi Race from the east (known as the Easterbo Farm Race just before it enters the Reserve at Pikes Lagoon). Within the wetland, there are two main flow lines developing from these surface inputs:

- The Central Wetland flow line derives from the Waikuku and runs from east to west. Flow from the TC Stream, draining Terrace C above Carters into the Waikuku, is very seasonal (Silbery, *pers. comm.*), and does not appear to be a significant input to the Reserve, unless there is a significant subsurface flow.
- The Southern Wetland is fed by two east-west flowlines: One derived solely from the Waikuku and the other, flowing down the southern boundary of the Reserve, from Pike's Lagoon. The Waikuku also supplies water to Pikes Lagoon. The 1981 map from Wassilieff *et al*, 1986, (Figure 11.2) indicates only one flowline serving the Southern Wetland, but this now needs revising as the southern drain carries some of the output from Pikes Lagoon.

Squires (2006) estimated that most of the Waikuku inflow is directed towards the southern section.

Some of the kahikatea trees in the Reserve are of the order of 200 years old, or more, indicating that the hydrological regime in Carters had been stable for at least this amount of time. However, in 1972-73, Pikes Lagoon was lowered to permit poplar planting along the southern margin of the Reserve and the extra drainage was diverted into the Reserve (see Figure 11.2). This additional input increased water depth too abruptly for the kahikateas to adapt with new adventitious roots and many died, creating what is now known as 'Dead Tree Swamp'.

About 1km of stopbanking was constructed along the Ruamahanga between 1960 and 1970 and this would also have contributed to changes in the Carters hydrology by altering the amplitude and duration of flooding.

Plants and plant communities adjusted to the new regime over the next 30 years. Squires (2006), estimating the water balance during 2002-03, suggested that the Waikoukou Stream supplied 83% of the water input and the Easterbo Farm race 3%, with rainfall providing 14%. He estimated that only half of the total annual input could be accounted for by evaporation and surface water output from defined channels into the Ruamahanga River at the southwestern boundary of the Reserve. In fact, during the summer period of 2002-03 surface outflow from the Central Wetland was zero. Squires suggested, therefore, a substantial loss by seepage into the surface sands and gravels in the southern section of the Reserve (ultimately to the Ruamahanga River as diffuse inputs). This view is also held by McAllister (2009, *pers. comm.*).

The present visit was made during the autumn (April 2010) and there was a strong flow beside the boardwalk, through the Central Wetland. This was mostly derived from a spring source at H1 (Fig. 11.1A), close to the DOC interpretation sign at the start of the boardwalk. This spring probably originates, through underground seepage, from the Waikuku (see chemistry section, below). During high flow periods, the Waikuku does, in any case, shallowly overtop, through a willow wetland (W2d, Fig. 11.1B), the watershed (hydrological divide), between its channel and the Central Wetland (Silbery, *pers. comm.*).

During the 2002-03 summer, Squires recorded Waikuku flows of only 16 L/s, about 10% of winter flow rates, and most of this passed down the southern flowline. So the question needs to be asked whether seepage losses are constant throughout the year, or whether they diminish during summer. If they are constant, which is the most likely situation, there ought to be a potential threat of water shortage in the wetland after visible output through the central flowline ceases in the summer.

However, there are very likely to be some additional groundwater inputs from artesian sources and seepage from Terraces C and D which will compensate for loss of groundwater to underlying sediments. The higher terraces do, after all, represent a large rainfall catchment area and a proportion of this water has to percolate into temporary storage in a superficial, unconfined terrace aquifer. Evidence for deeper water-bearing strata from the Terrace C S26/0772 bore log (see Figure 11.1A) is equivocal, though, as confined, water-bearing strata appear to occur only at a depth well below the surface elevation of Terrace A. If this lower aquifer is confined under pressure, it could still be a potential water source for the wetland.

Nevertheless, a single bore log is not much to go on, and the stratigraphy around Carters is quite complex and also variable, with several overlapping terraces and a number of old river channels, so artesian supplies cannot be ruled out. For instance, two areas (H1, H2) showing exceptionally lush raupo/flax growth indicate strongly flowing water. H1 is already known to be a spring with water similar to the Waikuku, but H2 would also be worth checking out for springflow and chemistry, as it may not be from the same source (see also discussion of S3 in the chemistry section below).

TD Stream (Figure 11.1A) drains Terrace D into the western end of the Central Wetland . It is a more substantial watercourse than the TC Stream, and may even flow year-round. It has not been investigated in the present survey, and Squires does not include it in his hydrological study of the Reserve. The 1981 map of Carters Bush (Figure 11.2) indicates it as a 'creek'.

Squires recorded six flooding events from the Ruamahanga River during the 2002-03 season, but although back-inundation regularly reaches right up to the start (eastern end) of the boardwalk, flooding duration averages only 12hr per event. This works out at only six days inundation throughout the year (mostly in the winter/spring period) and, considering that this flooding is not likely to be recharging any aquifers, it is not likely to be a major hydrological driver in wetland functioning. Short-duration and irregular flooding of this nature represents no threat to kahikatea, for instance.

A seasonal wetland at the northern extremity of the Reserve (W1, Figure 11.1B; Figure 11.2) is elevated (Terrace B) over the main wetland (Terrace A) and derives its water directly from rainfall and by seepage from Terrace C, which rises steeply upwards from it to the north. In fact, because of the impermeable nature of the clay-capped substrate on Terrace B, on-site rainfall alone may well be the major waterlogging factor, although the lushness of the flax where Terrace C overlaps the Terrace B boundary does suggest a more consistent water supply from sub-surface seepage.

11.4 Chemistry

Three samples were collected for water quality analyses:

S1. Waikuku Stream as it enters the northeast of the Reserve.
S2. Stream outlet from the Central Wetland before joining the Southern Wetland outflow.
S3. Seepage/spring zone at H1, 250m west of the Waikuku Stream.

S1 and S3 have broadly similar chemistry and are also fairly typical of shallow, fast-flowing surface aquifers in the Wairarapa. However, most major ion concentrations in sample S3 are 20-30% higher than S1 and this suggests that the Waikuku water chemistry is modified as it passes underground between the stream and H1.

S2, on the other hand, is clearly very distinct in its major anion and cation concentrations, and is more typical of water that has been for some time in sub-surface storage or travel through sediments. Sodium and chlorine, for instance are four times higher in S2 than in S1. Squires also recorded much higher conductivities for his C2 samples (a similar location to the S2 of the present study).

There are two possible explanations for this: either the TD Stream, which joins the Central Wetland outflow, has a quite different chemistry, or else there are quite large artesian springs supplying the Central Wetland, or seepage inflows originating from deep in Terrace C. This requires further investigation, although from the available evidence, temporary storage in Terraces C and D is the most plausible explanation.

Nitrogen is very low in S1 but three times higher in S2. Either Waikuku water is picking up additional organic nitrogen as it flows through the wetland, or the TD Stream and spring/artesian inputs to the Central Wetland are introducing nitrate from storage in a terrace aquifer, or in a deeper aquifer. Most of the S2 nitrogen is organic, but the water is very humic-stained and nitrate additions could well have been transformed to organic forms during 300-400metres of transit through the wetland.

Squires (2006) reports Waikuku nitrate concentrations in early spring 100 times higher than those in the present study. Either these are anomalous, or else an early spring peak in nitrate is normal for the Waikuku. Squires also concludes that Carters is a 'sink for nitrogen', but this is perhaps not very illuminating. Swamps can indeed have very large amounts of organic nitrogen in dead plant material (see e.g. Haruatai, Ch. 7) and they also have high microbial processing capacity for mineralization of this to ammonium (under anaerobic conditions), and nitrate (under oxidising conditions). In early spring, with rising temperatures and high flow rates of oxygenated water, a 'spring flush' of nitrate nitrogen would not be unexpected. However, there may be another explanation: Squires spring sampling may have coincided with spring fertilizer applications on farmland up the Waikuku Stream. Seasonal water quality sampling from appropriate locations would resolve this issue.

