Environment Waikato Technical Report 2005/17

Ecohydrological Characterisation of Opuatia Wetland and Recommendations for Future Management

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Summary

Many of the Waikato Region's wetlands have been destroyed. Opuatia Wetland is situated in the lower Waikato River catchment, North Island, New Zealand. The wetland catchment is predominantly agricultural land, and livestock which graze on the surrounding hill slopes have direct access to the wetland margins. This as well as agricultural runoff, pose a harmful source of nutrients.

Monitoring and research of the ecohydrology of Opuatia Wetland was initiated as a result of Environment Waikato's resource consent condition requirements to extend the existing Lower Waikato Flood Control Scheme. A combined effort by the University of Waikato and Environment Waikato (Waikato Regional Council) enabled a wetland monitoring network to be established in early 2003. This included vegetation plots, water table and river stage monitoring sites, a climate station and a micrometeorological station. This report outlines the findings from a MSc. research project studying the ecohydrology of Opuatia Wetland.

A combination of ecological, peat chemical and hydrological data was collected during two years of study. Gradients and patterns in dominant vegetation species reflected peat chemistry and hydrological regimes within ecohydrological zones of the wetland. These include:

- Vegetation gradient, with willow species (*Salix* sp.)-dominated sites at the wetland margins to *Empodisma minus*-dominated areas within the wetland expanse
- Nutrient gradient, with highest levels in willow-dominated areas and lowest in *Empodisma minus*-dominated areas
- Hydrology gradient, with variable water level regimes, agricultural runoff and flood inundation in the high nutrient, willow-dominated areas grading to the relatively stable water levels of the wetland expanse where nutrients are low due to the absence of surface flow and the higher importance of rainwater.

The wetland water regime was found to be generally shallow and stable indicating that the wetland is in good health, and with time, may become a suitable area for the colonisation of threatened species such as cane rush *Sporadanthus ferrugineus*. However, serious threats to the wetland ecosystem were identified. The major threats are: invasion of exotic species, in particular grey willow *Salix cinerea,* which has increased greatly since 1942; and stock access due to unfenced wetland margins.

Recommendations are made as to the future management of this wetland. The main recommendations are:

- Fencing of Environment Waikato's land which is adjacent to the wetland before the summer of 2005/06
- That Environment Waikato encourages landowners surrounding Opuatia Wetland to undertake or investigate nutrient management options to reduce agricultural runoff
- The removal of willows and other exotic species, especially in areas where they extend out across the central fen and bog portion of the wetland.

Acknowledgements

Thank you to Ken Whitney, landowner of much of Opuatia Wetland, who supported this wetland research by allowing access to his private property and the establishment of the vegetation plots and installation of hydrological monitoring equipment.

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1 Introduction

In the Waikato Region the area covered by wetlands has been greatly reduced as a result of modifications to hydrology including drainage and land clearance, runoff from agricultural land and pest invasion (Barnes *et al*., 2001; Clarkson, 2002).

The negative impacts resulting from this are numerous, including the loss of habitat for a diverse range of plants and animals. This habitat change includes a significant number of threatened species, loss of ecosystem services such as flood water storage, and the filtering of nutrients and sediment from discharged water.

Wetlands also hold a number of high values for nearby communities and tangata whenua including scientific, recreational, cultural and spiritual values (Barnes *et al*., 2001).

Located in the lower Waikato River Catchment, north of Lake Whangape (Figure 1), Opuatia Wetland consists of a variety of wetland types and functions ranging from areas of young peat bog to marginal swamp areas adjacent to the Opuatia River. The surrounding catchment is predominantly used for agriculture and livestock have access to parts of the wetland margins.

As a conditional requirement of a resource consent granted to Environment Waikato to extend the existing Lower Waikato Flood Control Scheme, which would result in a loss of periodic flooding over a 355 ha area of floodplain and wetland (Barnes *et al*., 2001), Environment Waikato carried out wetland enhancement measures in an area of degraded wetland. This involved the construction of bunds along the boundaries of an area of willow and pasture in order to increase the residence time of flood waters in the ecosystem and increase the position of the water table. This was based on the goals and objectives of Environment Waikato set out in the Opuatia Wetland Restoration Plan, which was required as a resource consent condition, are stated by Barnes *et al*. (2001) as follows:

- "*Restore a natural inundation regime to the mineralised wetland*
- *Raise the minimum groundwater levels of the Opuatia peat bog to maintain and enhance a functioning peat bog ecosystem*
- *Prevent stock access to the Opuatia peat bog*
- *Undertake weed control activities in areas of high ecological value*
- *Promote restorative plantings in areas of high priority*
- *Continue with vertebrate pest control programmes within the wetland*

- *Monitor changes to the wetland communities that occur following the above activities.*"

Due to the timing of the research it was not feasible to study the hydrology before and after the work had been carried out or its effect on the ecology of the area. However, the restored area lies immediately north of an area of Opuatia Wetland, which in its relatively unmodified condition, provided a means for observing the hydrological, ecological, and peat chemical and physical parameters of a nearby, relatively pristine wetland of high value in this region. Consequently, a study was carried out with support from Environment Waikato and was reported in the form of a University of Waikato MSc. thesis in order to increase our knowledge of wetland hydrological and ecological functioning and to identify threats to wetland health.

Environment Waikato has a number of policies relating to the sustainable management of wetlands in the Waikato Region.

Section 3.7.4.2 of the Proposed Waikato Regional Plan states that "*Environment Waikato will promote and support the creation of new wetlands and/or the enhancement/remediation of degraded wetlands to:*

1. *industry, as an environmental enhancement method*
2. *private landowners seeking to maximise recreational and/or wildlife values*
3. *resource consent applicants as a mitigation method where appropriate, for both regional council and territorial authority resource consents*
4. *owners of sites where the adverse effects referred to in Policy 1, in Section 3.7.3 occur*."

The Operative Waikato Regional Policy Statement (WRPS) (October 2000) states that threats such as stock access, decreasing water levels, land clearance, reclamation and conversion to agricultural land, and the mining of peat, place risks on wetlands in the Waikato Region. Anthropogenic pressures have had the greatest impact on lowland wetlands, which have been subjected to drainage and landuse changes for agriculture.

Section 3.4.8 of the WRPS reports that one of the characteristics of wetland ecosystems is that they are "*elements of natural character and natural features"* and they have a number of other values and qualities, including educational and aesthetic values, and the provision of habitat to support a large number of species of flora and fauna which live in and above the water. Wetlands both improve the condition of water and are valued for their potential for retaining flood water. Section 3.4.8 of the WRPS provides one of the objectives of Environment Waikato, which is to see *"an increase in the quantity and quality of the Region's wetlands*." The WRPS anticipates the following environmental results:

1. "*Unique botanical, aquatic and wildlife habitat of wetlands protected.*
2. *Wetland areas protected and enhanced.*
3. *No net loss of total wetland characteristics*."

The MSc. thesis research provided baseline reporting of a portion of Opuatia Wetland which is presently in a good state of health. It is nearly impossible to separate the physical hydrological science from the ecological processes in the wetland ecosystems. Therefore, wetland hydrology is often referred to as 'ecohydrology' due to the fundamental links between nutrients, water and plants within wetlands (Campbell & Jackson, 2004). For full details and results of the research carried out refer to Browne (2005). This report collates the main findings of this research which include:

- Description of the study area covering geology, climate, human influences, and the network of environmental monitoring sites
- Vegetation distribution of Opuatia Wetland including the invasion by exotic species
- Peat chemical and physical characteristics are outlined and the hydrological functions of the wetland summarised
- Discussion of the ecosystem pressures that are present at Opuatia Wetland and recommendations for the management and conservation of this wetland.

2 Opuatia Wetland

2.1 Study site description

Opuatia Wetland covers approximately 950 ha of low land, which is situated north of Lake Whangape in the lower Waikato River catchment, in the North Island of New Zealand (Figure 1). Other restiad[1] wetlands in the Waikato Region include Kopuatai (10,500 ha), Whangamarino (7,000 ha), and a small remnant of Moanatuatua bog (114 ha) (Clarkson *et al.*, 2004b).

[1] Restiad bogs are dominated by wire rush (*Empodisma minus*) and cane rush (*Sporadanthus ferrugineus*). These two indigenous jointed rushes belong to the Restionaceae family and hence the bogs are called restiad bogs.

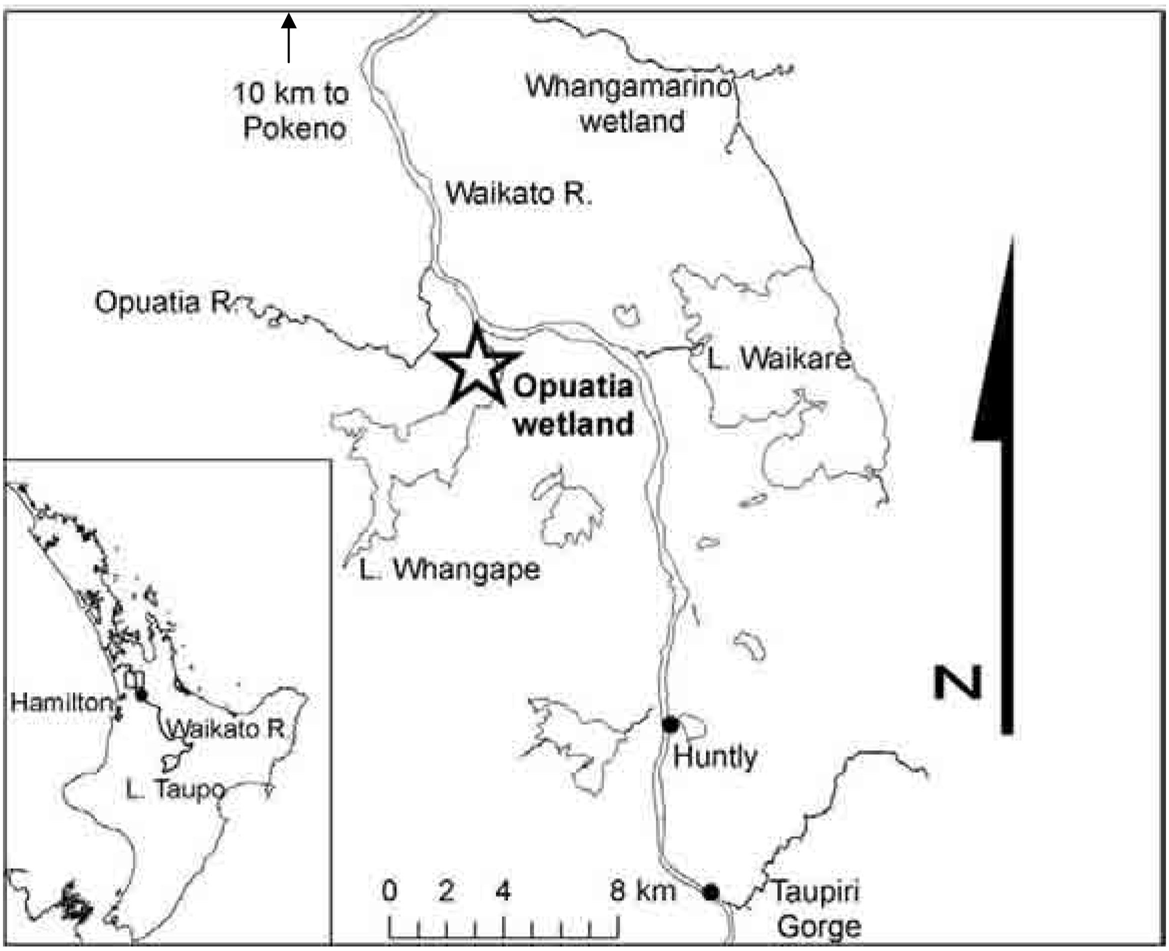

Figure 1: Geographical setting of Opuatia Wetland in the lower Waikato River catchment.

The extent of the study area for this research covers 260 ha of Opuatia Wetland and can be seen in Figure 2. It is bordered by hills to the north, east and south, which are utilised predominantly for agriculture and cropping. To the west, the study area is defined by the Opuatia River, which flows northeast to join the Waikato River approximately 7 km northwest of Rangiriri. The Opuatia River flows for approximately 50 km through a primarily pastoral catchment.

The wetland is largely privately owned and comprises a number of hydrological features, straddling several wetland types. These include fen, fen–young bog and swamp. Several ponds, drains, surface flow features, and the Opuatia River add to the hydrological complexity of this wetland.

The fen class of wetland is characterised by normally having a water table near the peat surface and receiving water and nutrients from nearby mineralised soils. The acidity and nutrient status is generally low to moderate. Bogs typically have a water table near or above the peat surface and are usually nutrient poor and acidic due to their sole hydrological source being precipitation. Swamps are often a mix of mineralised and peat substrates with ponded or gently flowing water occurring seasonally or for long periods.

Figure 2: Aerial photograph of Opuatia Wetland showing water bodies, wetland components and surrounding hills in pasture. The white line denotes the approximate study boundary and 'bunded swamp area' denotes the restored area to the northwest of the study area.

2.2 Geological history

Opuatia Wetland is located in the lower Waikato Basın, which extends from Taupiri Gorge in the south to Pokeno in the north (Figure 1). The basin chiefly comprises the Waikato River flood plain (Edbrooke *et al*., 1994). A number of shallow lakes occupy the basin including Lake Whangape, which lies immediately south of the wetland (Lowe & Green, 1992). Opuatia Wetland probably began to form when deposition of the Taupo Pumice Alluvium (TPA) by the ancestral Waikato River dammed drainage of the antecedent Opuatia Valley (Lowe, *pers. comm*.[2]).

Radiocarbon dating of a conifer root found in a core at 4.25 m depth from Opuatia Wetland gave an age of 1,838 ± 37 ^{14}C years before present (Wk 14820[3]). The date is fairly consistent with the occurrence of a thin layer of TPA at 3.4 m, which has an age of 1,850 ± 10 ^{14}C years before present (Frogatt & Lowe, 1990). The difference in depth of where these similar ages were found may be explained by the fact that the conifer root would have penetrated down into the ground as it was growing. A rate of peat accumulation of approximately 1.8 mm per year has been calculated from the age and depth of the TPA layer.

2.3 Climatic conditions

A fully automated climate station was installed in Opuatia Wetland in April 2003. Rainfall, air temperature, soil temperature at 0.1 m and 0.2 m depth, humidity, solar radiation, wind speed and wind direction were measured. Annual data for some of the variables are summarised in Table 1.

Precipitation and air temperature recorded at a climate station in Ruakura, 45 km South-southwest of Opuatia Wetland, was correlated with data collected in 2004 at the Opuatia Wetland climate station. These relationships were used to calculate a 30 year average for Opuatia Wetland air temperature and precipitation (Figure 3), which had R-squared values of 0.98 and 0.86, respectively. Ruakura was the closest climate station which had a long-term, consistent record of climate data

[2] Personal communication with Associate Professor David Lowe, University of Waikato.
[3] Prefix refers to University of Waikato Radiocarbon Dating Laboratory.

Table 1: Annual climatic and soil temperature characteristics at Opuatia Wetland 1st January 2004 to 1st January 2005.