TEST	Site	Carters	Carters	Carters
	Material	water	water	water
	Lab nos	783809.1	783809.2	784374.1
	Location	Waikuku	stream	spring
	Date	14.04.10	14.04.10	15.04.10
	Sample	S1	S2	S3
WATER	UNITS			
1. total nitrogen TN (3+4+5)	g/m^3	0.149	0.54	0.127
2. ammoniacal nitrogen (NH_4_N+NH_3_N)	g/m^3	<0.010	0.105	<0.010
3. Kjeldahl nitrogen TKN (2+organic N)	g/m^3	0.149	0.49	0.123
4. nitrite (NO_2_N)	$g/_m3$	<0.002	0.004	<0.002
5. nitrate (NO3_N)	g/m^3	<0.002	0.047	0.0036
6. nitrite+nitrate (NO_2+NO_3)	g/m^3	<0.002	0.051	0.0041
7. total phosphorus (all organic P+8)	g/m^3	0.073	0.136	0.076
8. dissolved reactive phosphorus DRP	g/m^3	0.059	0.102	0.048
9. sum anions (HCO_3+CO_3+Cl+SO_4)	Meq/L	1.03	3.5	1.29
10. sum cations (K+Na+Ca+Cl)	Meq/L	0.96	3.3	1.26
11. pH Laboratory	pH	7.6	7.2	7.0
12. pH Field	pH	7.2	6.7	6.8
13. electrical conductivity (EC) Lab	mS/m	10.5	35.1	13.6
14. electrical conductivity (EC) Field	mS/m	10.5	32.3	13.5
15. total alkalinity (as $CaCO_3$)	g/m^3	34.0	85	41.0
16. bicarbonate (HCO_3)	g/m^3	41.0	104.0	50.0
17. total hardness (Ca+Mg as $CaCO_3$)	g/m^3	29.0	85.0	41.0
18. dissolved calcium (Ca)	g/m^3	7.2	19.7	9.0
19. dissolved magnesium (Mg)	g/m^3	2.7	8.7	4.4
20.dissolved potassium (K)	g/m^3	1.23	2.5	1.19
21. dissolved sodium (Na)	g/m^3	8.0	35.0	9.5
22. dissolved chloride (Cl)	g/m^3	9.7	61.0	14.2
23. dissolved sulphate (SO_4)	g/m^3	4.0	1.94	2.7

Table 11.1: Carters Bush wetland water quality.

The higher phosphorus concentration in S2 must either derive from pastoral agriculture on Terrace D, or from phosphorus adsorbed on the silt load of the Ruamahanga which is deposited in Carters during flooding events and released as DRP (dissolved plant-available phosphorus) under anaerobic swamp conditions. Squires (2006) also noted a four-times higher DRP in Carters output compared with input, and this could also be phosphorus from Ruamahanga silt load.

11.5 Ecology and land use

Carters Bush is a true wetland 'complex', in that it includes floodplain swamp and semi-swamp forest, seasonal shrub swamp, reed swamp (particularly raupo/flax), willow swamp (carr), sedge swamp (particularly baumea and carex) and spring- fed swamps.

Like the Allen-Lowe Wetland, Carters has high species diversity distributed across several distinct wetland types, ranging from permanent to seasonal and from herbaceous to woody. Different types grade into each other, but the mosaic pattern of vegetation types at Carters mirrors well the variability in water availability, depth and flow rate.

A brief ecological survey was conducted in the early 1980s by Wassilieff *et al* (1986), and this includes a 1981 species list recording 217 native species and subspecies; exotics are not included in any detail, and only 24 bird species are noted. Enright *et al* (2006) have updated the inventory of plant taxa (species plus hybrids, etc) to 232 natives and 87 adventives. Wassilieff also includes a useful sketch map, delimiting vegetation communities and indicating probable water flow lines. Wassilieff's (1986) Reserve map (Figure 11.2) needs some revision, but its broad vegetation zones are still applicable, with some modifications. Dead Tree Swamp, for instance, appears to be more extensive 30 years after the map was prepared (e.g. more kahikatea deaths have occurred since the 1980s survey).

A.P. Druce visited the Reserve on a number of occasions between 1958 and 1989 and compiled a species list over this period which is now invaluable, because it enables some losses to be inferred. Enright *et al* (2006) note over 40 species that have not been seen now for many years, although intensive searching may well rediscover some of these.

In the present study, wet kahikatea swamp forest is represented by Dead Tree Swamp (W1, Fig. 11.1B) with *Cordyline,* mapou, mahoe, *Coprosma propinqua,* flax, *Carex* (*virgata, maorica*), etc. A few swamp maire were seen near the boardwalk.

Several drier variants of seasonal swamp forest are represented. Thus titoki, matai, totara, kowhai, kanuka, lacebark, in varying proportions, occur along the drier margins of the kahikatea (eg W2a) and, with *Streblus* (small-leaved milk tree), at W2b.

The seasonal wetland at W2c is unusual. Part of the area used to be a pine plantation, and tree lucerne was planted about 1984. Recently the pines were removed but many tree lucerne remain, providing light shade. Some totara have also been planted and kowhai and kanuka have self-seeded. The substrate is an impermeable clay (capping more porous river terrace deposits) and is therefore subject to sheet-flooding from rainfall and seepage/spring flow. Light levels are too low for a sedge or rush sward in this community and the ground is therefore dominated by bryophyte mats. The dense clay substrate and seasonal flooding prevent ecological succession, resulting in what can be called a 'flood-climax' wetland.

Towards the southern part of Terrace B, the W2c wetland type grades into a seasonal shrub swamp, dominated by mingimingi (C*oprosma propinqua).* There are several species of small-leaved shrub here, and the Department of Conservation has a planting and management programme to enhance this rare wetland type (Silbery, 2004). This is an important site in New Zealand botanical history, since Wassilief *et al* (1986) recorded here the new species which we now know as *Coprosma pedicellata*. Only five individuals of the original population of this species still remain here. *Olearia gardneri* is also being planted (as well as at Allen-Lowes Bush).

Crack willow carr is also a seasonal wetland (W2d), but it is restricted to the floodplain zone of the Waikuku Stream and to the riparian zone of the southwestern stream (around S2).

Permanent herbaceous swamp, characterised by flax, raupo, *Carex secta, Baumea, Blechnum* (kiokio), and *Cordyline* is common on both sides of the boardwalk (W3), and grades into kahikatea beyond. Flax, kiokio and raupo are plants with very variable stature and are therefore good indicators of high water flow rates (often artesian or spring water sources) when plant stature increases markedly, often up to 3m in height.

HYDROLOGICAL STATUS	WETLAND TYPE	SUBSTRATE	LOCATION	COMMENTS
Seasonal wetland	willow	mineralised	W2d	floodplain, seasonal flooding
	totara, kahikatea, titoki, kowhai	mineralised	W2a	floodplain, short flooding
	totara, *Streblus*, kahikatea, matai	mineralised	W2b	floodplain, seasonal waterlogging
	totara, kowhai, kanuka, lucerne	mineralised, impermeable clay	W2c terrace B	flood-climax community, short flooding to waterlogging.
	mingimingi, *Olearea* spp, *Lophomyrtus, Coprosma spp.*	Mineralised, clay	terrace B	short flooding - waterlogging
	tall fescue, *Cyperus*, pohuehue	mineralised	eg open area NE of W2b	seasonal flooding - waterlogging
Permanent wetland	kahikatea, swamp maire, etc.	mineralised to organic	W1	long flooding
	flax, raupo, baumea, ti tree	Palustrine (peat)	W3	long-flooding

Table 11.2: Wetland types in Carters Bush (refer to Figure 11.1B for locations).

Permanent herbaceous swamp grades into seasonal types where waterlogging is inconsistent or seasonal. Typical indicator species of this habitat type (eg NE of W2b)at Carters, as elsewhere, are *Carex geminata,* tall fescue, *Cyperus ustulatus, Holcus lanatus, Ranunculus repens*, etc.

There are no immediate, intractable weed problems in Carters. Tall fescue and blackberry are simply responding to diminished water availability. Crack willow is not a threat beyond the stream floodplains, because of its reproductive constraints. On the other hand, monitoring is needed to ensure that climbing spindleberry (C*elastrus orbiculatus)* and smilax (*Asparagus asparagoides*), which are both present in small numbers, do not get out of control.

11.6 Threats

- As usual for wetlands, hydrological sustainability is the principal concern. The wetland looks very healthy, and it has now largely adjusted to the changes which caused the 1970s damage. It is a pity that recovery was not monitored over that period. Current volume inflows are probably more than adequate year-round. However, there are considerable uncertainties over spring and artesian inflows and seepage outflows, so further studies are needed to better understand the hydrological balance of the wetland and to develop, perhaps, a predictive model to assist with future management decisions.

Carters Reserve is the recipient of a surface water supply that has made a long journey through intensifying farming systems. Farm water demands are highest during summer low flows and summer water availability is quite likely to decline further as catchment storage capacities are reduced through increased runoff rates.

- At this stage there are no obvious threats based upon water quality concerns, other than future intensification of farming upstream.

- Climbing spindleberry and smilax are already present, and *Clematis vitalba/foetida, Tradescantia, Selaginella* and *Lonicera japonica* (Japanese honeysuckle) are potential threats, so vigilance, and a policy of containment, are needed. The native pohuehue (*Muellenbeckia australis*) has weedy characteristics in drier open areas and may need control in, for instance, the divaricate shrub restoration areas at W2b and W2c.

11.7 Conclusions and recommendations

- Like the Allen-Lowe wetland, Carters has high habitat and species diversity and is a major biodiversity asset. Hydrologically, it is mostly a riverine or floodplain wetland, but it has many ecological features in common with palustrine wetlands. The kahikatea stand is the most distinctive floodplain feature and the more herbaceous palustrine features have probably developed as the duration of flooding events has diminished.

- Water supplies are good and probably reliable in the shorter term. In any case, the options for major hydrological modifications are very limited. The surface water supply is determined largely by farming demands, so control of up-stream water rights (boreholes and stream/race abstraction) could restrict further decline in water supply, but would not be able to make additional water available.

  However, minor adjustments, using existing surface water supplies, are possible - such as altering the balance between the two flowlines through the Reserve. It would be relatively easy, for instance, to direct more flow down the northern route (Dead Tree Swamp) if necessary.

  Although certainly present, the extent of spring, seepage and artesian inputs is still speculative, so any potential for future manipulation is equally uncertain.

- Vegetation monitoring in the Central Wetland area would identify any deleterious trends in hydrology. For example, tall fescue would be a good indicator of any progressive drying. Kahikatea trees need to be monitored to establish whether any are still stressed, or in decline. Checks for epicormic shoots and canopy dieback should be made, and selected trees checked (girth monitoring) for growth rates. An automatic water-level probe in Dead Tree Swamp would record hydrological trends in real-time.

- A more comprehensive survey of water chemistry is needed in order to identify, and delimit, different water sources. Initially this need only be a survey of electrical conductivities, with more detailed analyses, as required, to characterise sources more precisely.

Sample S2 chemistry indicates that there are likely to be sub-surface inputs to the wetland – probably from Terraces C and D, so there are likely to be artesian/spring inputs other than H1 and H2, either from the margins of higher terraces, or from deeper confined aquifers. Even the relatively small differences between S1 and S3 need further investigation. The number of bore logs available for reference is small and the stratigraphy of the terraces and floodplain around Carters is complex, so further elucidating the geohydrology of the wetland may not be so straightforward.

- Seasonal nutrient concentrations need further study to confirm whether or not the high nitrate concentration recorded by Squires (2006) was a spring flush, whether the explanation lies in farm management, or whether there is some other cause.

- The 1981 vegetation map (Wassilieff *et al,* 1986; see Figure 11.2) needs upgrading, so that wetland types, and their vegetation sub-types, can be standardised. Boundaries between types should be located by GPS, so that data can be entered into a GIS format, together with photopoints for monitoring vegetation changes. It would be particularly useful if plant species could be recorded as relative abundance for each vegetation zone. A monitoring programme with a 5-6 year return period would be appropriate.

- Possum, rat and mustelid control programmes are obviously desirable. In fact, as of early 2012, the Department of Conservation is in discussion with potential care groups over establishing both pest animal and pest plant control programmes in Carter's Bush (Tony Silbery, *pers. comm.*).

11.8 Carters photographs

Photo 11.8.1: Dead tree Swamp, looking south from the boardwalk. The shrubs are mostly mingimingi and ground flora is dominated by purei and baumea sedges.

Photo 11.8.2: The isolated nature of this tall, vigorous raupo stand (H2) suggests an artesian water source.

Photo 11.8.3: Vigorous raupo/flax stand at H1 (sample site S3) is indicative of a strong and consistent spring flow. The large sedge sward is *Carex geminata.* Although some dead kahikateas on the right were clearly affected by 1970s flooding, the stand of trees centre left is a seasonal swamp forest type (W2a) near the watershed between the central wetland and the Waikuku Stream.

Photo 11.8.4: Terrace D rises steeply behind semi-swamp forest towards the western end of Carters. Seepage from the higher terraces (C and D) probably make considerable contributions to the Carters water supply.

Photo 11.8.5: Part of Terrace B, with an impermeable clay cap that retains shallow surface flooding and prevents development of typical forest (it is a 'flood-climax' community) and, particularly, any herbaceous understorey. These are tree lucerne, but totara (planted in places) has started to replace the short-lived lucerne and waterlogging-adapted shrubs such as tauhinu, mingimingi and *Lophomyrtus* have established well, forming a unique type of semi-swamp tree/shrub wetland.

12. GENERAL CONCLUSIONS

The ten wetlands surveyed in this study cover a range of different types, different hydrologies and different management problems.

12.1 Wetland types: present study

The ten wetlands surveyed in this study incorporate seven out of eight of Johnson & Gerbeaux' (2004) main freshwater wetland types. Whilst this sounds very impressive, it must be remembered that there are numerous sub-types and regional variants, and some of these are included in Table 12.1.

Wetland type	Wetland areas corresponding to type
bog	**Mangaroa
fen & spring fen	Te Hapua, Allan-Lowe, Mangaroa (gulleys)
swamp	**Kathihiku (mostly seasonal), **Te Hapua, **Waingawa, *Carters, **Allen-Lowe (some seasonal), Mangaroa (gulleys), *Foremans, *Barton's (mostly Southern Wetland)
shrub swamp	Allen-Lowe, Carters
swamp forest	**Haruatai, *Carters, **Allen-Lowe, Taumata (seasonal)
swamp carr	Carters, *Barton's
marsh	*Barton's, Waingaro, Te Hapua
turf	Barton's, Kathihiku (lagoon), Te Henga (J & J's and Trotters)
seep/flush/spring	*Allen-Lowes, Carters, **Waingawa, *Haruatai (suspected), **Foremans, Kathihiku (suspected), *Te Hapua (dunes at least), Mangaroa (suspected).
dune slack/lake	*Haruatai, **Te Hapua
Shallow water	**Barton's, **Foremans, Waingawa, Taumata (channel, seasonal), *Te Hapua
lagoon	**Barton's
floodplain	*Taumata (seasonal), *Waingawa, **Carters
constructed wetl.	*Te Hapua, Foremans (enhanced)
wetland complexes	**Te Hapua, **Allen-Lowes, **Carters, *Barton's, Foremans, Waingawa

Table 12.1: Wetland types recorded in study wetland areas.
** wetland mostly of this type
* large proportion of wetland of this type
[no star] wetland type present in small area or areas

The diversity of wetland types can only be retained by maintaining the range of different habitat conditions that support them – particularly the hydrological regimes, but also remembering that eutrophication trends will need to be contained in several wetlands (eg Te Hapua, Waingawa at least). This means identifying wetland type boundaries (eg seasonal swamp, springs and seeps) and plant community boundaries (eg raupo stands, divaricate shrub communities, sedge swards) and monitoring for change using fixed study plots and photopoints. Selecting the best points for long-term monitoring does require a good knowledge of each specific wetland, and this only comes out of the processing of primary survey data.

Detailed species lists only exist for two wetlands (Allen-Lowes, Carters), but these do not provide ecologically useful information, such as location, relative abundance or community affiliation. Several wetlands have restoration potential, such as Trotters, Kathihuku, Taumata and Waingawa, but these would not be straightforward and would probably need some community input to maintain momentum and on-going maintenance.

12.1.1 Wetland values

All of the wetlands studied in this survey have **landscape amenity values**: they provide variation in landscapes which are dominated by farming and other forms of land development. Thus the constructed wetlands of Te Hapua restore character to the formerly denuded coastal landscape, a modified Foremans Lagoon is an attractive feature seen from SH2, and the wetland remnants at Waingawa and Taumata are rare islands of native vegetation in seas of grass. Wetlands can also have value for their **restoration potential**, as at Te Hapua (Trotters), Kathihiku, Foremans, and Taumata, and weed and pest control can potentially enhance the biodiversity values of all wetlands.

As biodiversity includes both species and habitat diversity, all of the wetlands have **biodiversity values**. In general, plant species diversity increases with habitat diversity, so the larger wetlands of Allen-Lowes and Carters are particularly important, as they are also for **wildlife values** (birds and fish, etc). Nevertheless, the smaller wetlands still have very significant value for bird feeding and breeding, and potentially for mudfish.

Recreation values apply to Foremans and Barton's Southern Wetland (wildfowl hunting), to Carters (public access), and to Te Henga (private restoration and amenity planting). There are **flood protection and geomorphology values** at Mangaroa, and **farming values** at Barton's Southern Wetland, Taumata and Mangaroa. Haruatai and Carters have significant **carbon sequestration** values and Mangaroa has **carbon storage** value.