Mean annual air temp (°C)	Predominant wind direction	Total annual precipitation (m)	Mean wind speed (ms^{-1})	Mean relative humidity (%)	Mean soil temp at 0.1 m and 0.2 m, respectively (°C)
12.71	West-southwest	1.288	1.6	90.4	12.1, 12.4

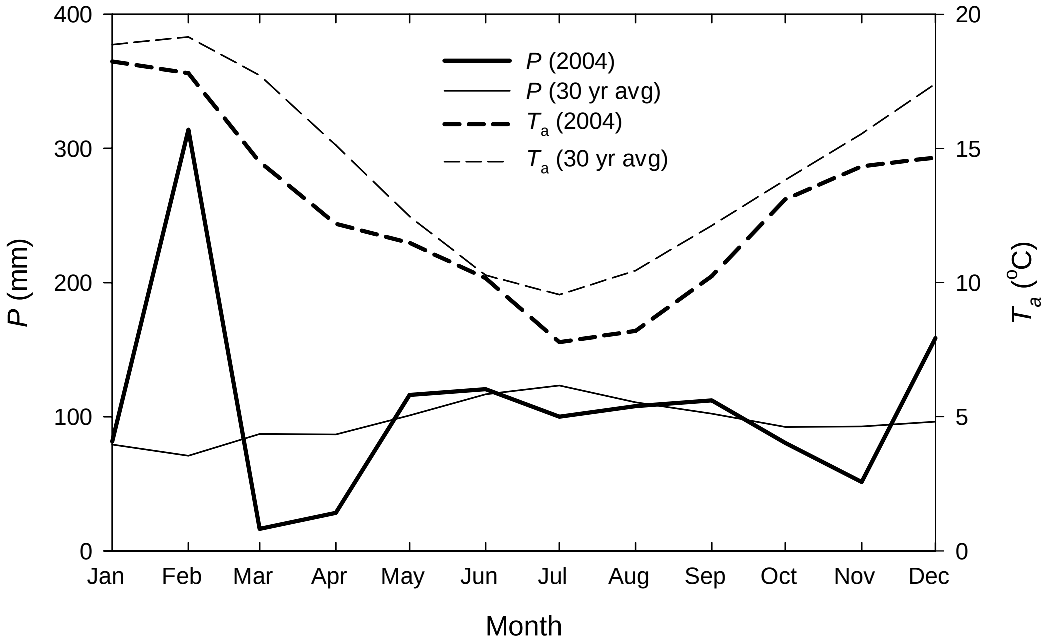

Figure 3: Monthly averages of air temperature (T_a) and monthly totals of precipitation (*P*) at Opuatia Wetland in 2004 compared to 30 year averages of precipitation and air temperature recorded at Ruakura.

Opuatia Wetland was colder in 2004 than the average air temperature over the last 30 years. The 30 year average air temperature at Opuatia Wetland calculated using the correlation between Opuatia climate station and Ruakura was 14.37 °C, while the measured average air temperature at Opuatia Wetland in 2004 was 12.71 °C. Rainfall was much greater in February 2004 and lower in March, April and November 2004 compared to the 30 year average. Using the relationship between Opuatia Wetland climate data and long-term data at Ruakura, it was calculated that the average total annual precipitation over the last 30 years at Opuatia Wetland was 1,159 mm which is 129 mm less than the 2004 total of 1,288 mm. This difference may be attributed to the large rainfall event which occurred in the wetland catchment prior to the February/March flood event.

2.4 Human influences

Wetland ecosystems are vulnerable to a number of threats. The past 150 years have seen extensive settlement by Europeans, which has had significant impact due to widespread drainage for agricultural purposes (de Lange *et al*., 1999; Clarkson, 2002, Clarkson *et al.,* 2004a). By looking at the distribution of peat-derived soils, it can be shown that wetlands once covered around 110,000 ha of the Waikato and Hauraki Plains in the North Island (Shearer, 1997; Clarkson, 2002). Today only around 32,000 ha remain in the Waikato Region[4] .

Lowering of the water table can have serious implications for a wetland including the loss of plant species that depend on a high water table (Clarkson, 2002). A decrease in water levels allows oxygen to enter the peat, changing microbial processes and enhancing nitrification. As the soil oxidises, dryland species such as blackberry *Rubus fruticosus* and bracken *Pteridium esculentum* are able to begin colonisation and a loss of standing water results in habitat changes that may exclude those which provide nesting sites for water birds. Terrestrial predators have easier access to the wetland in the absence of standing water and the wetland's connection to associated rivers and streams may cease, inhibiting fish migration (Sorrell *et al*., 2004). Therefore, drainage remains the major anthropogenic threat to wetlands.

The steam train era of the 1930s and 1950s introduced another human influence on wetlands in New Zealand as the frequency of wetland fire events increased substantially (Clarkson, 2002). New Zealand wetland vegetation is not adapted to fire and some very important wetland species including *Empodisma minus* (hereafter referred to as *Empodisma*) take a long time to regenerate following fire events. Nutrient levels can be affected and the resulting ash and charcoal from fires can harm invertebrates and fish (Sorrell *et al*., 2004). However, fire events have also been found to enhance species richness and support threatened species such as *Anzybas carsei*[5] (Norton & de Lange, 2003).

Fertiliser drift and agricultural runoff from land neighbouring wetlands may permit invasive exotic species to dominate. Tall invasive species such as willow can be particularly threatening as they overtop and shade lower native communities. This leads to displacement of native plant communities, forcing changes to wetland habitat

[4] *What wetlands have we got?* Waikato Regional Council website: http://www.ew.govt.nz/enviroinfo/water/wetlands/whatwetlands/index.htm, 14/2/05.
[5] Referred to by Norton & de Lange, (2003) as *Corybas carsei.*

and critically affecting the native fauna, which rely on native plants for their survival (Clarkson, 2002).

Opuatia Wetland complex, including the area outside the extent of this research, has been reduced in area by more than 10%, from 1,100 ha originally to 950 ha today (Clarkson *et al.*, 2004b). The portion of the wetland complex used for this study excludes a large amount of land dominated by willow species and equates to approximately 260 ha (Figure 2).

2.5 The monitoring network

As depicted in Figure 4, the network of monitoring sites consists of eight 2 m by 2 m vegetation plots and twelve automatic water table dip wells of which three comprise both a shallow dip well and deep piezometer, which record the water table and hydraulic head, respectively. Hydrological monitoring sites were placed in a longitudinal and transverse transect, providing a means of measuring spatial variation in water table across various vegetation types. These two cross sections coupled with water level data, provide a three dimensional perspective of the wetland water table. A climate station and a micrometeorology station have been installed at two individual sites in the wetland. Furthermore, a river stage recorder, consisting of an encased capacitance probe mounted beside a staff gauge, was used to compare the water levels within the wetland to the Opuatia River level.

The eight vegetation plots were set up by Environment Waikato in 2003 in conjunction with ten initial water level monitoring sites. The locations for each of these vegetation sites were chosen in order to achieve an adequate representative sample of the typical plant communities within the vegetation type, with at least two plots per major vegetation type (Figure 4) (Environment Waikato, 2003). These plots were used to ground-truth the vegetation distribution map created during this research.

The Opuatia River staff gauge contains a capacitance probe, which is securely housed in a steel pipe to prevent damage from flood debris and vandalism. The river staff gauge site does not have a related vegetation plot. A further two water level monitoring sites were installed in October 2003 by the University of Waikato in the northern end of the wetland (Figure 4). These two loggers were installed to determine the behaviour of the water table in the northern area of the wetland as well as the slope of the water table to determine flow directions in this narrow area.

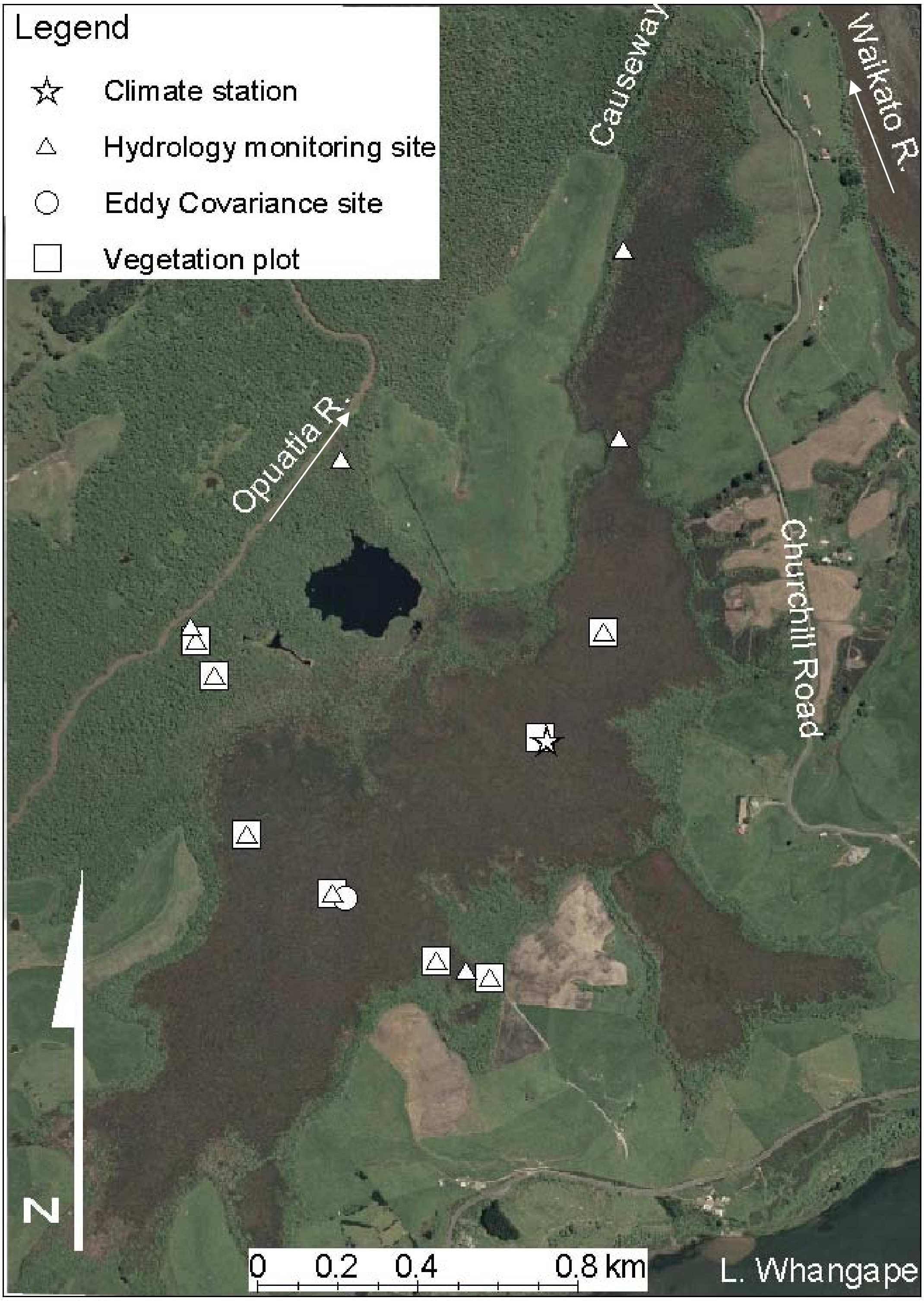

Figure 4: The Opuatia Wetland monitoring network.

3 Vegetation

Reeves and Haskew (2003) undertook vegetation mapping of Whangamarino Wetland, approximately 14 km northeast of Opuatia Wetland using aerial photographs taken in 2001 and 2002. The production of the vegetation map was achieved through three steps defined by the authors:

- use of aerial photographs to interpret different vegetation types
- verification of interpreted images (ground-truthing)
- production of the map.

A similar methodology was utilised for this study in order to produce a map of the distribution of dominant vegetation species at Opuatia Wetland. In addition, a series of maps illustrating the progression of the invasion of willow species into the wetland since 1942 was created using photographs from 1942, 1963, 1979 and 2003.

3.1 Present day distribution

Hydrological, peat chemical, and vegetation mapping has indicated that Opuatia Wetland swamp vegetation grows where nutrients are more readily available. The higher availability of nutrients is most likely due to the movement of groundwater, or the flooding of Opuatia River. Additional nutrients may be made available through runoff from the agricultural margins of the wetland. Swamp areas tend to support a higher proportion of exotic species such as willow, while nutrient limited areas such as the centre of the wetland where the water source is predominantly rainfall tend to be restricted to native vegetation adapted to such conditions such as *Empodisma*, *Baumea* spp. and tangle fern *Gleichenia dicarpa* (Figure 5). Major patterns of vegetation distribution were revealed through mapping of dominant species (Figure 6) at Opuatia Wetland.

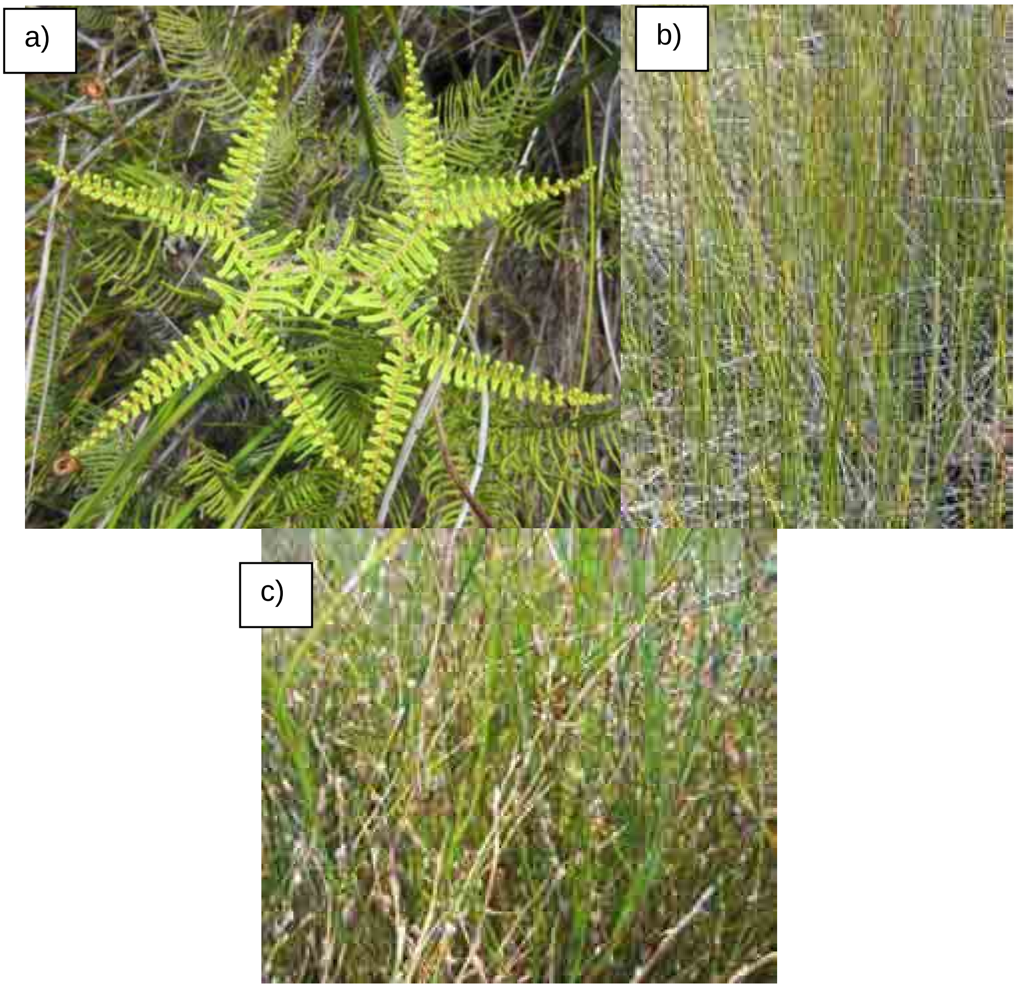

Figure 5: (a) tangle fern *Gleichenia dicarpa*, (b) *Baumea teretifolia* and (c) *Empodisma minus* in Opuatia Wetland.

Willow species dominate the margins of the wetland where higher nutrient levels are expected. Two species of willow are present at Opuatia wetland. The first, crack willow *Salix fragilis*, dominates areas on or near the levees of Opuatia River, which when in flood delivers nutrients to the area and may play a role in vegetative dispersal of this species. The second, grey willow *Salix cinerea*, occurs on all margins along the wetland borders. Figure 6 reveals a possible environmental gradient which progresses in most areas from willow-dominated vegetation associations to manuka *Leptospermum scoparium*-dominated associations, which surround the margins of the wetland and are located on the inner side of the grey willow margins. The gradient continues inward from here to become increasingly dominated by *Empodisma*, the primary peat former.

Distinct bands of *Baumea* species were mapped and appear to extend from east to west across the wetland (Figure 7), between zones dominated by *Empodisma*. It is possible that these signify water tracks where slowly flowing water is transporting nutrients from other parts of the wetland catchment and, therefore, supporting the growth of *Baumea* spp.

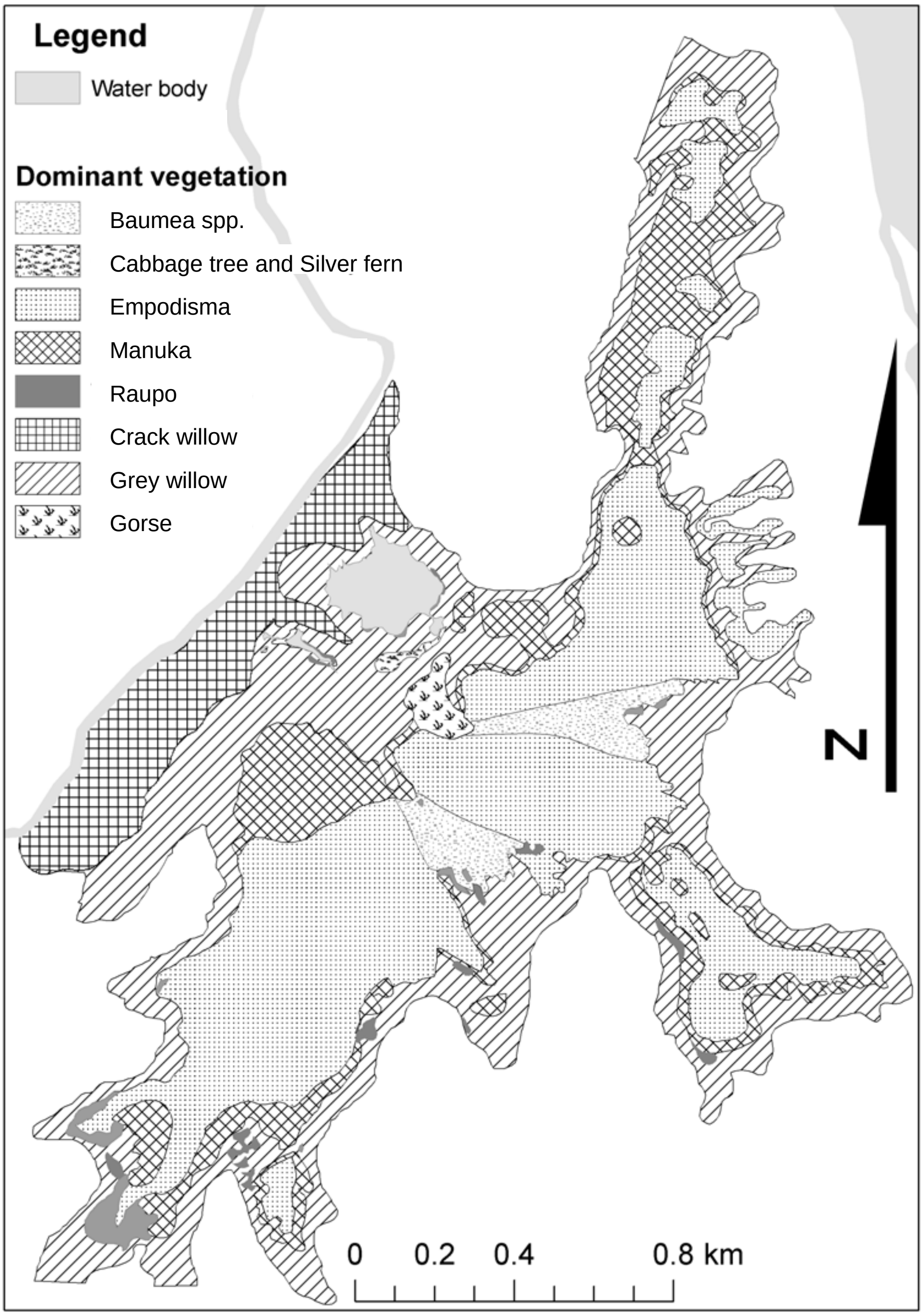

Figure 6: Vegetation distribution of Opuatia Wetland.

The hypothesis of water tracks in Opuatia Wetland was investigated using RTK-GPS survey instrumentation and the longitudinal cross-section, which intersects the areas where these bands are located, can be seen in Figure 8.

Figure 7: Oblique aerial photographs taken in October 2003 showing the location of areas of distinct bands of *Baumea* spp. vegetation, which could signify the presence of water tracks. Solid arrow denotes the southern water track identified through a GPS survey.

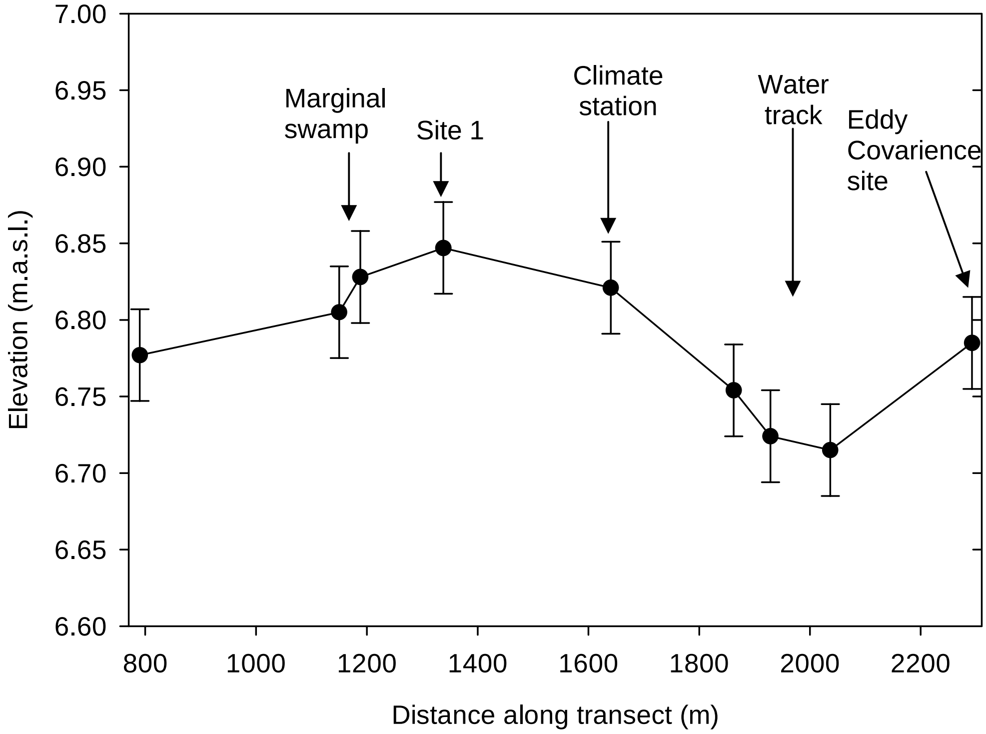

Figure 8: A view of a section of the longitudinal transect. Error bars show approximate vertical accuracy of GPS equipment. Marginal swamp label denotes two GPS readings which are included in the longitudinal transect, but occur near the wetland margins.

This survey supports the existence of the proposed water tracks as a depression can be seen near the location of one of the tracks with slight doming of the water table on either side. This evidence is not conclusive, but supports the theory which is also backed up by the vegetation patterns in the wetland.

A further point of interest is the isolated communities of raupo *Typha orientalis,* which is a species that prefers fertile conditions. These isolated communities may remain as part of larger areas once dominated by this species, which have been invaded and displaced by grey willow.

Finally, a remnant community of cabbage trees *Cordyline australis* and silver fern *Cyathea dealbata* are situated amongst grey willow near the large pond, which can be seen as the large water body on the western side of the mapped area (Figure 2). One kahikatea *Dacrycarpus dacrydioides* was identified in this area. A significant area of gorse *Ulex europaeus*, which poses a threat to native wetland species, lies immediately east of this area of native vegetation.

The distribution of dominant species of vegetation at Opuatia Wetland shows a strong gradient from the swamp-like margins to the fen or bog-like centre of the wetland.

3.2 Invasion of willow species since 1942

While both crack and grey willow are present at Opuatia Wetland, grey willow has invaded at a much greater rate due to its ability to set seed and is, therefore, a more significant threat to Opuatia Wetland (Figure 9 and 10). The extent of willow-dominated areas since the early 1940's to the present day can be seen in Figure 10.

In 1942 crack willow comprised over 10% of the wetland area, but since this time it has remained generally unchanged apart from a minor decrease in area occurring since the 1980s when it was invaded by grey willow (Figure 10). On the other hand, grey willow shows a very large increase from less than 2% of the wetland area in 1942 to close to 30% of the wetland area at present. This rapid increase in area dominated by grey willow may not continue as the lower nutrient levels of the peat it will have to colonise may inhibit its growth. Using the same trend of the grey willow invasion from 1979 to present, the future coverage of grey willow and crack willow can be calculated. If no willow control is carried out and this trend is used, by 2024 grey willow dominated areas will have increased to 38% and crack willow will have decreased to 7.6%. By fitting a linear trend line to the data from 1942 to present grey willow is predicted to reach 42.5% by 2024 and crack willow will comprise 9.3% in the same time period.

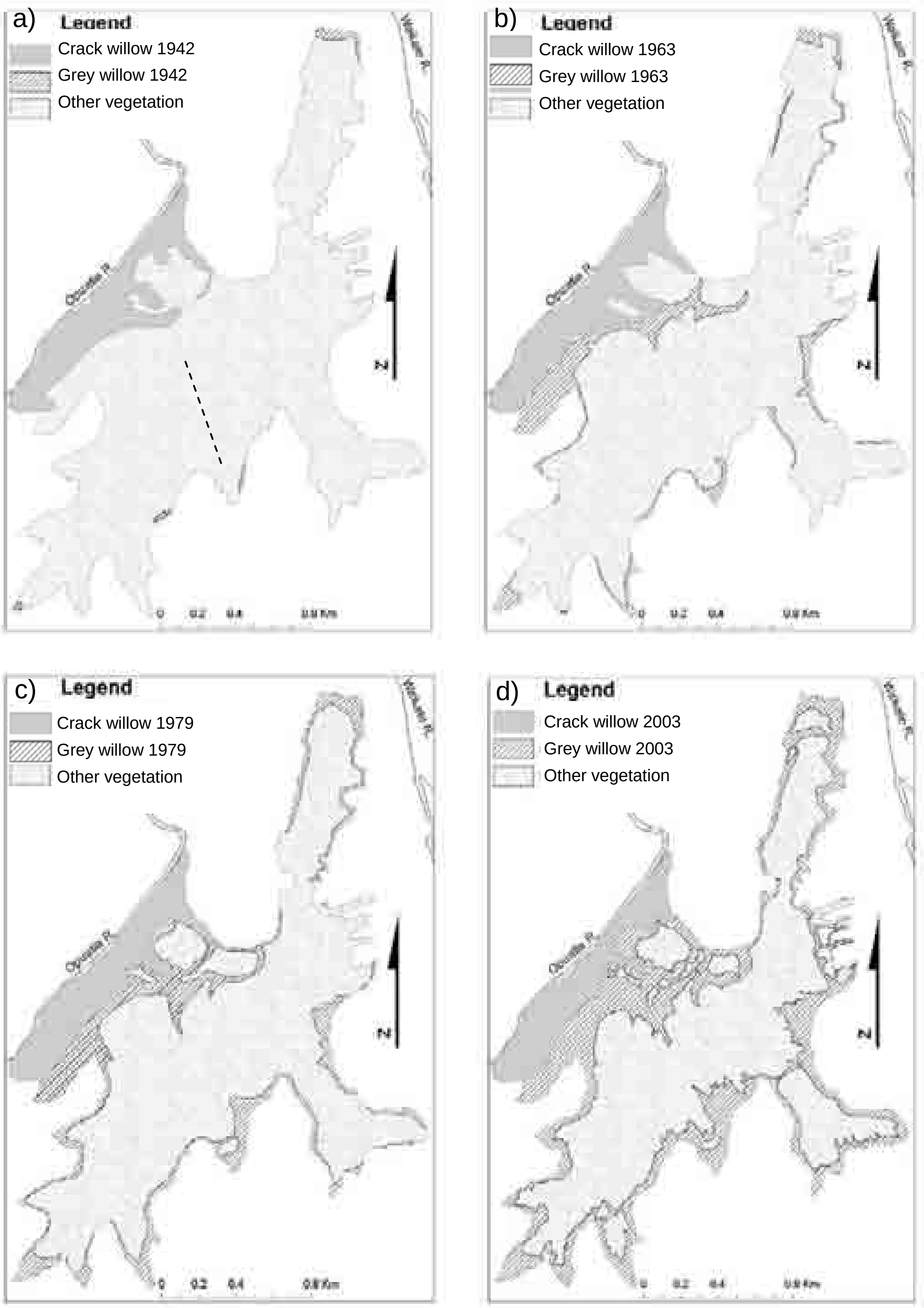

Figure 9: The state of invasion of grey willow and crack willow on the borders of Opuatia Wetland in a) 1942 (dashed line indicates presence of a drain), b) 1963, c) 1979 and d) 2003. Mapping was carried out using aerial photographs.

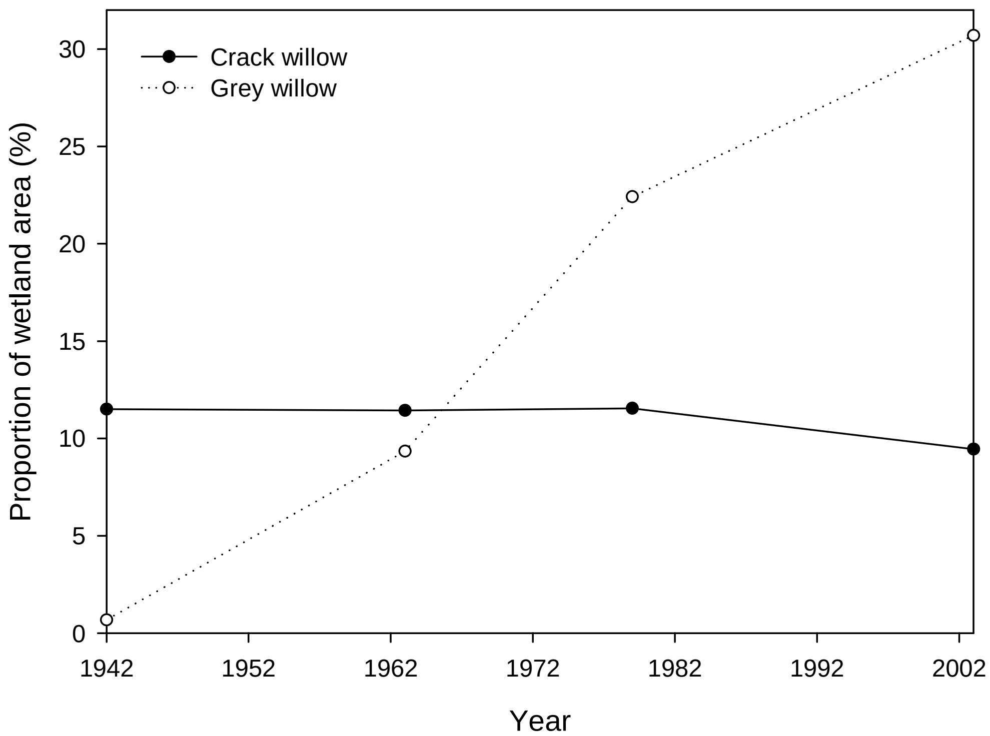

Figure 10: The change in willow species area at Opuatia Wetland expressed as a percentage of wetland area (wetland area can be seen in Figure 9 as the outline of the willow invasion maps).