Wetlands also have a number of other less tangible, but equally important, values, such as **water retention/conservation,** and **nutrient processing and silt removal.** These values also frequently have 'cross-boundary' implications because, as is the case in the present report, water supplies are often derived from extensively farmed, or otherwise developed, areas. Landscape-scale values such as these are often overlooked, but their importance is becoming increasingly important.

In the developed landscape (farming, urban infrastructure, etc), water is drained when it is not required and irrigated (or otherwise used) when there is demand. This can create significant 'drought zones' in the landscape, where the small water cycle is disrupted. Kravčík *et al* (2008) note that the removal of trees and replacement with low-growing crops has increased local temperatures and reduced rainfall in an area of Slovakia. Although the climate of central Europe is very different from that of New Zealand, the same principles apply and only the scale of the drought effect differs. Even in New Zealand, wetland water retention values are not given enough credit for their role in conserving water resources and mitigating local climate. Although there are many other references supporting the importance of wetland landscape values, the Kravčík *et al* study is cited here because it was sponsored by a local community concerned about its declining water resource during the growing season.

In order to prevent encroachment, or to strengthen the case for controls over the quality and quantity of inflow waters, 'status' is usually needed for the wetland, as in Table 12.1.

Status	Wetlands
QEII Covenant	Waingawa, Te Hapua (some)
South Waikato District Council	Barton's Lagoon
Ducks Unlimited	Foremans Lagoon
Fish & Game NZ	Barton's Southern Wetland
Unallocated Maori land	Haruatai
Department of Conservation	Carters Bush, Lowes Bush
Private land	Te Henga wetlands, Kathihiku, Mangaroa, Taumata

Table 12.2: Ownership status of wetlands in the present report.

This wide range of ownership is typical of wetlands as a whole in the Wellington region, so there is a need to ensure that consistent advice on wetlands management is made widely available. An important aspect of this advice needs to be that, although there are some over-arching principles, each wetland has unique features and each valuable wetland must have its own dedicated management plan, particularly with regard to water and nutrient management.

12.1.2 Native and exotic species

Wetlands rating highly for naturalness (a high proportion of native species) have the highest biodiversity value (eg particularly Carters and Allen-Lowes). Lowland wetlands are very vulnerable to colonisation by exotic species, and usually the smaller the wetland, the larger the proportion of exotics. However, wetlands should not necessarily be accorded low values just because of high numbers of exotic species. The value of each wetland must be assessed on an individual basis, and factors such as recreational value, landscape amenity value, hydrological value and water treatment value taken into account.

Thus, Haruatai has many serious infestations of aggressive introduced climbers and exotic ground flora, but the forest still has high value for naturalness based upon its assemblage of tree species. Reducing the prominence of exotics is just a management issue.

Foremans has far more exotics than natives, but as a wetland it still has considerable wildlife value and landscape diversity value – and because its water supply is reliable it has a realistic restoration value (at least in theory).

Mangaroa peatland has no ecological values left, but it still has geomorphological value as a rare peatland type, additional scientific value for its long historical record and, of course, (probably) flood protection value.

Much of Barton's Southern Wetland is a turf dominated by exotics, but it may well be providing good habitat for certain small native species. Similarly, Trotters (Te Hapua) has a useful native palustrine flora mixed with natives, and there is restoration potential (as well as threats such as the aggressive exotic oval sedge). Photo. 8.2 shows a *Cotula* turf along the margins of the drainage lagoon at Kathihiku.

12.1.3 Organic and mineral substrates

Of the wetland types listed in Table 12.1, only the marsh does not lay down peat or organic silt at some time, but most marshes are contiguous with peat-accumulating swamps where water is more permanent (eg the Barton's Southern Wetland). Peat does not form in highly seasonal wetlands (Haruatai, Kathihiku, contemporary Mangaroa, Taumata), or in highly dynamic ones (high-flow sectors of Barton's, Foremans). Peat does form where waterlogging is near-permanent and oxygen saturation low (Allen-Lowes southeastern spring, Carters central wetland, Kathihiku marae spring, Te Hapua fens), and historical deposits (now degrading) exist in some places (Mangaroa, Kathihiku drainage network, Te Hapua, Waingawa farmland).

The rate and extent of peat formation and decomposition is a useful monitoring parameter in wetlands because it is an indirect measure of hydrological stability. For instance, marked mild steel rods will monitor both peat growth (negative or positive) and the depth of the oxygenated zone (rusting depth). An information pamphlet on monitoring and sustaining peat and organic silt deposits and using peat formation as an indicator of wetland health could make a useful contribution to wetland sustainability.

Apart from the management of peats within wetland reserves, there are, of course, places in the Wellington region where organic soils are being farmed (including Mangaroa, Te Hapua and, extensively, north of Otaki). Farming peats is not, in the longer term, a sustainable activity, but there are best practice farming methods which can minimise problems. A small information/reference pamphlet or booklet may help to establish some consistency in the management of peat soils (see eg Environment Waikato, 2006; Thompson, 2012). Issues such as drainage and nutrient levels (effects on peat shrinkage and decomposition rates) are the most important to address from a soil conservation perspective, but the same issues can create significant cross-boundary problems for adjacent conservation wetlands, where high water tables are essential and accumulation of dead organic material is a desirable ecological process.

12.2 Hydrology

Hydrology is the most important driver in wetland functioning, so it deserves priority consideration in management planning. Most wetlands need hydrological regimes which are reliable in the long term, because community- and ecosystem-level processes typically have time frames measured in decades. This often conflicts with the short time-frames of most management planning for land-use development programmes. The Allen-Lowes wetland, for instance, is still adjusting to retirement of the area from grazing many years ago; the kahikatea deaths in Carters wetland started to occur within two years of the altered hydrological regime in the 1970s, but ecological adjustments are still occurring as a result of that change. Any consistent increase or decline in water level, or sustained change in seasonal patterns of water availability will result in progressive vegetation changes.

Compromise over groundwater levels is usually something which is not possible without changing wetland structure or functioning. Reducing the water flow rate will reduce the area of wetland in almost all demand-type wetlands and, because ecological processes are often slow, wetland decline a few years down the track is sometimes linked too late with water supply changes favouring development.

There are three categories of water source for wetlands: surface water, subsurface groundwater (shallow or deep) and rainwater. Table 13.3 classifies wetlands by water source, but also uses chemical signatures to characterise water sources, and sometimes to indicate or predict a particular water source when direct hydrological evidence is lacking.

Only one wetland (Barton's) is almost completely dependent on surface water flow, and only one (Mangaroa) almost completely dependent on a rainwater supply. Several (Waingawa, Carters, Allen-Lowes, Foremans, Te Hapua, possibly Haruatai and Kathihiku), are wholely (excepting rainfall) or partially supplied by shallow-aquifer groundwaters. Five (Carters, Allen-Lowes, Te Hapua, Haruatai, Taumata) have, or may have, deep aquifer inputs.

Changes to water supply can therefore occur in a number of different ways and have a number of different effects. For instance, reduction in supply lowers turnover rate in open-water wetlands (eutrophication threat) and increases seasonality in palustrine wetlands, favouring weedy species and causing organic soil shrinkage. Several other associated side-effects of changes to water supply are described in earlier chapters (see also water balance equation in Section 1.5.1).

Usually, little can be done about variations in rainfall from year to year, or about longer-term trends, for that matter, but management plans for all wetlands do need to take into consideration the expected frequency of drought and flood years. Changes in rainfall may also indirectly affect surface runoff and deep aquifer recharge. But where management planning can really make a difference is in the allocation of water resources to users who compete with wetlands for water supplies: farming (drainage, irrigation, abstraction), industry, domestic and municipal abstraction, etc.

The historical removal of natural vegetation from the hills reduced water storage and rendered water supplies more seasonal, artificial drainage has further increased the seasonality of water, and now irrigation and borehole abstraction are making further changes to the small water cycle and to the water balance equation at local and regional scales. The loss of wetlands has almost certainly changed the local climate in regions like the Wairarapa Plains, particularly through changes to evaporation patterns. Wetlands are highly sensitive to water balance changes and they are therefore important monitoring locations.

Hydrology is difficult to score from a single site visit (Clarkson *et* al, 2003; Forsyth & Dixon, 2006), but the present study has tried at least to identify wetland water sources, estimate their relative contributions, make recommendations for future hydrological studies and draw attention to immediate and future hydrological threats.