Catchment modification resulting from conversion to farming may have provided an environment favoured by introduced willow species. It is possible that grey willow was beginning to colonise Opuatia Wetland in 1942, with isolated growth occurring in some areas. In the 1942 aerial photographs, the areas of 'grey willow' were difficult to decipher as photograph definition is poor. The areas of taller vegetation assumed to be grey willow may have been stands of kahikatea, in which case grey willow may not have been present at this time. However, a small amount of grey willow was present in the Whangamarino wetland in 1942 (Reeves, *pers. comm.*[6]).

Drains were identified as linear features appearing in the 1942 photographs of Opuatia Wetland. One large drain stretched across a section of the wetland and is indicated as a dashed line in Figure 9a. This drain appeared to act as a vector for establishment as the 1963 photographs show grey willow starting to follow this drain into the wetland from the west. Willow does not appear to have advanced any further by 1979 and the drain is almost indistinguishable in the photographs most likely due to insufficient upkeep.

[6] Personal communication with P. Reeves, National Institute of Water and Atmospheric Research.

The current state of willow infestation at Opuatia Wetland can be seen in Figure 9d. Grey willow has increased substantially in area and is now strongly established along every part of the wetland border. Consequently, the area of native wetland vegetation is declining. Grey willow is also affecting the wetland interior where young trees have been observed at several locations.

3.3 What is being lost by the invasion of grey willow?

Since 1942, grey willow has invaded areas which were probably originally dominated by manuka and kahikatea. Presently, kahikatea are largely absent from Opuatia Wetland, with the exception of several trees including one specimen situated near the pond on the western side of the wetland.

From 1963 onwards, bands of grey willow can be seen reaching out from the eastern margin and tapering off as they infiltrate the wetland centre. These may be following water tracks. Without immediate management it is possible that grey willow will infiltrate the wetland enough to link with colonies invading from the western side of the wetland. Such a scenario places the wetland ecosystem at risk of fragmentation.

However, since the late 1990's there has been a reduction in the amount of crack willow due to it being defoliated by sawfly *Nematus oligospilus*. The defoliation of the crack willow can be seen in Figure 11.

It appears that the effects of the sawfly are absent on the western side of Opuatia River and in the grey willow-dominated margins of the wetland. The defoliation and dieback of crack willow may improve conditions for shorter vegetation due to a decrease in shading, but it could also create an empty niche for grey willow to invade. The Waikato River banks have been recently invaded by an exotic tree called alder *Alnus glutinosa*, which is replacing crack willow. It is possible that this species may invade the areas of crack willow die back at Opuatia Wetland.

Figure 11: Aerial photograph showing dieback of crack willow at Opuatia Wetland possibly due to effects of sawfly.

4 Peat physical and chemical characteristics

Peat chemistry was analysed for 28 samples collected throughout the wetland. Some physical analyses were also carried out on the samples. The sample sites were selected by considering the dominant vegetation distribution, so that chemical data could be obtained for a range of ecosystem conditions.

The 28 sample sites were placed into groups using multivariate analysis based on the relative proportions of vegetation species at each site. The resulting seven groups were used as a basis for data analysis.

It was found that each of these seven groups fit into a successional sequence or trend. For example, willows are a common tree species in swamp ecosystems in the Waikato Region and along with *Carex* spp. and willow weed *Polygonum salicifolium*, comprises one of the groups. Further towards the end of the successional sequence *Empodisma* becomes dominant as the wetland changes from a fen to a young bog and the dominance of this species is characteristic of another group of sample sites determined by the multivariate analysis.

A further environmental gradient relating to peat fertility was discovered through running a Principal Components Analysis of peat chemical and physical characteristics. The gradient follows an increase in fertility from *Empodisma*-dominated species to willows (Figure 12). These groups of samples are dominated by different species of vegetation and are likely to source water from different origins. Therefore, the levels of nutrients may indicate hydrological differences between areas.

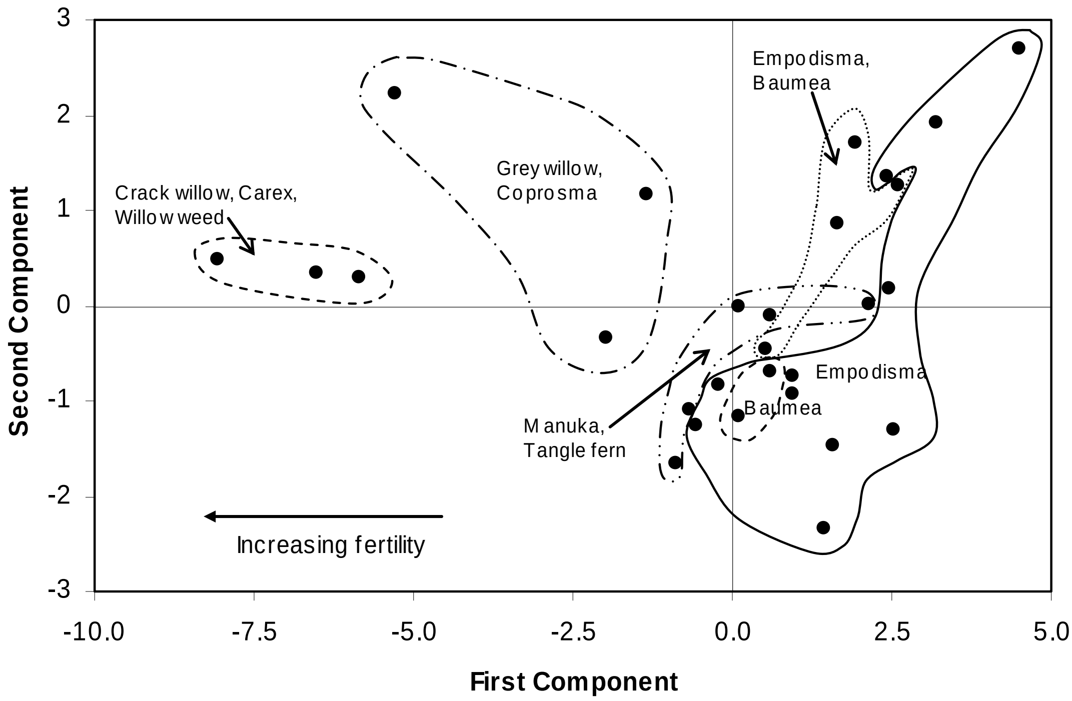

Figure 12: Two dimensional score plot of the chemical and physical data obtained from the 28 peat samples. Vegetation groups derived from the cluster analysis are overlaid.

Peat chemical data collected from Opuatia Wetland were compared to statistics for chemical data collected at other New Zealand sites during other studies (Table 2). For the purposes of comparison, sample sites were divided into two groups: Opuatia swamp sites, and Opuatia bog sites. Swamp areas were found to be typical for New Zealand wetlands. Averages for areas termed ‘bog sites’ are less consistent with other New Zealand data, but fall within the range of New Zealand data for most chemical variables.

Table 2: Mean and range (in brackets) of soil parameters for six bogs and 17 swamps sampled in field trials in New Zealand. TC = Total carbon, TN = Total nitrogen, TP = Total phosphorus. Data are from Clarkson *et al.* (2004a) with averages and data ranges added for Opuatia Wetland swamp (n = 6) and bog areas (n = 22).

	Bogs	Swamps	Opuatia bog sites	Opuatia swamp sites
Soil pH	4.0 (3.7–4.4)	5.2 (4.1–5.9)	4.99 (4.31–5.36)	5.05 (4.81–5.39)
TC*	92.7 (24.1–239.8)	39.8 (5.2–100.6)	33.27 (24.18–43.29)	39.79 (29.79–47.40)
TN*	0.82 (0.02–1.83)	2.12 (1.15–3.24)	1.35 (0.69–1.98)	2.39 (1.72–2.78)
TP*	0.08 (0.01–0.20)	0.28 (0.15–0.59)	0.08 (0.03–0.13)	0.26 (0.18–0.33)
C:N	48.5 (35.9–79.7)	18.0 (14.2–30.6)	26.41 (17.0–49.0)	16.67 (14.0–19.0)
C:P	1904 (533–4221)	163 (45–435)	507.1 (236.9–1041.8)	161.35 (116.3–212.7)
N:P	39.0 (20.6–81.6)	9.1 (4.0–20.6)	18.79 (13.70–27.30)	9.54 (8.34–11.72)

*units of mg cm^{-3}

The pH of Opuatia bog sites are higher and have a greater range when compared with other New Zealand bog sites. Total C and N appear to be slightly lower at Opuatia bog sites than in other New Zealand bogs, but fall within their range. Total P shows similarity between the two data sets. The ratios of C:N, C:P and N:P at Opuatia bog sites are lower than other New Zealand bogs, but the ranges overlap slightly.

In comparison with data from various New Zealand swamps, Opuatia swamp sites had more similar pH values than the comparison between bog sites and other New Zealand bog sites. This is probably indicative of the 'Opuatia bog sites' group being used to describe all samples taken on the inner side of the boundary between marginal willow species and the *Empodisma*- and *Baumea*-dominated wetland expanse, therefore including fen areas as well as bog areas. In general, Opuatia swamp site data are relatively consistent with other New Zealand swamp sites, as the range of the Opuatia data sets fall within the range of data for other New Zealand swamp sites and their means are reasonably similar. Opuatia Wetland bog sites have an average peat N:P ratio of 18.79:1, indicating that they are P-limited, while Opuatia swamp sites appear to be N-limited (Table 2). Thus, bogs face more of a limitation to biological production compared to swamps, which have a higher availability of nutrients.

Trends between the seven sample groups determined by multivariate analysis generally show a clear progression in nutrient levels from the *Empodisma*-dominated group (lowest levels) to the willow-dominated group (highest levels). This reflects the hydrological conditions at the sites contained in these groups. Lower levels of nutrients at *Empodisma*-dominated sites may indicate the dominance of rainfall as the water supply, while willow-dominated cluster groups tend to have a larger surface water component.

During interpretation of the chemical and physical data obtained from the 28 peat samples, some peat properties were found to be better indicators of vegetation type and successional stage than others. The most indicative chemical properties at Opuatia Wetland appear to be Total Ca, Mg, Fe, K and P, as well as the ratio of N:P.

5 Hydrology

5.1 Monitoring network

The hydrological monitoring network consisted of 11 dip well sites containing 1.5 m Odyssey™ capacitance probes measuring water levels every 15 minutes. These sites were established in two transects (Figure 13). Of these sites three are paired dip well sites in that they have an additional 2 m deep piezometer also logging at 15 minute scan periods.

The Opuatia River contains a staff gauge and a 3 m Odyssey™ capacitance probe logging at 15 minute intervals. The Opuatia climate station collects climate data as well as recording water levels with a pressure transducer. The Opuatia Eddy Covariance (EC) site measured fluxes of CO_2, water vapour and energy and photosynthetically active radiation (Figure 13). The EC technique and a full list of the instrumentation is further explained by Thornburrow (2005). Both the climate station and the EC site measure variables including rainfall, wind speed, wind direction, air temperature, soil temperature and humidity. The EC site also houses a pressure transducer to monitor water levels. When hydrological monitoring sites are manually downloaded, a series of measurements are taken independent of the dip well probes in order to check for errors in the dataset.

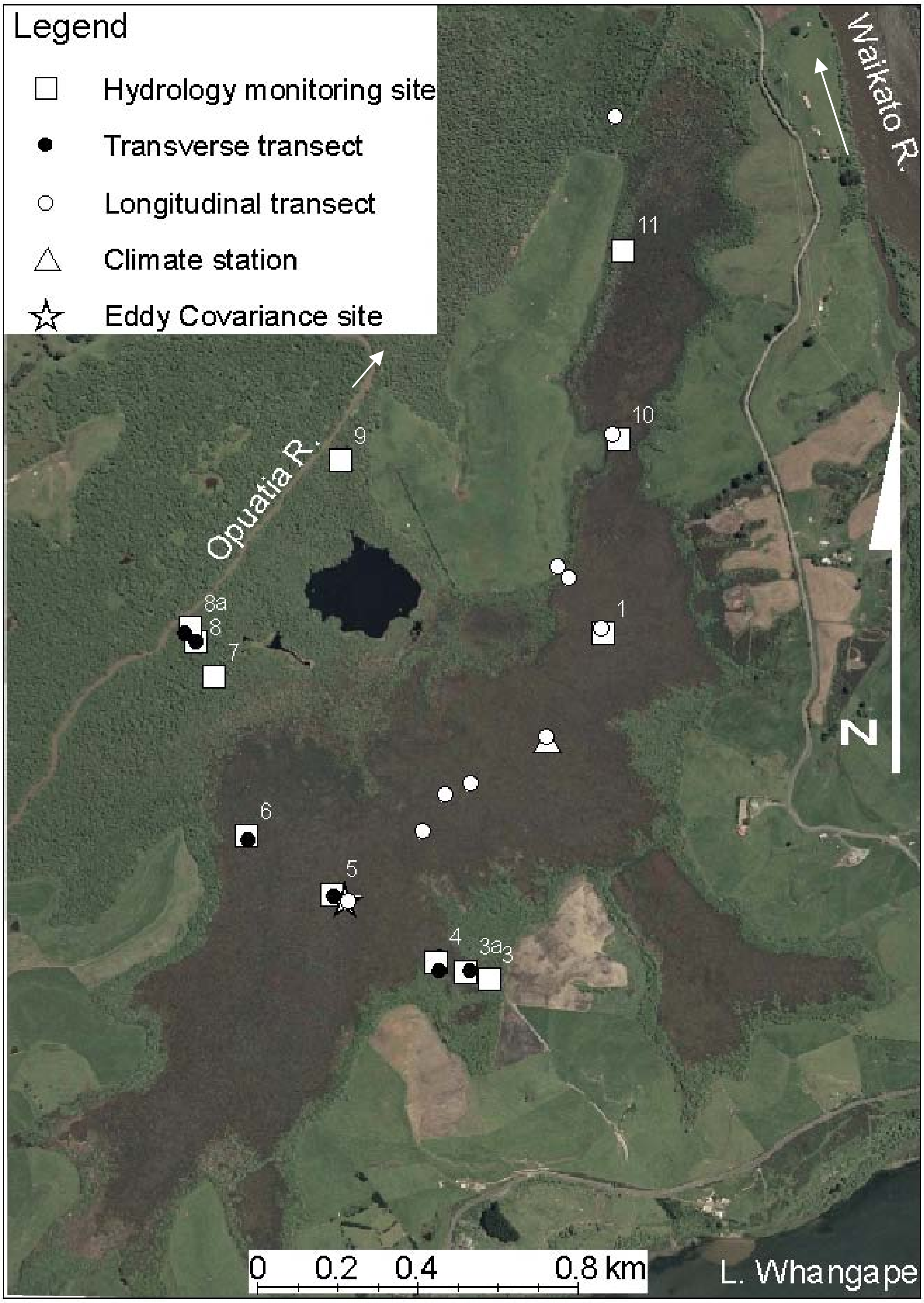

Figure 13: The hydrological monitoring network, water level transects and additional GPS locations at Opuatia Wetland. Labels refer to site names.