12.3 Water chemistry

After hydrology, water quality is the second most important driver of wetland functioning. Major anion and cation concentrations only influence wetland type through pH (acidity/alkalinity) and through osmotic effects when dissolved solid levels are very high (as in estuarine swamps). For instance, if the pH is lower than 5.0 then some plants have difficulty taking up phosphorus.

Although the number of water quality samples collected from each wetland was very small and they were all collected within a single three-week period, analyses are still considered to reliably characterise the wetlands and to provide meaningful comparisons between them. The 2010 summer was not a drought year and weather conditions during late summer/autumn were stable, so groundwater inputs were all active and rainwater did not dilute nutrient signatures.

12.3.1 Major ions

Major ions are valuable as indicators of water sources and Table 12.3 is an attempt to identify, for the 10 wetlands surveyed, chemical signatures linking wetland water chemistry with probable water supplies. The signatures are not necessarily definitive – often their diagnostic value is only relative – that is, within the context of a particular wetland.

A. Three of the Wairarapa wetlands receive fast-flowing water ultimately from the Waingawa River, with a total dissolved solids content of only about 20-30% higher than rainfall. These wetlands are receiving mainly water which has at no stage flowed sub-surface.

B. These waters have travelled at least part of their journey to the wetland through a shallow, unconfined sub-surface aquifer, picking up additional ions from mixed sediments and gravels. Barton's is included because although its main water supply is from a race, the race originates as a seep.

C. Water in deeper confined aquifers has spent more time in contact with surrounding rock and sediments and therefore has a higher overall concentration of dissolved solids, although sulphate does not always follow this trend. Dominant ions will depend on both the the stratigraphy and the residence time in the aquifer.

D. Water from ancient dune storage usually shows carbonate/bicarbonate and calcium indicators, often with higher sodium and chloride. All of these are also indicators of deeper confined aquifers, so it can be difficult to distinguish surface from deeper waters in coastal wetlands. Analysis of borehole water and heavy metal analysis would be useful here.

E. Two wetlands show considerable accumulation of salts. Evaporation of either A., B. or C. waters and lack of flushing could explain this in the case of Haruatai and Taumata. Borehole chemistry would assist with interpretation in both cases.

Simple electrical conductivity surveys of all wetlands (except perhaps Barton's) would yield much indicative information on water sources and dilutions, and more borehole chemistry would assist with interpretations of surface samples.

12.3.2 Nutrients

F. Apart from nitrogen and phosphorus, the 'eutrophication signature' may also include sulphur (eg Haruatai S1, Simmonds S1, Foremans) where agriculture supplies the nutrients. A 'typical' eutrophic wetland is Pateka, or Jill & Joy's, in the Te Hapua complex. These shallow water bodies are very susceptible to algal blooms because of their low flow rates, summer heating and low oxygen levels. However, the high nitrogen concentration in Barton's does not result in eutrophication processes, because the rate at which water moves through the wetland is so high that algal blooms and floating weed mats (duckweeds and water fern) do not have time to develop before plants and cells are flushed away.

The 'trophic status signature', then, is only an indicator of the potential for eutrophication, if other requirements are satisfied. High organic nitrogen is not itself a eutrophication threat, unless conditions exist for its conversion to ammonium or nitrate. Eutrophication also needs adequate available phosphorus before high nitrogen becomes a threat, so Barton's Lagoon and Waingawa, for instance, are not under immediate threat, but Pateke and parts of Foremans are.

Water source	Chemical signature	Wetlands with signature
A. Race/stream (Wairarapa)	EC <10mS/m Major cations <10g/m^3	Waingawa S1, Carters S1, Allen-Lowes S1,
B. Shallow aquifer (unconfined)	EC 10-15mS/m Na, Cl <15g/m^3	Waingawa S2, Carters S3, Foremans S1, Simmonds S1 Mangaroa
C. Deeper aquifer (confined)	EC 20-30mS/m High cation/anion	Carters S2, Allen-Lowes S3,
D. Dune storage	EC ca 30mSW/m High CO_3/HCO_3 & Na/Cl	Te Hapua
E. Groundwater fed, but no defined inflow or outflow	EC ca50, very high major ions	Haruatai S2, Taumata
F. Agriculture	N >1g/m^3, P >0.2g/m^3 S >8g/m^3	Taumata, Simmonds 1, Te Hapua, Foremans, Waingawa S2

Table 12.3: Possible chemical signatures.
There are obvious broad correlations, but the data-set is small. EC….Electrical conductivity in mS/m (= total dissolved solids)

Chlorophyll-a analysis is a useful biological indicator of eutrophication processes, as also is dissolved oxygen concentration. They were not used in the present survey because of time constraints for sampling during what is an exploratory investigation. Any future monitoring as part of management plans would be likely to base lake assessments on the trophic level index (Section 1.5.1).

In some wetlands, even rough flow-gauging of the outflows can enable water chemistry data to estimate spring inflows (eg Waingawa). Also, knowing both flow rate and nutrient concentration allows estimates to be made of nutrient mass-transfer between water bodies, so that the relative chemical influence of different water inputs can be assessed this would be useful at Carters, Allen-Lowes and Te Hapua).

12.4 Summary of main threats and recommendations

Forsyth & Dixon (2004) note that the median size of the 133 wetlands recorded on the GWRC Wairarapa Wetland Database is only 2.3ha. Remnant (ie small) groundwater wetlands are very vulnerable to changes in water supply, but the specific effects of reduced water availability vary from wetland to wetland. Te Henga wetlands would benefit from more inflow because it would reduce the eutrophication problems; Kathihuku is over-drained and non-wetland plants are invading; Taumata needs more water to flush salts from the soil, and Haruatai may need more water in the near future for the same reason; when Mangaroa is fully converted to agriculture it may well need irrigation (at least for crops).

Threats to structure, functioning or biodiversity	Wetlands affected
Currently inadequate water	Te Henga, Kathihiku, Taumata
Potential reduction in surface water supply	Waingawa, Barton's, Mangaroa, Foremans, Haruatai, Allen-Lowes, Carters
Changes to springs and seeps	Waingawa, Barton's, Mangaroa(?), Te Hapua, Haruatai, Allen-Lowes, Carters
Possible inputs from confined aquifers or outputs to them	Haruatai, Taumata(?), Allen-Lowes, Carters, Te Henga, Mangaroa(?)
Currently eutrophic	Te Henga, Haruatai(?)
Potential increase in nutrient status	Probably all wetlands, to a great or lesser extent
High TDS, plant stress	Haruatai, Taumata
Weed control needed	Probably all wetlands, some more than others
Inadequate fencing	Waingawa, Kathihiku
Industrial impacts	Waingawa, Foremans
Peat shrinkage	Mangaroa, Barton's

Table 12.4: Main threats to wetlands in this study.

Several wetlands are vulnerable to any declines which may occur in surface water supplies susceptible to farming intensification. Many have springs or seeps deriving from subsurface unconfined aquifers which could also potentially be depleted by, for instance, increased evaporation losses from farmland or by shallow bore useage. Carters appears to lose water to a lower aquifer, and Te Henga may do so but, of the ten wetlands studied, only Allen-Lowes has an unequivocal deep aquifer input. However, as noted above, there are possibilities for confined aquifer links at Mangaroa, Haruatai, Taumata and Te Hapua. Barton's main supply could be affected by increased irrigation offtakes, or by changes to the natural seep from the Tauherenikau River. Waingawa hydrology could be affected by changes to land use or water abstraction either above or below the wetland. Weir-supported wetlands (Waingawa, Foremans) could change from supply-driven to demand-driven if adequate water does not flow over the weir.

As soon as the rate of water supply to a wetland falls below the rate of loss, seasonal hydrological responses become prominent. When there is no defined surface outflow and groundwater losses are negligible, wetlands contract when the rate of water supply falls below evaporation (see Section 1.5.1). Evaporation is difficult to measure (though easy to very roughly estimate), so hydrological modelling and monitoring of surface waters (and groundwaters if possible) is an important part of wetland management plans.

In other words, in order to manage a wetland effectively its hydrology must be understood with some degree of certainty and some appropriate key parameter (usually water level or weir flow) should be monitored. Thus real-time water-level recorders were recommended for six wetlands which need hydrological models to establish baselines for management plans. These models would identify parameters which could then be monitored to detect any significant hydrological changes in the future.

Seeps and springs are difficult to gauge directly, but electrical conductivity measurements may be enough to both locate seeps (eg at Waingawa and Allen-Lowes) and estimate (by dilution) their flows when there are also surface water outputs. These simple measures can be supplemented by chemical analyses for major ions as necessary. Carters and Allen-Lowes are two obvious prime candidates for further hydrological studies, but such studies are essential if Kathihiku is to have a restoration plan, and also at Haruatai to enable management decisions to be made.