5.2 General variation in the water table regime at Opuatia Wetland

Opuatia Wetland has a water table which is close to or above the surface and relatively steady throughout most of the year (Figure 14). During the study period, minimum water levels occurred in late summer and autumn (February to April), which was also found to be the case at Moanatuatua Bog in a study carried out in 1999 when monthly evaporation either approximated or exceeded monthly rainfall during this time of the year (Grimshaw, 2000). More drainage from Opuatia Wetland is likely in summer also. Greatest seasonal variation occurs near the river as the Opuatia River level affects the rate of groundwater discharge from the wetland (Figure 26).

However, in 2004 this late summer and autumn minimum period may have experienced a higher water table than average due to the additional water added to the wetland during the February/March 2004 Waikato River flood event, which has a return period of 15 years. The effects can be seen as a high peak of the water table at the climate station (Figure 14) followed by a late summer minimum water table which possibly, with the absence of the large flood event, would have reached levels as low as at other sites in May or June of the previous year (Figure 15). The February flood event was caused by the Waikato River backing up into the Opuatia River and overtopping its banks, rather than by local rainfall at Opuatia. The total rainfall measured at the Opuatia Wetland climate station in February 2004 was larger than the calculated 30 year average. Most of the rainfall for this month occurred in early February and produced a small peak in the water table regime rather than the large peak of the February/March flood event, which was a result of heavy rainfall outside of the Opuatia River catchment (Figure 14).

Water table regimes are presented along cross sections of the wetland (Figure 13). The transverse transect (Figure 15) reveals transitions between swamp, fen, bog and swamp sites adjacent to the Opuatia River (sites 3–8). The longitudinal transect (Figure 16) encompasses fen and bog type areas (sites 11–5).

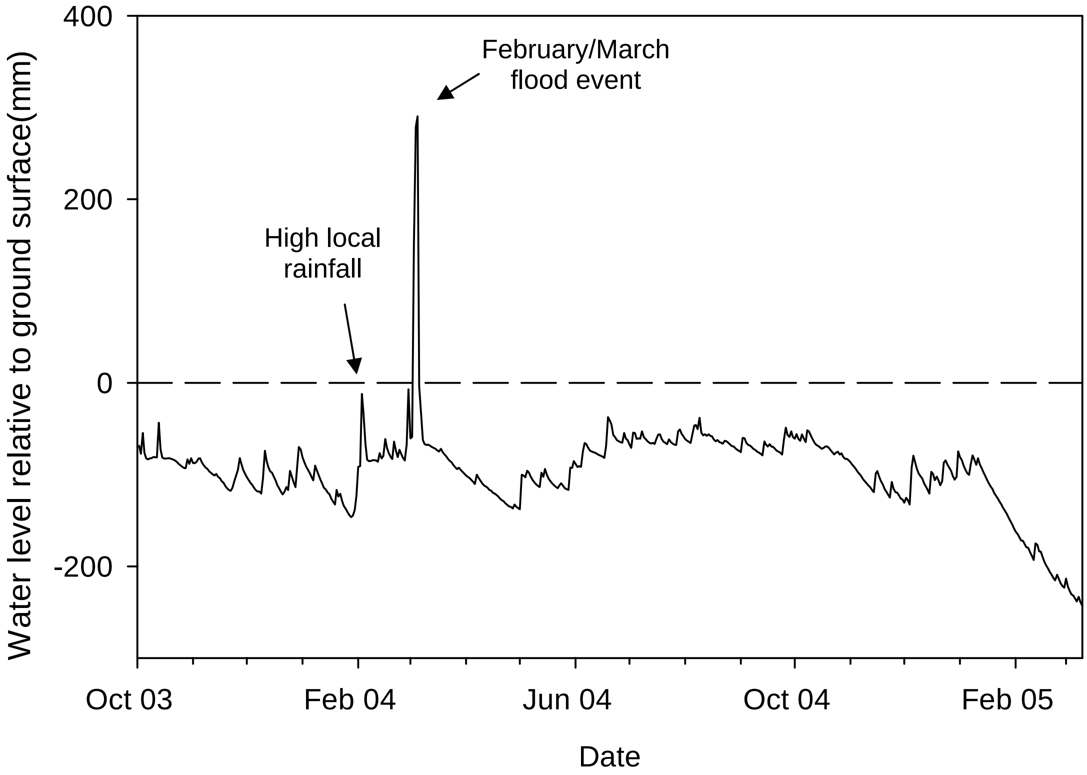

Figure 14: Climate station water level data showing seasonal water level trends. The dashed line denotes ground surface.

5.3 Transect across the wetland

The main differences in annual water table regime between sites occur in relation to varying wetland classes (Figure 15). Swamp sites (sites 3, 7 and 8) possess a water table above the peat surface, while fen and bog sites (sites 4, 5 and 6) typically have a water table at, or not far below, the peat surface. Sites located in areas where conditions are characteristic of swamp environments such as in sites 3, 7 and 8 differ greatly from other sites in the way in which they respond to water inputs. The response appears greater, possibly because surface water is flowing into these areas, magnifying the effect of rainfall. Therefore, the swamp environments of Opuatia Wetland have a more variable water table regime than fen and bog environments. Swamp environments which are influenced by the Opuatia River such as in sites 7 and 8, show an additional pattern in response to inundation from small floods from the Opuatia River.

Broad differences along the transverse transect include the position of the water table, which begins above the soil surface at site 3, where the peat has a greater mineral component and is dominated by willows, but is below the surface at sites 4, 5 and 6, (Figure 15) which all possess a firm peat substrate formed by vegetation including

Empodisma and tangle fern. The next sites along the transverse transect are site 7 and 8 (Figure 15) which, like site 3 have a water table above the soil surface, a higher soil mineral component, and are colonised by swamp flora and dominated by willow. While the eastern and western extremes of the transect both occur in swamp-like environments, an apparent difference between them is the effect of Opuatia River, which periodically floods into the western swamp margins. This is most obvious when comparing sites 3 and 8 (Figure 15), where the periods of inundation by floodwaters in the first graph are absent in the latter. This flood signal lessens towards the centre of the wetland, with site 7 showing a greater effect than 8, and further into the wetland at site 6 no river influence is apparent (Figure 15).

The bog and fen type sites of the transect have a relatively stable water table regime, while swamp environments on the edges of the transect show a more “flashy” and variable regime. Sites 3, 7 and 8 appear to show more seasonality than the fen and bog sites, while site 4 appears to have no significant seasonal pattern.

The longitudinal transect (Figure 16) reveals more water table regime patterns. The location of the sites shown in Figure 16 can be seen in Figure 4. All the sites along this transect have a water table that remains below the peat surface for the majority of the year (Figure 16). This transect begins at site 11, which is located in a fen-bog area dominated by manuka. This site, and site 10 (bog), are situated in the northern area of the wetland, and appear to have different water table regimes to the other sites in Figure 16. While the climate station (fen) and sites 1 (bog) and 5 (fen-bog) show a late summer minimum and some degree of seasonality, this characteristic is not apparent at site 11 and only slightly at site 10. This may indicate a hydrological boundary occurring between these two sets of sites, causing them to behave differently. The Waikato River flood event, which peaked on 4 March 2004 and inundated the entire wetland, is evident at sites 11, 10, and 4, however, the climate station site is the only site along this transect which shows the maximum flood level as it uses a pressure transducer water level recorder which cannot be overtopped.

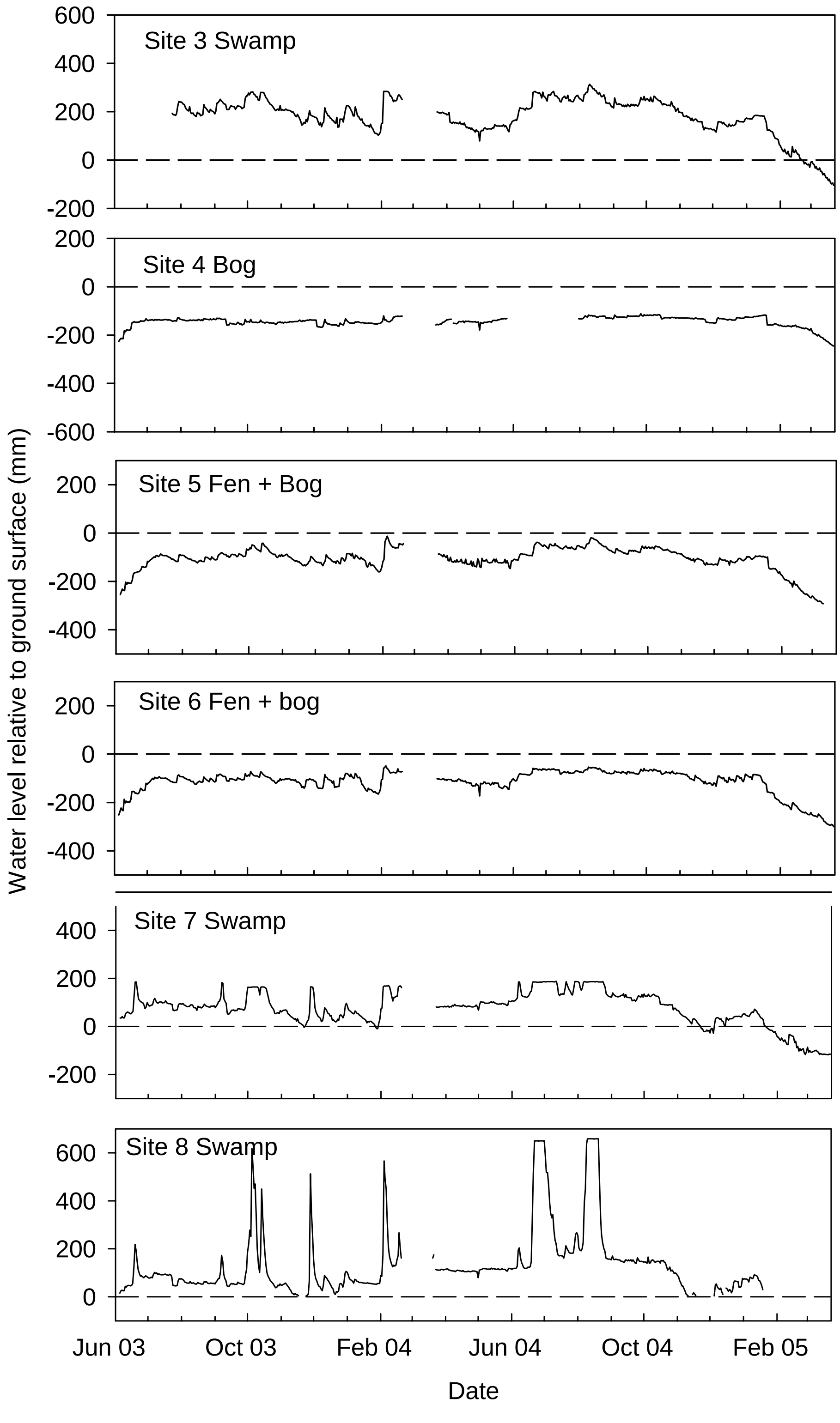

Figure 15: Water table regimes of six sites across a transverse transect, Opuatia Wetland June 2003 to March 23 2005. All graphs have the same vertical exaggeration. The flat tops to high peaks occur when flood events overtop the water level recorder. Dashed lines indicate peat surface. Missing data in March is due to instrument failure during the large flood event.

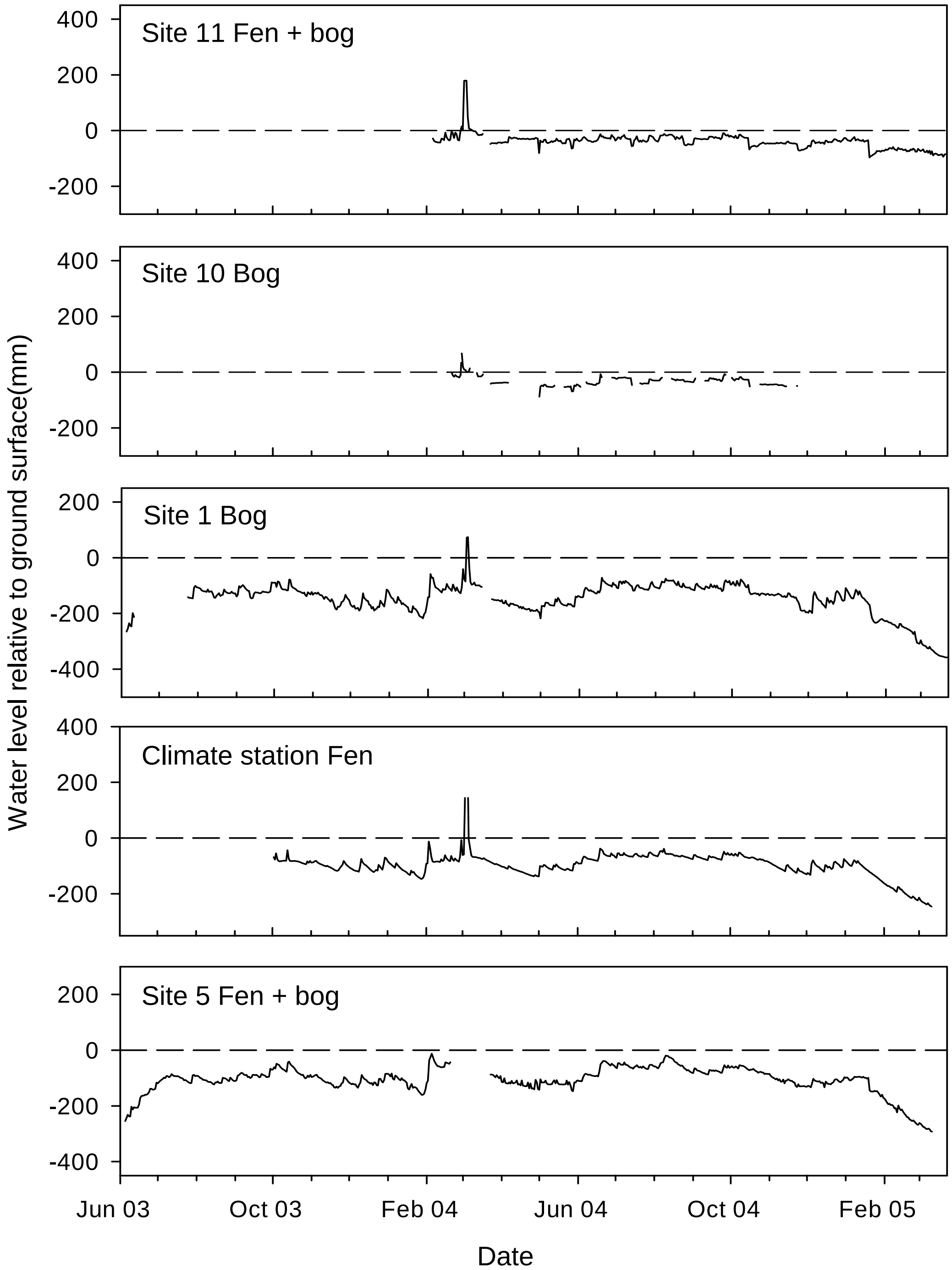

Figure 16: Water table regimes of five sites which lie on a longitudinal transect, Opuatia Wetland June 2003 to March 23 2005. All graphs have the same vertical exaggeration. Dashed lines indicate peat surface. Missing data in March is due to instrument failure during the large flood event. Other missing data is due to instrument failure or to later time of deployment for some sites.