There is potential for most wetlands to receive increased nutrient loads in the near future and therefore monitoring programmes would be useful to pick up changes before they have visible effects on wetland vegetation. If it is possible to further refine Table 12.3, a greater degree of certainty about chemical signatures would help both primary surveys like the present study and also monitoring programmes for specific wetlands. As noted above, chemical signatures can be useful in hydrological interpretation. Nitrogen isotope studies could also assist hydrological interpretation at, for instance, Te Hapua, Barton's and Haruatai – and maybe at Carters.

Water quality and hydrological data, then, can provide more or less immediate indications of environmental change, but plants are integrators of ecological parameters and usually respond slowly over time. Good management planning requires both types of indicator: chemistry and hydrology to give 'early warning' and plants/plant communities to show cumulative responses. The most vulnerable communities to chemical change are usually high-biodiversity communities in low-nutrient wetlands; the most at-risk to hydrological change are demand-driven wetlands in which total water inputs are insufficient to meet wetland demands without a change in vegetation type. Several wetlands in the present study have the potential to change their character with changes in either water chemistry or hydrology and the present study has provided baseline information which will enable observation plots and photopoints to be strategically placed to detect community change.

Many exotic plant species are 'weedy' (they have fast growth rates and usually respond vigorously to increased nutrient availability) and control measures are often needed. All wetlands studied in this report have weeds that need controlling or, at least, monitoring. Even native raupo needs management in some wetlands (Te Henga, Barton's, potentially even Allen-Lowes). Fast-growing exotic species can suppress the growth of natives, they can also influence hydrology by interfering with water flow. Cyanobacterial blooms can have toxic effects.

A final suggestion for compilers of species inventories: lists of species are useful records of one aspect of biodiversity, but it would be more useful for management purposes if ecological information could also be noted (location, community type, relative abundance). Wetlands are dynamic systems and species come and go as ecological succession increases shading and chemistry and hydrology change. Small plants are particularly vulnerable – as has been pointed out for turf communities. For instance, the uncommon and diminutive *Crassula ruamahanga* occurs on a footpath at Carters Bush, but there is very little open habitat elsewhere that it could survive. Ecological information with species inventories updated every few years would assist with tracking processes of change.

Holistic management is needed in order to work towards sustainability. Wetlands cannot be managed in the same way as mesophytic forests, as the water table in small wetland remnants is contiguous with that outside the wetland and groundwater and deep aquifer supplies are influenced by other factors. The key to sustainable wetlands management is indeed the informed, and wise, management of water supplies.

Wetlands are excellent indicators of catchment health and landscape change processes, so the monitoring of wetlands for progressive changes in hydrology and water chemistry is not only essential for biodiversity management, it also provides information on overall catchment processes.

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APPENDIX A

Wetland record sheet for Indicator Components of wetlands (Clarkson *et al*, 2003).

Table 2: Wetland Record Sheet

Wetland name: **Date:**
Region: **GPS/Grid Ref.:**
Altitude: **No. of plots sampled:**

Classification: I System	IA Subsystem	II Wetland Class	IIA Wetland Form

Field team:

Indicator	Indicator components	Specify and Comment	Score 0– 5[1]	Mean score
Change in hydrological integrity	Impact of manmade structures			
	Water table depth			
	Dryland plant invasion			
Change in physico-chemical parameters	Fire damage			
	Degree of sedimentation/erosion			
	Nutrient levels			
	von Post index			
Change in ecosystem intactness	Loss in area of original wetland			
	Connectivity barriers			
Change in browsing, predation and harvesting regimes	Damage by domestic or feral animals			
	Introduced predator impacts on wildlife			
	Harvesting levels			
Change in dominance of native plants	Introduced plant canopy cover			
	Introduced plant understorey cover			
Total wetland condition index /25				

[1]Assign degree of modification thus: 5=v. low/ none, 4=low, 3=medium, 2=high, 1=v. high, 0=extreme

Main vegetation types:

Native fauna:

Other comments:

Pressure	Rating[2]	Specify and Comment
Modifications to catchment hydrology		
Water quality within the catchment		
Animal access		
Key undesirable species		
% catchment in introduced vegetation		
Other pressures		
Total wetland pressure index /30		

[2]Assign pressure scores as follows: 5=very high, 4=high, 3=medium, 2=low, 1=very low, 0=none

APPENDIX B

Plant species referred to in the text

[*native species; introduced species un-starred]

ALGAE, BRYOPHYTES

Asterella tenera		liverwort
Gonocarpus micranthus		liverwort
*lichens	many species	fungus/alga combination
Ricciocarpus natans		liverwort
Sphagnum	sphagnum moss	moss

FERNS

Azolla filiculoides	water fern	Red floating aquatic
Blechnum novae-zelandiae	kiokio	Common swamp fern
Cyathea dealbata	mamaku	Tree fern
Dicksonia squarrosa	wheki	Tree fern
Glychenia dicarpa	tangle fern	Bogs and low-nutrient wetlands
Pteridium esculentum	bracken	
Selaginella kraussiana	selaginella	Exotic fern-ally, serious weed

HERBS

Apium nodiflorum	water celery	Waterlogged ground
Bidens pilosa	beggars ticks	Tall wetland herb
Callitriche stagnalis	starwort	Often dense mats in shallow water
Ceratophyllum demersum	hornwort	Aggressive submerged aquatic
Cotula coronopifolia	batchelor's button	Swamp margins
Crocosmia x crocosmiiflora	montbretia	Weedy, waste ground, shade tolerant
Dianella nigra	turutu	Swamp
Drosera spp	sundew	Insectivorous plant
Galium palustre	marsh bedstraw	Wet ground
Galium trilobum		Small native, waterlogged turf
Hydrocotyle novae-zelandiae		Small native, waterlogged turf
Ipomoea indica	blue morning glory	Convolvulus-like scrambling weed.
Lotus pedunculatus	lotus	Wet swamp margins
Leycesteria formosa	Himalayan honeysuckle	Drier swamp margins.
Mazus novae-zelandiae	dwarf musk	Small creeping native, springs and open palustrine swamp

Mimulus guttatus	monkey musk	Streamsides and swamps, shade-tolerant
Myosotis laxa	water forget-me-not	Rough, wet pasture & swamp margins
**Myriophyllum propinquum*		Small aquatic
**Myriophyllum triphyllum*		Small aquatic
Oenanthe aquatica	horsebane	Swamp and stream margins
Parunticellia viscosa	tarweed	Parasitic on grasses in wet pasture, spreading.
Polygonum spp	willow weed	Wetland herb - several species
**Potamogeton cheesmanii*	manihi	Submerged aquatic
Potamogeton crispus	curly pondweed	Submerged aquatic
**Ranunculus amphitrichus*		Uncommon native buttercup in grass/sedge mats.
Ranunculus flammula	spearwort	Wet ground
Ranunculus repens	creeping buttercup	Seasonally waterlogged ground
Rorippa spp	water cress	Several species, mostly adventives
Rubus sp	blackberry	Seasonally dry wetland margins
Rumex crispus	curled dock	Commonest exotic dock, wet ground
Spirodela punctata	purple-backed duckweed	Floating aquatic
Tradescantia fluminensis	tradescantia	Invasive weed of wet or dry ground, shade-tolerant
Trifolium spp	clovers	
Veronica anagallis-aquatica	water speedwell	Shallow water, wetland margins
Veronica serpyllifolia	turf speedwell	Wet pasture on wetland margins.

SEDGES, RUSHES, REEDS, GRASSES

Agrostis stolonifera	creeping bent	Grass or marsh/swamp edges, often under willows or manuka
Agrostis tenuis	browntop	Grass on poor soils
**Baumea articulata*	jointed twig-rush	Large sedge of shallow lake margins.
**Baumea rubiginosa*		Sward-forming sedge of palustrine swamp
**Carex dissita*		Small sward-forming sedge of open palustine floodplains and seasonal swamp forest pools
**Carex geminata*		Large sward-forming sedge
**Carex lessoniana*		Large sward-forming sedge
**Carex maorica*		Large tussock-forming sedge
Carex ovata	oval sedge	Aggressive weed of wet pastures
**Carex secta*	purei, tussock sedge	Large tussock-forming sedge
**Carex virgata*		Tussock-forming sedge
**Cordateria selloana*	pampas grass	Aggressive exotic, waterlogging-tolerant
Cynosurus cristatus	crested dogs tail	Grass of poor soils
Cyperus eragrostis	umbrella sedge	Invasive exotic
**Cyperus ustulatus*	giant umbrella sedge	Native, damp swamp edges
Dactylis glomerata	cocksfoot grass	Tussocks on dry or damp soils

**Eleocharis acuta*	sharp spike-sedge	Swamp margins, shallow water
**Eleocharis gracilis*	slender spike-sedge	Swamp margins, wet turf
**Eleocharis sphacelata*	bamboo spike-sedge	Tall sedge, pools, swamps
Glyceria declinata	glaucous sweetgrass	Shallow flooded turf, floating leaves
Holcus lanatus	Yorkshire fog	Grass of poor soils & swamp margins
Isachne globosa	swamp millet	Palustrine swamp, shallow pools
**Isolepis prolifer*		30cm dense sward-forming sedge
**Isolepis* spp		Small sedges in wet ground
Juncus articulatus	jointed rush	Loosely-tufted rush in rough wet pasture/shallow swamp
Juncus effusus	soft rush	Tufts in wet ground
**Juncus gregiflorus*		Tussock-forming rush, wet ground
**Juncus pallidus*		Tussock-forming rush, shallow swamp
**Juncus sarophorus*		Robust native rush, shallow swamp
Lolium perenne	ryegrass	Dry pasture
Paspalum distichum	Mercer grass	Aggressive exotic wetland grass
**Phormium tenax*	flax, harakeke	Large native agave, swamps
Schedonorus phoenix	tall fescue	Large tussock grass, seasonal flooding
**Schoenoplectus validus*	lake clubrush	Shallow lake margins
**Typha orientalis*	raupo	Tall swamp reed

WOODY and CLIMBING PLANTS

**Alectryon excelsus*	titoki	Tree, drier parts of swamp forests
Alnus glutinosa	alder	Exotic, river banks, swamp edges
Asparagus asparagoides	smilax	Aggressive exotic scrambler
Asparagus scandens	climbing asparagus	
**Beilschmiedia tawa*	tawa	Large tree, dry forests
Berberis glaucocarpa	barberry	Exotic shrub, forest margins
**Carpodetus serratus*	putaputaweta	Waterlogging tolerant shrub/tree
Celastrus orbiculatus	climbing spindleberry	Aggressive exotic climber
Chamaecytisus palmensis	tree lucerne	Planted, stockfodder & honey, waterlogging tolerant
**Clematis foetida*	a native clematis	Climber. Uncommon.
Clematis vitalba	old man's beard	Invasive exotic climber
Cobaea scandens	cathedral bells	Aggressive exotic climber
**Coprosma propinqua*	mingmingi	Common, often dominant, wetland shrub.
**Coprosma robusta*	karamu	Large-leaved shrub of dry forest, or swamp forest edges.
Coprosma spp		Many species of shrubs , particularly small-leaved ones.
Corosma pedicellata		Rare small-leaved shrub (Carters)
**Coprosma tenuicaulis*	swamp coprosma, hukihuki	Common small shrub, particularly in swamp forest

***Cordyline australis*	cabbage tree, ti kouka,	Palustrine swamps
Cytisus scoparius	broom	Disturbed land & dry swamp margins
***Dacrycarpus dacrydioides*	kahikatea	Conifer. Commonest swamp forest tree
***Dysoxylum spectabile*	kohekohe	Large tree, dry forests
***Geniostema ligustrifolium*	hangehange	Forest edge shrub
***Hoheria sexstylosa*	lacebark	Streamsides and swamp forest edges
***Kunzia ericoides*	kanuka	Semi-swamp forest & forest edges
***Laurelia novae-zelandiae*	pukatea	Swamp forest tree
***Leptospermum scoparium*	manuka	Widespread shrub
Ligustrum lucidum	tree privet	Waterlogging tolerant, semi-swamp- forest
Ligustrum sinensis	Chinese privet	Shrub, dry & semi-swamp forest
Lonicera japonica	japanese honeysuckle	Invasive exotic climber
***Lophomyrtus obcordata*		Small-leaved shrub (Carters)
***Melicytus micranthus*	small-leaved mahoe	Forest edge shrub, tolerant of seasonal waterlogging.
***Melicytus ramiflorus*	mahoe	Small tree, dry or wet forests
***Metrosideros perforata, M. fulgens*	climbing ratas,	Climbers, dry and wet forests
***Muellenbeckia australis*	pohuehue	Scrambling shrub, seasonal swamp or coastal
***Myrsine australis*	mapou	Shrub/small tree, waterlogging tolerant
***Myrsine salicina*	toro	Large shrub of forest edges
***Olearea virgata*	tauhinu	Small-leaved shrub in shrub swamp. Uncommon.
***Olearia gardneri*		Small-leaved shrub (Carters)
***Passiflora tetrandra*	passion vine	Climber, dry or swamp forest
Phytolacca octandra	inkweed	Common weed of forest and drier disturbed swamp margins
***Pittosporum eugenioides*	tarata	Forest edge shrub
***Plagianthus regius*	lowland ribbonwood	Semi-swamp forest
***Podocarpus totara*	totara	Conifer. Seasonally waterlogged semi-swamp tree
***Prumnopitys taxifolia*	matai	Conifer, flooding tolerant
Rosa rubiginosa	sweet briar	Drier swamp marginis.
Salix babylonica	weeping willow	Decorative tree of lake edges
Salix fragilis	crack willow	Exotic tree of riverbanks & seasonally flooded floodplains
Salix matsudana var. *tortuosa*	twisted willow	Often planted near lakes.

Sambucus niger	Elderberry	Drier swamp margins.
Solanum pseudocapsicum	Jerusalem cherry	Common weed of drier parts of swamp forest
**Sophora microphylla*	kowhai	Small tree, semi-swamp forest
**Streblus heterophyllus*	small-leaved milk tree, turepo	Semi-swamp tree, uncommon.
**Syzygium maire*	swamp maire	Uncommon tree of permanent swamps
Ulex europeus	gorse	Dry fringes only of wetlands

VERNACULAR NAMES

alder	*Alnus glutinosa*
asparagus	[see: *Asparagus*]
bamboo spike-sedge	**Eleocharis sphacelata*
barberry	*Berberis glaucocarpa*
batchelor's button	**Cotula coronopifolia*
beggars ticks	*Bidens pilosa*
bent grass	[see: *Agrostis*]
blackberry	*Rubus spp*
blue morning glory	*Ipomoea indica*
bracken	**Pteridium esculentum*
bracken	**Pteridium esculentum*
broom	*Cytisus scoparius*
buttercup	[see: *Ranunculus*]
cabbage tree	**Cordyline australis*
cathedral bells	*Cobaea scandens*
Chinese privet	*Ligustrum sinensis*
climbing asparagus	*Asparagus scandens*
climbing spindleberry	*Celastrus orbiculatus*
climbing ratas	**Metrosideros* spp
clover	*Trifolium spp*
cocksfoot	*Dactylis glomerata*
crack willow	*Salix fragilis*
creeping bent	*Agrostis stolonifera*
creeping buttercup	*Ranunculus repens*
crested dog's tail	*Cynosurus cristatus*
curled dock	*Rumex crispus*
curley pondweed	*Potamogeton crispus*
dwarf musk	**Mazus novae-zelandiae*
fescue	[see: *Schedonorus*]
flax	**Phormium tenax*
forget-me-not	[see: *Myosotis*]
giant umbrella sedge	**Cyperus ustulatus*
glaucous sweetgrass	*Glyceria declinata*
gorse	*Ulex europaeus*
hangehange	**Geniostema ligustrifolium*
harakeke	**Phormium tenax*
honeysuckle	[see: *Lonicera*]
hornwort	*Ceratophyllum demersum*
horsebane	*Oenanthe aquatica*
inkweed	*Phytolacca octandra*