5.4 Surface water contours and flow directions

Seasonal average water levels above sea level were calculated for a number of sites. It was intended that summer 2004 (December to March) and winter 2004 (June to September) would be compared to provide two seasonal extremes. However, the data set from summer 2003/2004 was not used due to the effect of the February/March flood; which would have disrupted the typical seasonal water table pattern in summer. Therefore, winter 2004 and summer 2005 contours were drawn and directions of flow revealed for these seasons (Figure 17 and 18).

Surface water contours are conducive to the theory of water tracks occurring at two locations in the wetland, with slightly domed areas on either side. A high area is located in between the wetland expanse and the northern area of the wetland, which may indicate a flow divide, hydrologically separating it from the main wetland body. Water is likely to be discharging in a northerly direction from this point and is likely to be exiting across the causeway. Contours become increasingly closely spaced with distance towards Opuatia River, indicating a higher hydraulic gradient and possible discharge from the fen and bog areas of the wetland into the riverside swamp areas, and the ponds and river. During the summer months of 2005 the water table elevation contours are placed significantly closer between the wetland and Opuatia River. Thus, indicating a much steeper hydraulic gradient and, therefore, potential for greater groundwater flow from the wetland to the Opuatia River. However, the domed areas maintained higher water levels.

The causeway area in the northern part of the wetland has a steep gradient (Figure 29(b)) towards the causeway. The transverse cross section shows a steep gradient in the willow-dominated region near the river at the beginning of the transect (Figure 29(a)), indicating that a hydraulic gradient exists and that provided the hydraulic conductivity of the substrate permits passage, this is an area of wetland discharging to the Opuatia River.

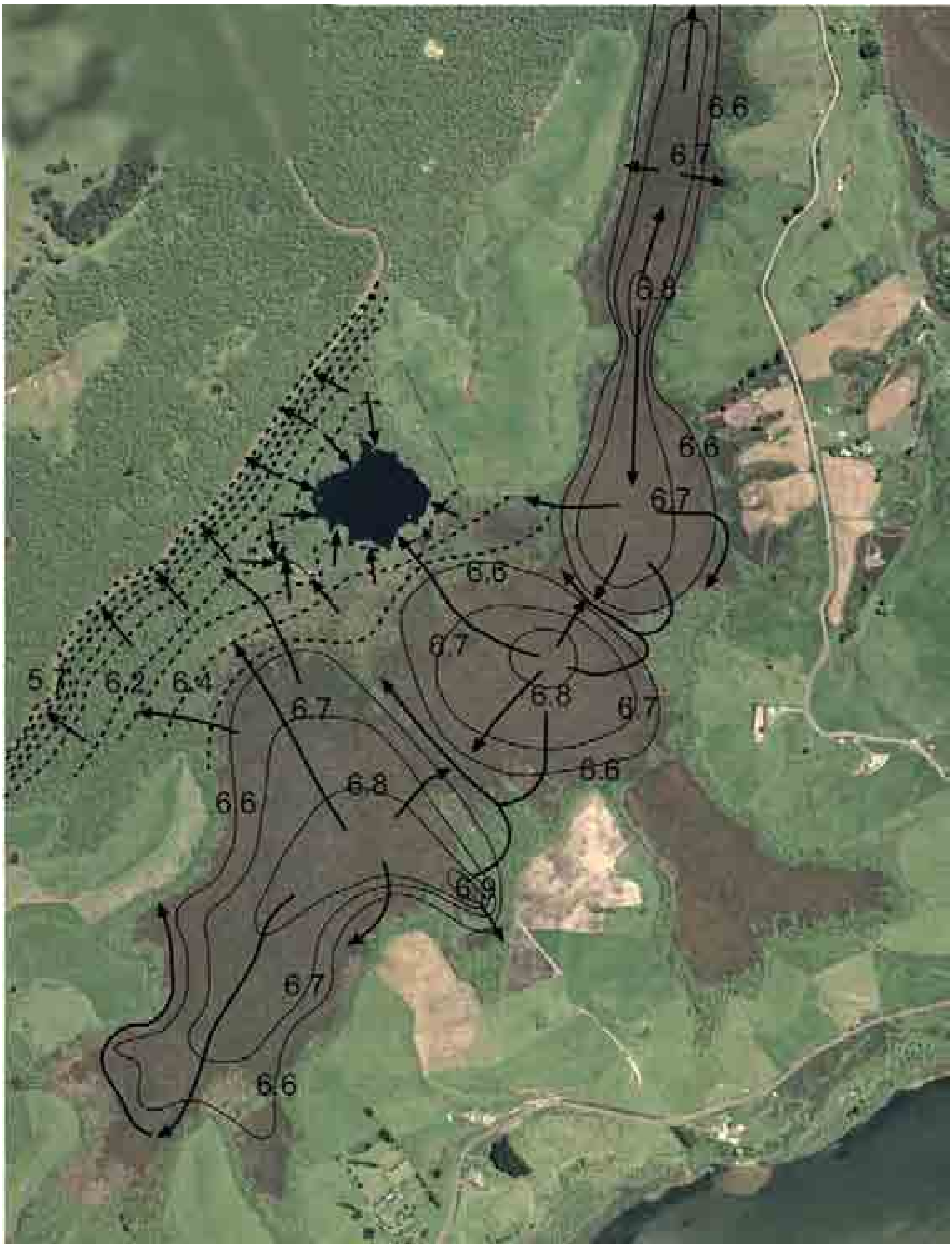

Figure 17: Average water level surface contours at intervals of 0.1 metres above sea level and flow directions for 1 June to 1 September 2004. Dashed contours are inferred.

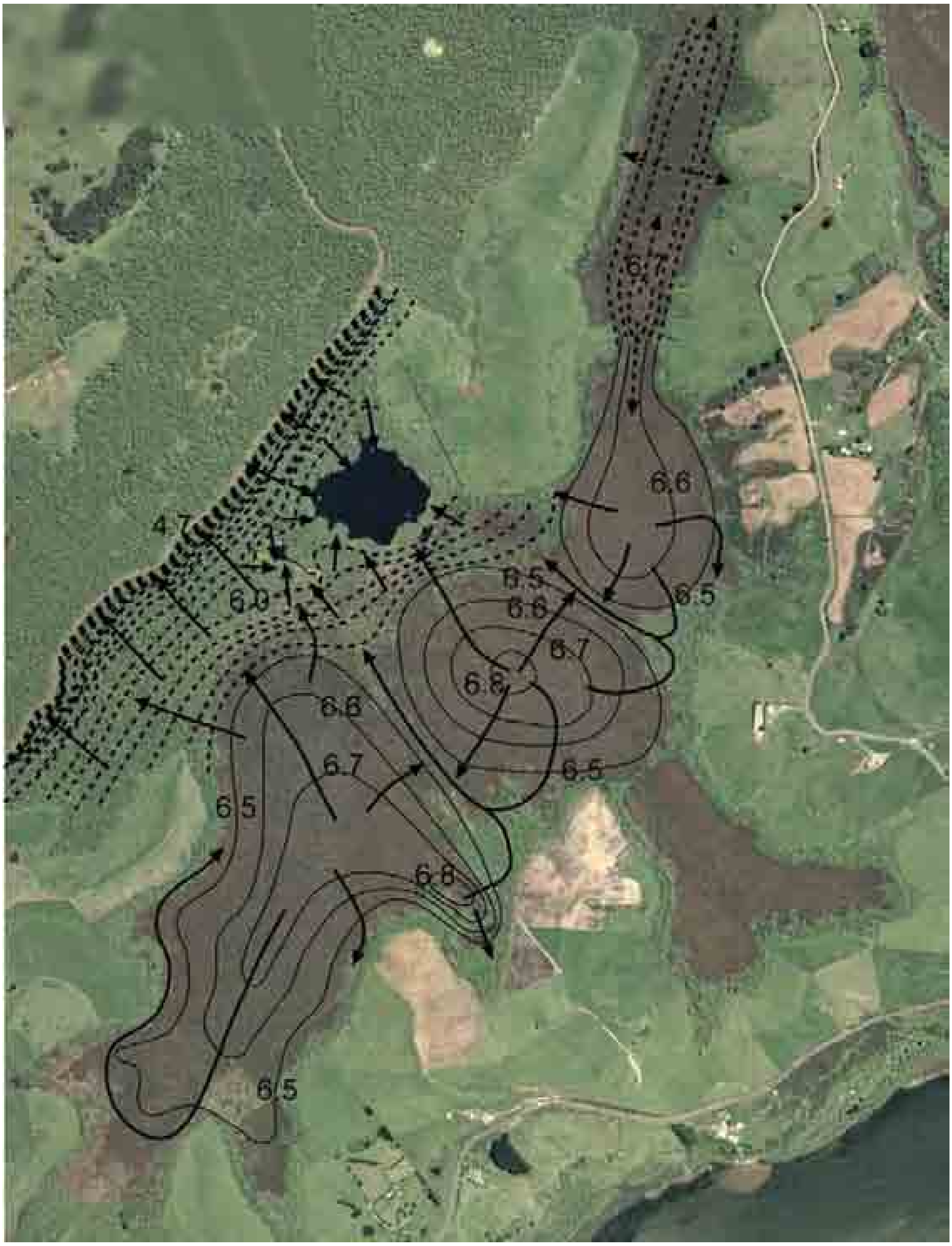

Figure 18: **Average water level surface contours at intervals of 0.1 metres above sea level and flow directions for 1 December to 1 March 2005. Dashed contours are inferred.**

5.5 The hydrological regime at bog sites

While bog sites typically have a more stable water table regime than swamp environments, site 4 (Figure 19(b)) behaves differently. Site 1 is used for comparison as it has behaviour which is consistent with most other bog sites. While the two sites have similar average water table positions beneath the surface, site 1 is more extreme and unstable. Site 4 shows very little variation throughout the year and rainfall events have only a small influence. The annual regime shows no seasonal trend.

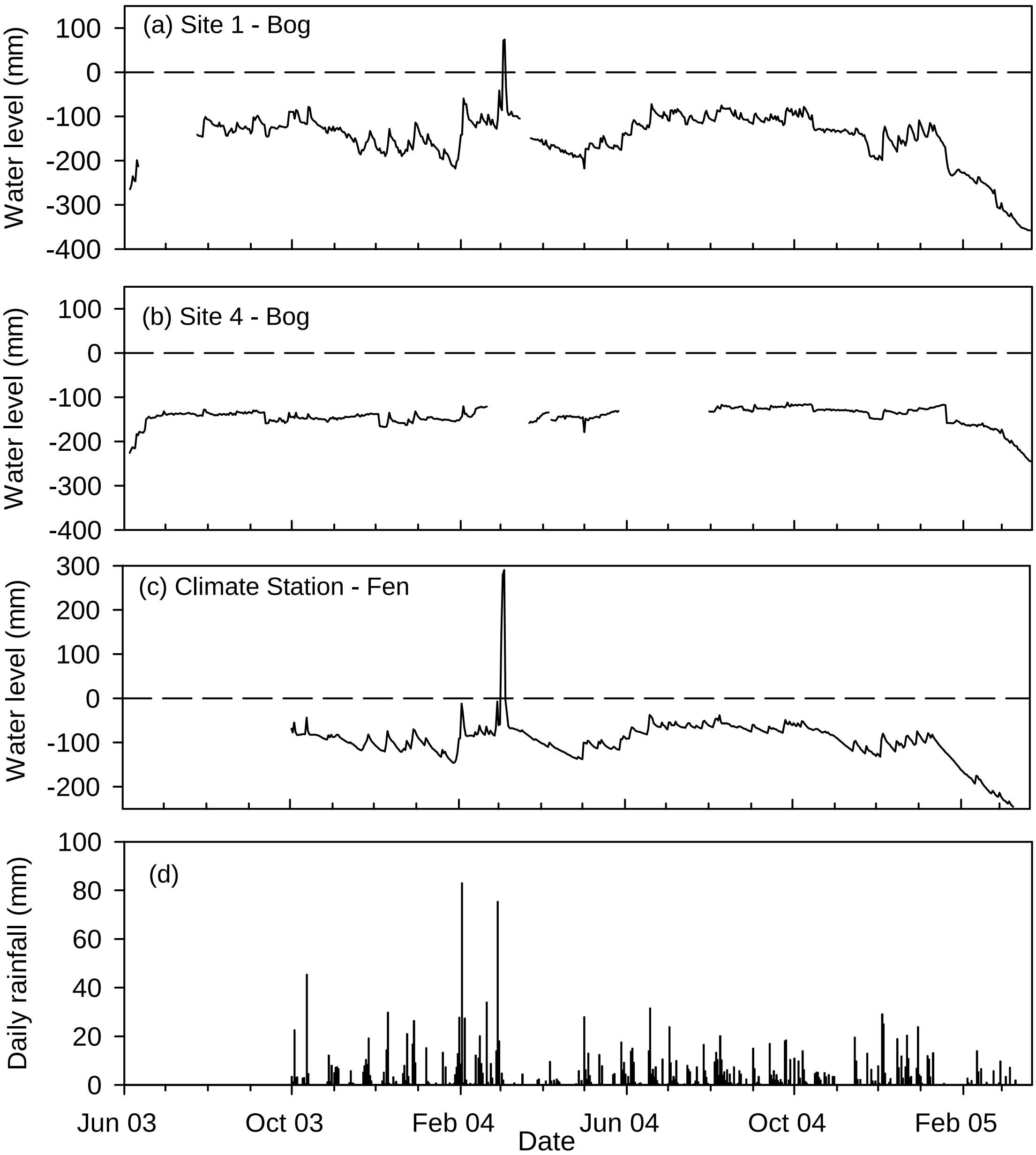

Figure 19: Midnight water table levels relative to peat surface (0 mm) at sites (a) 1, (b) 4, (c) climate station, and (d) total daily rainfall measured at the Opuatia Wetland climate station.

The climate station dip well, which is situated in an area of the wetland that has typical characteristics of a fen, shows the same patterns of response to rainfall as site 1. The stability of the water levels at site 4 may be due to a floating peat layer, which moves with the water level; hence even though the water level may be moving with rainfall, the depth below peat surface will not change significantly. The movement of the peat surface relative to reference steel poles at all sites is plotted in Figure 20.