Japanese honeysuckle	*Lonicera japonica*
Jerusalem cherry	*Solanum pseudocapsicum*
jointed rush	*Juncus articulatus*
jointed twig-rush	**Baumea articulatus*
kahikatea	**Dacrycarpus dacrydioides*
karamu	**Coprosma robusta*
kenuka	**Kunzea ericoides*
kiokio	**Blechnum novae-zelandiae*
kohekohe	**Dysoxylum spectabile*
kowhai	**Sophora microphylla*
lacebark	**Hoheria sexstylosa*
lotus	*Lotus pedunculatus*
lowland ribbonwood	**Plagianthus regius*
mahoe	**Melicytus ramiflorus*
maire	[see: *Syzygium*]
mamaku	**Cyathea dealbata*
manihi	**Potamogeton cheesmanii*
manihi	[see: *Potamogeton*]
manuka	**Leptospermum scoparium*
mapou	**Myrsine australis*
marsh bedstraw	*Galium palustre*
matai	**Prumnopitys taxifolia*
Mercer grass	*Paspalum distichum*
mingimingi	**Coprosma propinqua*
monkey musk	*Mimulus guttatus*
montbretia	*Crocosmia x crocosmiiflora*
musk	[see: *Mazus & Mimulus*]
old man's beard	*Clematis vitalba*
oval sedge	*Carex ovalis*
pampas grass	*Cordateria selloana*
passion vine	**Passiflora tetrandra*
pohuehue	**Muellenbeckia australis*
pondweed	[see: *Potamogeton*]
privet	[see: *Ligustrum*]
pukatea	**Laurelia novae-zelandiae*
purei	**Carex secta*
purple-backed duckweed	*Spirodela punctata*
putaputaweta	**Carpodetus serrata*
rata	[see: *Metrosideros*]
raupo	**Typha orientalis*
ribbonwood	[see: *Plagianthus*]
ryegrass	*Lolium perenne*
selaginella	*Selaginella kraussiana*
sharp spike-sedge	**Eleocharis acuta*
slender spike-sedge	**Eleocharis gracilis*
small-leaved mahoe	**Melicytus micranthus*
small-leaved milk tree	**Streblus heterophyllus*
smilax	*Asparagus asparagoides*
soft rush	*Juncus effusus*
spearwort	*Ranunculus flammula*
sphagnum	**Sphagnum spp*
spike-sedge	[see: *Eleocharis*]
starwort	*Callitriche stagnalis*

sundew	**Drosera* sp
swamp coprosma	**Coprosma tenuicaulis*
swamp maire	**Syzygium maire*
swamp millet	**Isachne globosa*
sweetgrass	[see: *Glyceria*]
tall fescue	*Schedonorus phoenix*
tangle fern	**Gleichenia dicarpa*
tarata	**Pittosporum eugenioides*
tarweed	*Parunticellia viscosa*
tauhinu	**Olearea vigata*
tawa	**Beilschmiedia tawa*
ti kouka	**Cordyline australis*
titoki	**Alectryon excelsus*
toro	**Myrsine salicina*
totara	**Podocarpus totara*
tradescantia	*Tradescantia fluminensis*
tree lucerne	*Chamaecytisus palmensis*
tree privet	*Ligustrum lucidum*
turf speedwell	*Veronica serpyllifolia*
turepo	[see: *Streblus*]
turutu	**Dianella nigra*
twisted willow	*Salix matsudana*
umbrella sedge	*Cyperus eragrostis*
water forget-me-not	*Myosotis laxa*
water celery	*Apium nodiflorum*
water cress	*Rorippa spp*
water fern	**Azolla filiculoides*
water speedwell	*Veronica anagallis-aquatica*
weeping willow	*Salix babylonica*
wheki	**Dicksonia squarrosa*
willow	[see: *Salix*]
willow weed	*Polygonum* spp
Yorkshire fog	*Holcus lanatus*

APPENDIX C
Water quality sampling procedures

Sample collection

1. pH, conductivity, total alkalinity, total nitrogen & phosphorus.

   Filled one litre polyethylene bottle. No preservative.

2. Total Kjeldahl nitrogen (TKN)

   Fill 250mL polyethylene bottle, sulphuric acid preserved.

3. Dissolved nutrients (DRP, NO_3_N, NO_2_N, NH_4_N), anions (Cl, SO_4, etc)

   Take sample with syringe, pass through 0.45micron filter.
   Transfer to 100mL polyethylene bottle, no preservative.

APPENDIX D
Laboratory analyses (Hill Laboratories)

SUMMARY OF METHODS

The following table(s) gives a brief description of the methods used to conduct the analyses for this job. The detection limits given below are those attainable in a relatively clean matrix. Detection limits may be higher for individual samples should insufficient sample be available, or if the matrix requires that dilutions be performed during analysis.

Sample Type: Aqueous

Test	Method Description	Default Detection Limit	Samples
Anion / Cation profile, dissolved metals trace level		-	1-2
Total Kjeldahl Digestion	Sulphuric acid digestion with copper sulphate catalyst.	-	1-2
Total Phosphorus Digestion	Acid persulphate digestion.	-	1-2
Total anions for anion/cation balance check	Calculation: sum of anions as mEquiv/L.	0.07 meq/L	1-2
Total cations for anion/cation balance check	Calculation: sum of cations as mEquiv/L.	0.05 meq/L	1-2
pH	pH meter. APHA 4500-H^+ B 21st ed. 2005.	0.1 pH Units	1-2
Total Alkalinity	Titration to pH 4.5 (M-alkalinity), autotitrator. APHA 2320 B (Modified for alk <20) 21st ed. 2005.	1.0 g/m^3 as $CaCO_3$	1-2
Bicarbonate	Calculation: from alkalinity and pH, valid where TDS is not >500 mg/L and alkalinity is almost entirely due to hydroxides, carbonates or bicarbonates. APHA 4500-CO_2 D 21st ed. 2005.	1.0 g/m^3 at 25°C	1-2
Total Hardness	Calculation from Calcium and Magnesium.	1.0 g/m^3 as $CaCO_3$	1-2
Electrical Conductivity (EC)	Conductivity meter, 25°C. APHA 2510 B 21st ed. 2005.	0.1 mS/m	1-2
Dissolved Calcium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.05 g/m^3	1-2
Dissolved Magnesium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.02 g/m^3	1-2
Dissolved Potassium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.05 g/m^3	1-2
Dissolved Sodium	Filtered sample, ICP-MS, trace level. APHA 3125 B 21st ed. 2005.	0.02 g/m^3	1-2
Chloride	Filtered sample. Ferric thiocyanate colorimetry. Discrete Analyser. APHA 4500 Cl^- E (modified from continuous flow analysis) 21st ed. 2005.	0.5 g/m^3	1-2
Total Nitrogen	Calculation: TKN + Nitrate-N + Nitrite-N.	0.05 g/m^3	1-2
Total Ammoniacal-N	Filtered sample. Phenol/hypochlorite colorimetry. Discrete Analyser. (NH_4-N = NH_4^+-N + NH_3-N). APHA 4500-NH_3 F (modified from manual analysis) 21st ed. 2005.	0.010 g/m^3	1-2
Nitrite-N	Automated Azo dye colorimetry, Flow injection analyser. APHA 4500-NO_3^- I (Proposed) 21st ed. 2005.	0.002 g/m^3	1-2
Nitrate-N	Calculation: (Nitrate-N + Nitrite-N) - NO2N.	0.002 g/m^3	1-2
Nitrate-N + Nitrite-N	Total oxidised nitrogen. Automated cadmium reduction, flow injection analyser. APHA 4500-NO_3^- I (Proposed) 21st ed. 2005.	0.002 g/m^3	1-2
Total Kjeldahl Nitrogen (TKN)	Total Kjeldahl digestion, phenol/hypochlorite colorimetry. Discrete Analyser. APHA 4500-N_{org} C. (modified) 4500 NH_3 F (modified) 21st ed. 2005.	0.10 g/m^3	1-2
Dissolved Reactive Phosphorus	Filtered sample. Molybdenum blue colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 21st ed. 2005.	0.004 g/m^3	1-2
Total Phosphorus	Total phosphorus digestion, ascorbic acid colorimetry. Discrete Analyser. APHA 4500-P E (modified from manual analysis) 21st ed. 2005.	0.004 g/m^3	1-2
Sulphate	Filtered sample. Ion Chromatography. APHA 4110 B 21st ed. 2005.	0.5 g/m^3	1-2

Sample Type: Soil

Test	Method Description	Default Detection Limit	Samples
Sample Registration*	Samples were registered according to instructions received.	-	1-2
Soil Prep (Dry & Grind)*	Air dried at 35 - 40°C overnight (residual moisture typically 4%) and crushed to pass through a 2mm screen.	-	1
Total Carbon	Dumas combustion.	0.1 %	1
Total Nitrogen	Dumas combustion.	0.04 %	1
'Total' Phosphorus	Nitric/hydrochloric digestion (based on US EPA 200.2) followed by ICP-OES. (Total recoverable nutrients reported on a dry weight basis) The levels from this method are referred to as 'Totals' in quotation marks, as they will be a slight under-estimation of the true Totals for some elements.	40 mg/kg	1
Volume Weight	The weight/volume ratio of dried, ground soil.	0.01 g/mL	1