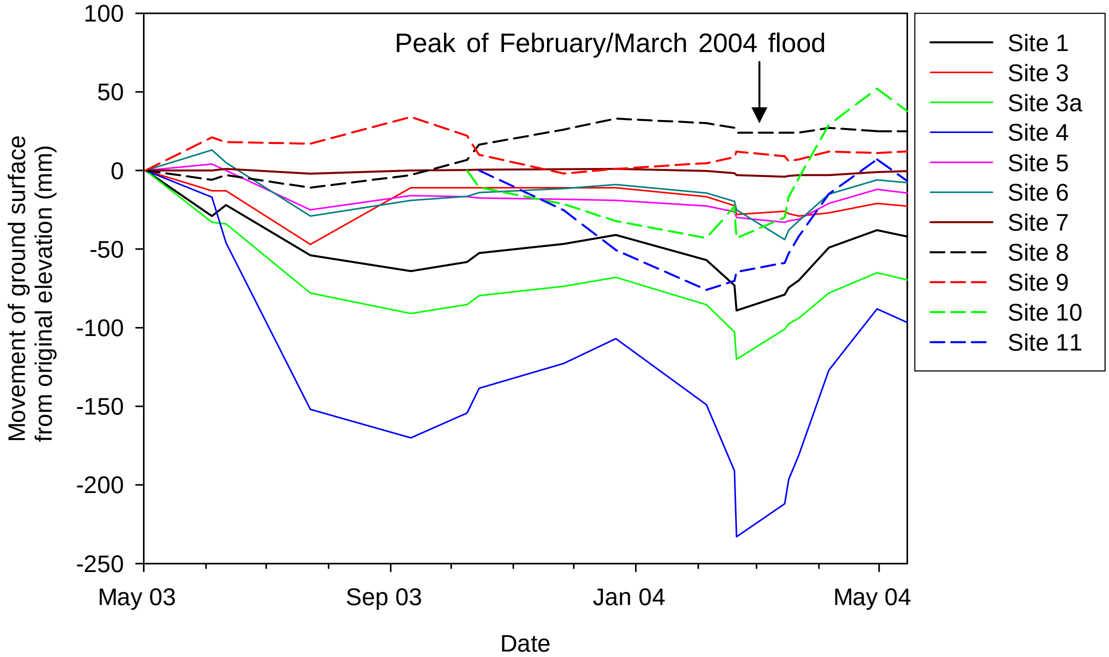

Figure 20: Movement of the ground surface relative to a reference pole anchored in the mineral substrate below peat deposits.

Figure 20 shows that the peat surface at site 4 has the greatest vertical movement totalling 233 mm over a year and hence, is possibly detached from the substrate and moving with the water level fluctuations

A small degree of seasonality can be seen in Figure 20. The ground surface at Opuatia Wetland seems to decrease in height from January to March, possibly due to greater evaporation over the summer months. The February/March 2004 flood event indicated on Figure 20 appears to have had an effect on the peat surface movement, causing it to increase in height over the late summer months when it would usually be lower. Sites 7 and 8 are located in areas which have a higher peat mineral content and so do not show the same surface movement that the sites with a significant peat component show. Site 9 is located on the levees of Opuatia River and has mineral soils. Hence, the surface movement at this site is small scale and follows a different annual trend. Sites 3, 5 and 6 behave similarly in terms of surface movement. Site 3 is a swamp site on the eastern side of the wetland, while 5 and 6 are fen and bog sites, so it is unusual that these two different wetland environments move similarly. Site 3 and site 7 are both swamp environments but site 3 shows more variation throughout the year. Site 7 belongs to the crack willow, *Carex* spp. and willow weed group determined by cluster analysis. This group was found to have much higher ash content than the grey willow and *Coprosma* spp. group that site 3 belongs to. This difference may be accountable for the stability of the surface at site 7 versus the variation at site 3. Sites 10, 11, 1 and 3a are all either fen or bog sites, and apart from site 4, show the greatest degree of peat movement throughout the year.

5.6 Opuatia Wetland water balance

A wetland receives water through precipitation, groundwater, and surface water flow or runoff. Storage can take place in soil, subsoil and in living plants. Loss of water from a wetland occurs by surface water outflows, groundwater, and evaporation (Campbell & Jackson, 2004). The balance between these variables is called the wetland water balance.

Inflows for the water balance of Opuatia Wetland include groundwater, precipitation, catchment runoff and flood events from the Waikato River and Opuatia River.

The long-term wetland water budget must be balanced by the water leaving the system. The hydrological system of Opuatia Wetland loses water through surface water discharge, groundwater discharge, and evaporation. One area where the wetland loses water via surface outflows is at the causeway entrance to the wetland area (Figure 2). During rainy seasons water flows across the causeway and out of the wetland system (Figure 21). However, this discharge is ignored as it discharges from an area that is believed to be hydrologically isolated from the main wetland body due to the presence of a proposed flow boundary, occurring somewhere between sites 10 and 1. While Figure 8 reveals the highest point and therefore most probable location of a flow boundary to be near site 1, the lower levels next in the transect correspond to the marginal swamp area of the wetland, which typically has lower water level elevation due to doming. Therefore, these points are ignored and the flow boundary is assumed to be somewhere between site 1 and site 10, where the gradient begins to steepen once more.

The second area of discharge is from the western edge of the wetland expanse towards the Opuatia River. Springs are evident during the summer months when the Opuatia River level is low.

Figure 21: Causeway entrance to the wetland. This area allows discharge of water across it during the wetter months of the year. View north along causeway.

Evaporation from the wetland catchment surface is calculated using an evaporation model together with data collected at the eddy covariance site (EC site) near the centre of the wetland. This method requires the catchment to be separated into main vegetation types (Figure 22) so that evaporation from pasture can be modelled. The evaporation data for the bog areas surrounding the EC site (Figure 13) has been directly measured and will be used as an estimate of evaporation over the entire swamp, fen and bog area of the catchment (Figure 22). As previously stated, the northern area of the wetland is not considered to be hydrologically linked to the main wetland body and, therefore, is excluded from the evaporation estimation.

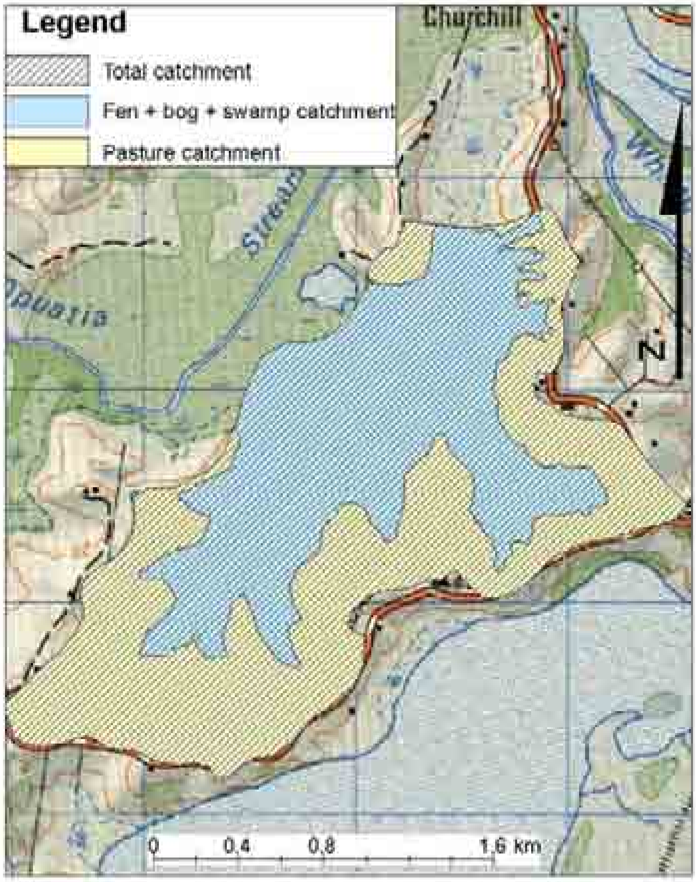

Figure 22: The distribution of the pasture, and swamp and bog type components of the Opuatia Wetland watershed.

Areas dominated by willow vegetation are likely to have greater evaporation than areas of fen and bog. The large area of crack willow near the Opuatia River (Figure 6) has been excluded from the catchment area used to calculate evaporation. The willow margins surrounding the remainder of the wetland have not been omitted on the assumption that they will not significantly distort the water balance. The areas of the individual components of the wetland catchment are given in Table 3.

Table 3: The area of pasture, and the remaining swamp and bog type components of the wetland catchment. Note: The area of the swamp fen and bog catchment differs from the wetland area given earlier, which encompasses the area of swamp all the way to the Opuatia River.

Catchment component	Area (ha)
Pasture	204
Swamp, fen and bog	185
Total catchment	389

Estimation of evaporation from the pasture catchment was undertaken using the Food and Agricultural Organisation of the United Nations (FAO-56) version of the Penman-Monteith equation. The residual[7] of the pasture water balance was added to the residual depth of the swamp, fen and bog catchment to plot the total monthly residual or discharge from the wetland (Q_{out}) (Figure 23).

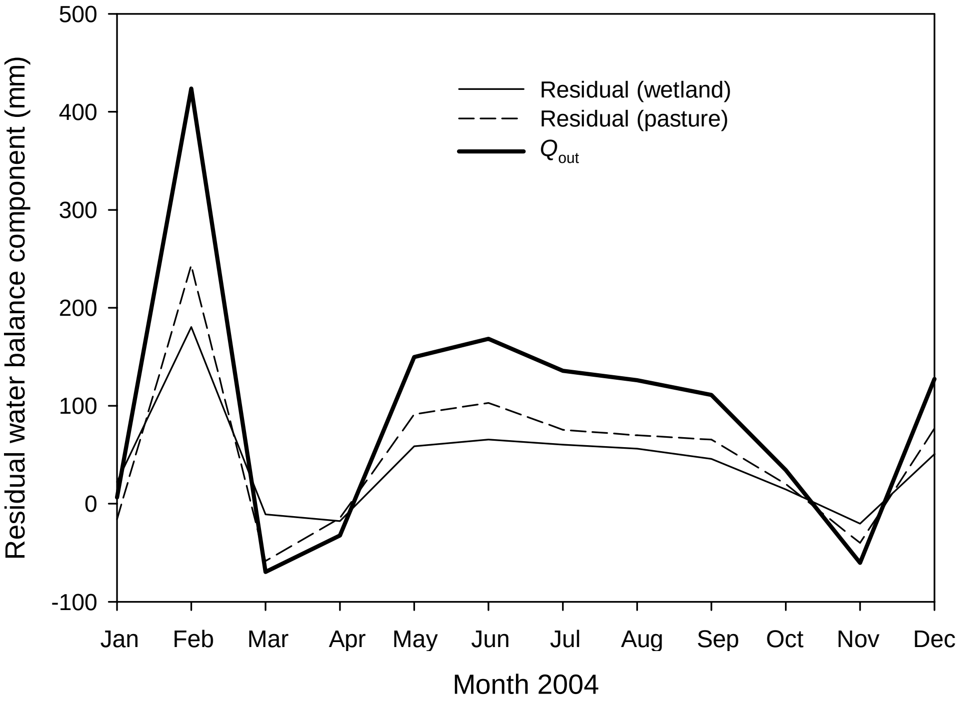

Figure 23: Monthly residuals taken from the pasture, swamp, fen and bog water balances. The residuals were summed to calculate total discharge (Q_{out}) from the wetland. Pasture residual is scaled to represent a depth over the wetland.

Daily totals of rainfall and evaporation were summed and plotted to show the cumulative annual water balance for Opuatia Wetland (Figure 24). The residual water depth indicates the proportion of rainfall that is discharged from the wetland as opposed to evaporated. The residual from the pasture is greater than the wetland residual for the majority of the year, indicating that most of the discharge from the wetland is supplied by runoff from the pasture catchment rather than from the wetland.

[7] The term residual is used to describe what is left in the wetland system after losses by evaporation have been taken into account. The residual is what is available to flow out of the wetland system as a discharge.

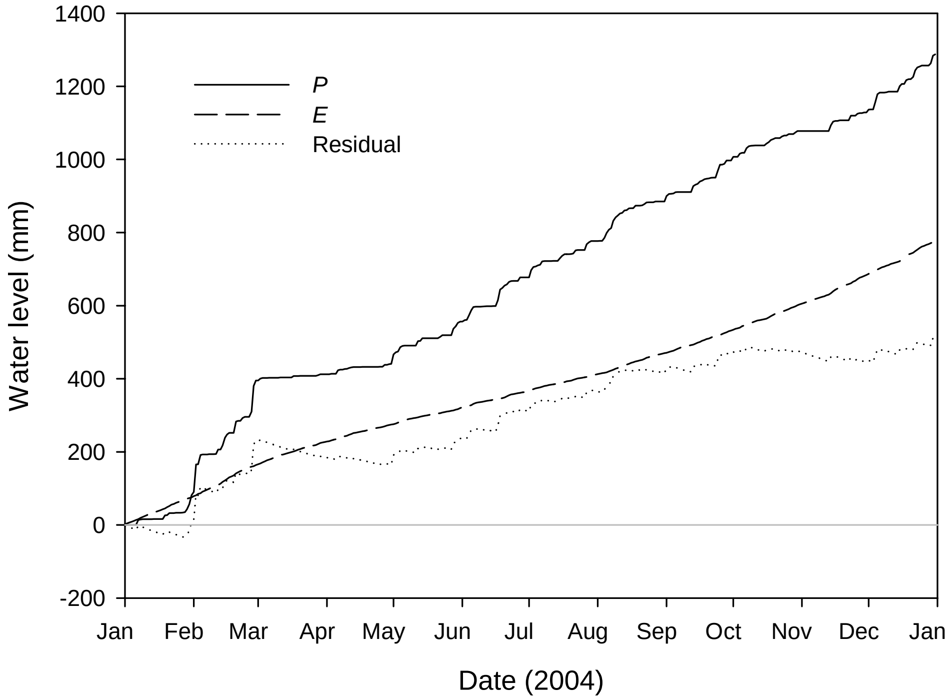

Figure 24: Annual (2004) cumulative water balance for Opuatia Wetland. Measurements from the EC site. *P* = precipitation and *E* = evaporation.

The steepest area of the cumulative precipitation occurs from January to March, indicating higher precipitation during this period. The residual is also greater over this period, indicating a larger depth of the water being discharged from the system. Evaporation however, stays relatively constant throughout the annual cycle. Total precipitation was 1,288 mm for 2004 The total annual discharge (residual) from the wetland is significantly less than the depth evaporated and equates to a discharge of 1,121 mm or 0.07 m^3s^{-1}. Annual evaporation from the swamp, fen and bog catchment was 778 mm. The sum of the annual evaporation and discharge from the wetland exceed precipitation, which is most likely due to the floodwaters entering the wetland system during the February/March 2004 flood event.

In order to better understand the seasonal trends in the wetland water balance, a monthly water balance was plotted (Figure 25).

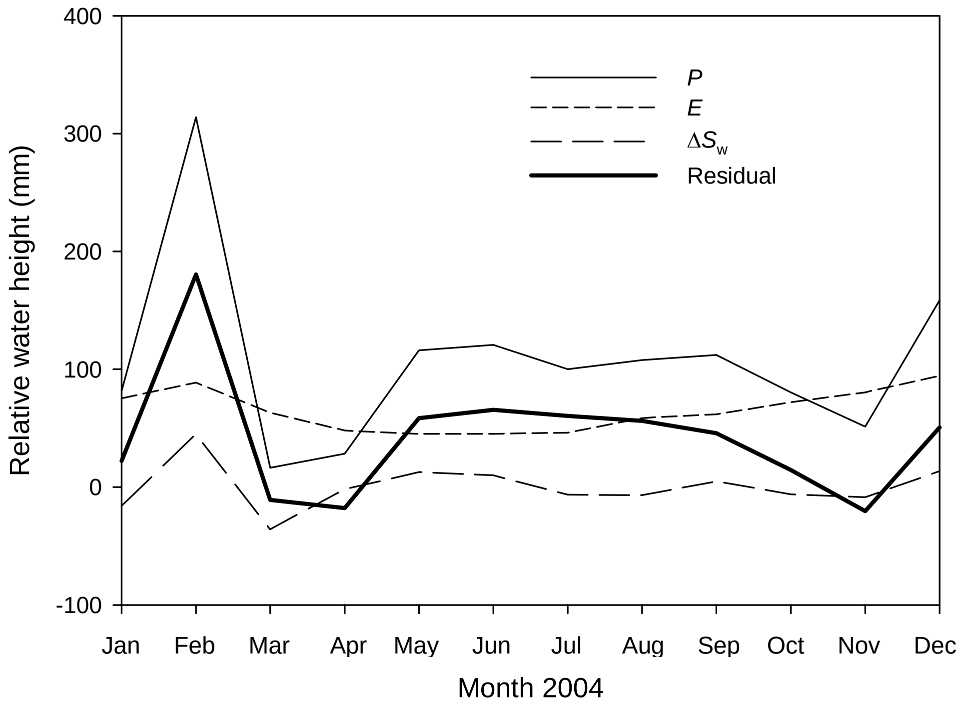

Figure 25: Monthly water balance for the fen and bog area of Opuatia Wetland. *P* = precipitation, *E* = evaporation and ΔS_w = change in water table storage.

Precipitation is high in February due to a large amount of rainfall prior to, but not associated with, the February/March flood event. The residual is also higher during February as well as the storage which would have increased as a result of flooding. Evaporation, although higher in the summer months, is the most constant component of the water balance and exceeds precipitation in March and October to early November. Following the February/March floods, storage decreases again as does discharge and rainfall before increasing again in April. From here storage, precipitation and discharge do not vary considerably until September, when precipitation and discharge decrease.

5.7 Opuatia River hydrology

Opuatia River is a tributary of the Waikato River. The nearest Waikato River stage recorder to the Opuatia River confluence is 7.4 km upstream at Rangiriri. The relationship between the Waikato River at Rangiriri and the Opuatia River at the stage recording site can be demonstrated by comparing their hydrographs between October 2003 and January 2004 (Figure 26).

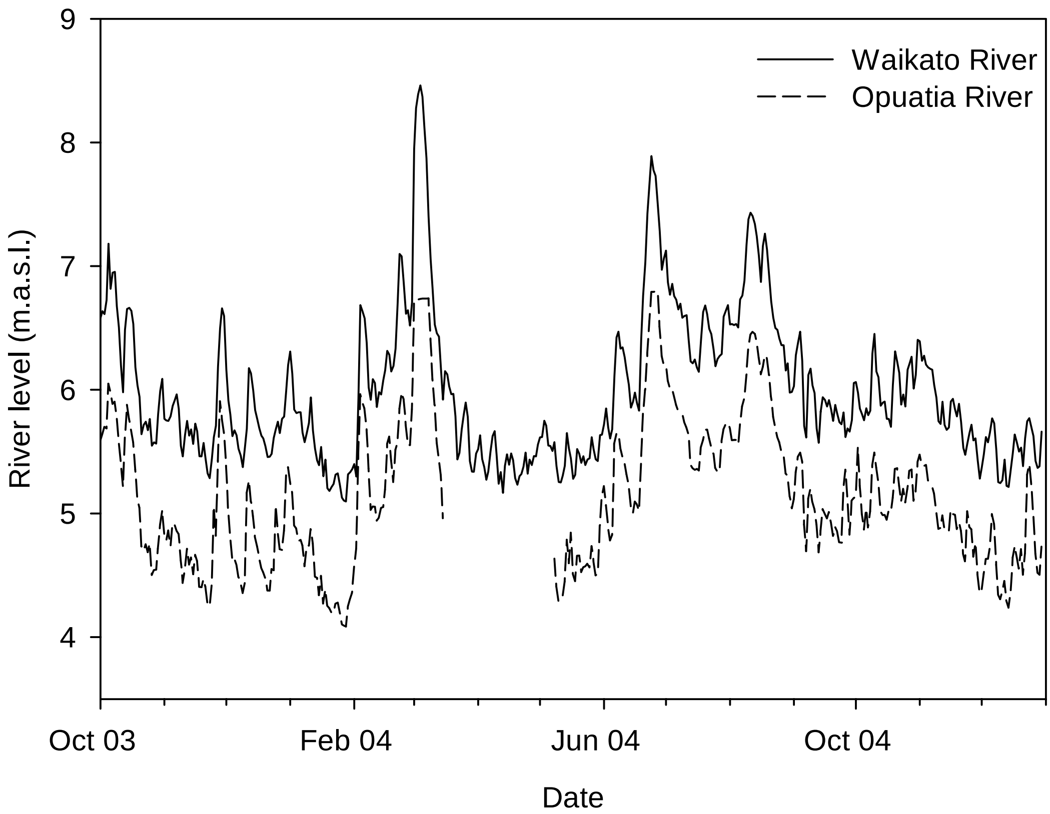

Figure 26: **Waikato River and Opuatia River stage single midnight values from October 2003 to January 2004. The flat tops on the Opuatia River level data occur due to overtopping the instrumentation during flood events.**

The goodness of fit of the water level data collected for the two rivers can be seen in the correlation plot (Figure 27).

An offset of approximately 1 m is evident in Figures 26 and 27 and can be explained by the distance from Rangiriri to the confluence between the two rivers. The natural gradient on the Waikato River causes the downstream confluence to be significantly lower than the height of the river at Rangiriri. The relationship between the two hydrographs is linear, with a gradient of close to one and an R-squared value of 0.94. The fit between the two rivers is sufficient to justify using the height of the Waikato River as an indicator of the approximate height of the Opuatia River at the same point in time and for extending the data outside the study period. The excluded data at the top of the cluster of points shows the maximum possible level of Opuatia River before it overtops the instrumentation while the Waikato River stage continues to rise within its channel. The slight bulge of data to the left of the cluster is most likely an expression of local flood events following rain in the Opuatia River catchment affecting Opuatia River, but not the Waikato River at Rangiriri.

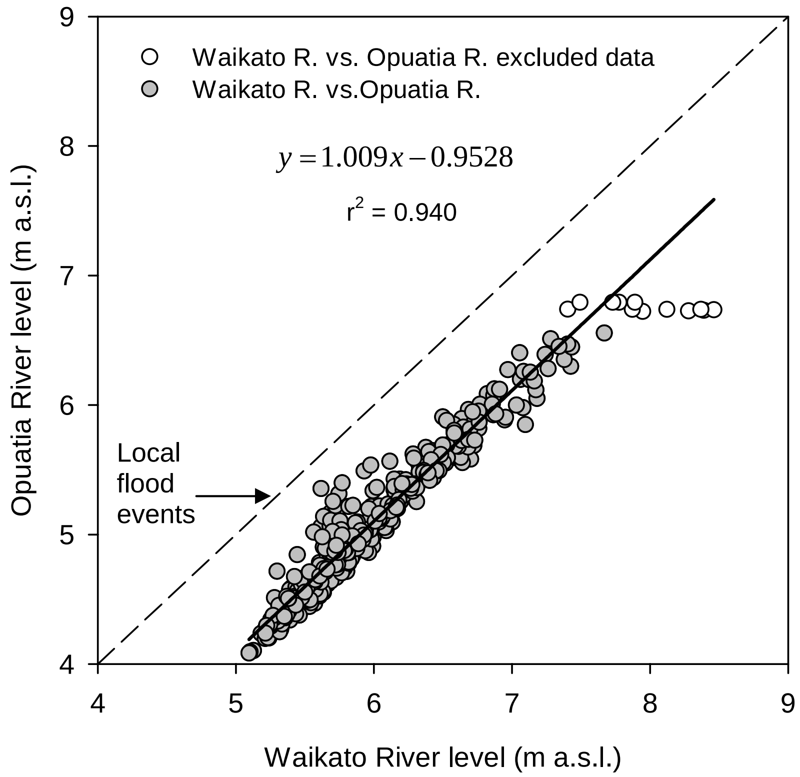

Figure 27: Waikato River at Rangiriri versus Opuatia River stage. Dashed line denotes 1:1 line.

5.8 Flood events

On 4 March 2004 the Waikato River reached flood peak after heavy rainfall occurred within its catchment. While Opuatia Wetland received 83 mm of rainfall on the 28 February, no significant rainfall occurred after the 29 February 2004 and during the flood event. The effect of the increased Waikato River stage caused the Opuatia River to back up and overtop its banks. This caused a large flood event in the wetland margins alongside the Opuatia River. Floodwaters also reached the wetland centre as a result of the Waikato River overtopping its banks to the northeast of the wetland, or the extension of floodwaters originating from Opuatia River. It is possible that both of these factors had a role in the flooding of the wetland centre, which at its peak rose to approximately 7.2 metres above sea level (m.a.s.l), which as an average depth across the wetland expanse is approximately 0.464 m higher than average annual water levels. However, in areas of swamp near the Opuatia River such as site 8, levels were observed from silt and debris on the vegetation and a height was estimated at 1.8 m above the ground surface (Figure 28). In the swamp areas on the opposite side of the wetland at site 3, flood level observations were recorded as approximately 0.57 m above the ground surface. In the wetland centre pressure transducers at the EC site and the climate station measured flood heights above the peat surface of 0.317 and 0.299 m, respectively.

The February/March flood event, which according to Environment Waikato peaked at approximately 1,210 m^3s^{-1} or 8.47 m stage at Rangiriri on March 4 2004, has a calculated return period of 15 years or a 6.7% chance of occurrence in any one year. In order to breach its stop banks the Opuatia River must reach a height of 5.782 m.a.s.l. The February/March flood peaked at 7.2 m.a.s.l. at the wetland centre, which is 1.418 m in excess of what is required to flow into the wetland. Floods of a lesser degree occur very regularly. Approximately seven minor floods (river levels higher than 5.782 m.a.s.l.) that inundated the wetland margin can be seen in Figure 26. From 1 October 2003 to 30 December 2004 the Opuatia River stage was higher than 5.782 m.a.s.l. and thus flooded over its stop banks approximately 13% of the time.

Figure 28: The maximum flood water level on 4 March 2004 can be clearly seen by silt-covered crack willow near site 8. Arrows indicate maximum stage height.

The maximum flood water level in the wetland centre can be seen in Figure 29, which shows the maximum height above sea level recorded by both the EC site and the climate station dip wells, which use pressure transducers.

The difference between the storage capacity of the wetland at the time of the flood and the volume of flood water that entered the wetland equates to what would be temporarily stored in the wetland.

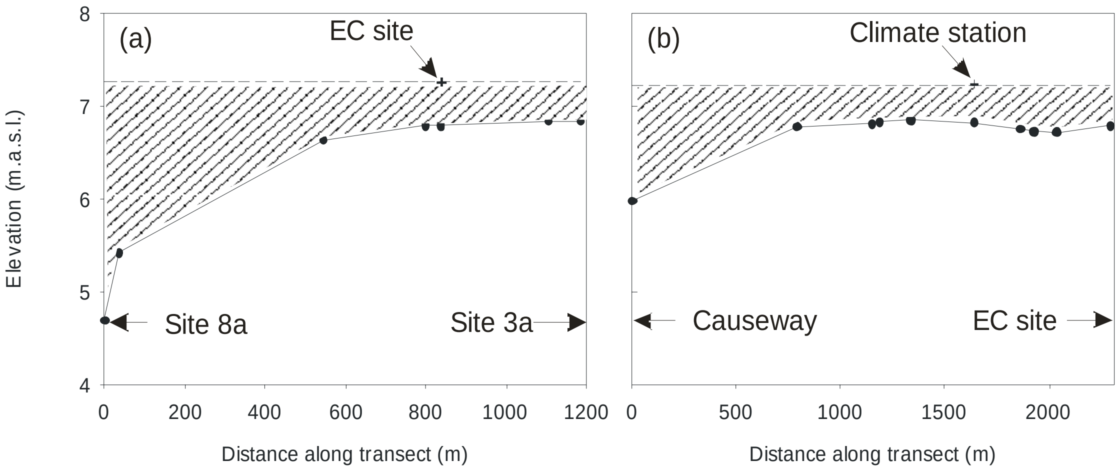

Figure 29: Transects of Opuatia Wetland showing water level elevation above sea level in December 2003. (a) Transverse cross-section beginning on the eastern side of the wetland and ending at Opuatia River on the western side of the wetland (Figure 13), (b) longitudinal cross-section beginning in the north and stretching towards the south (Figure 13). Dashed line indicates highest extent of flood waters on 4 March 2004 taken from data at the EC site and the Climate Station, shown as crosses. Shading indicates area for which a flood inundation volume was calculated. December 2003 levels were used because some survey sites do not have water level recorders.

The volume of floodwaters held in the swamp margins, fen and bog area of the wetland (Figure 22), but excluding areas dominated by crack willow on the western side of the wetland, at the peak of the February/March flood was estimated to be 858,400 m^3. This volume was calculated by finding the annual average water level height above sea level at sites 1, 3a shallow, 4, 5 shallow, 6, the climate station and the EC site. These average heights were then each subtracted from the maximum flood height to find the depth height of the maximum floodwaters on 4 March 2004 (7.2 metres above sea level) above the average water surface at each of these sites. The resulting depths were averaged to give an average floodwater depth across the area shown as fen, bog and swamp catchment in Figure 22. The resulting additional depth of water in the wetland area depicted in Figure 29 and Figure 22 at the flood peak was 0.464 m. This value multiplied by the area of the swamp, fen and bog area (Figure 22) enabled a volume to be calculated. The area that lies west of the blue swamp, fen and bog area depicted in Figure 22 and east of the Opuatia River has an area of approximately 317,975 m^2. The height of the February/March 2004 flood event taken shortly after by examining silt deposits on vegetation was estimated to be 1.8 m above the ground surface or 1.66 m above the average water level near site 8. Site 8 flood height was averaged with site 6, which was incorporated to provide a slope between the wetland body and the Opuatia River. The average flood height above average water levels at these two sites was multiplied by the area to give a flood storage volume of approximately 348,342 m^3. The northern portion of the wetland study area (Figure 22), which stretches north from the upper boundary of the fen, bog and swamp catchment and is approximated by the blue dashed contour in Figure 22 was also incorporated. Using averages of the water level elevation at the causeway entrance when the GPS survey was carried out in December 2003 and the average water levels at site 10, an average flood depth in this area was calculated as 0.814 m and equates to 244,200 m^3 of water stored in this area during the peak of the February/March 2004 flood.

Therefore, the total storage volume of Opuatia Wetland expanse during the peak of the February/March 2004 flood was approximately 1,450,942 m^3.

6 Current ecosystem pressures

The presence of several drains seen in early aerial photographs indicates that Opuatia Wetland has been subjected to hydrological modification in the past. In addition to this, water table levels may have been affected by the lowering of the Waikato River bed. The construction of causeways through parts of the wetland may have caused local water table and flow path changes. The main causeway located in the northern region of the wetland is presently in use. Evidence of historical causeways has been found in other parts of the wetland. The large pond located in the western area of the wetland has reduced greatly in size since 1942, which is probably due to it draining into the Opuatia River via a constructed drain. In 2003 bunds were constructed by Environment Waikato along the Opuatia River and the wetland downstream of study area. These were intended to increase the water table in these areas as a part of wetland restoration works.

The presently high and stable water table at Opuatia Wetland must be maintained to ensure the future health of the ecosystem. A lowering of the wetland water table can increase oxidation of peat, leading to decomposition and the release of nutrients. Some exotic dryland plants are able to colonise areas of decreased water levels (Clarkson *et al*, 2004a). It is possible that the combination of lowered river levels and the construction of the bunds may be decreasing the frequency of natural flood events. This may enhance ombrotrophic[8] bog formation by limiting nutrient input. The high levels of nutrients provided by large flood events, which reach the relatively nutrient poor wetland centre, may affect the wetland's ecology.

[8] Ombotropic wetland receive water almost exclusively from precipitation.

Dryland species such as gorse, wilding pine and heather have colonised some areas of Opuatia Wetland, and need to be controlled. It is likely that hillslope runoff has increased since historical bush-felling, which could have changed the duration, volume and nutrient levels of water entering the wetland as runoff following rainfall.

The most significant pressures on Opuatia Wetland are the invasion of exotic species, unrestricted animal access leading to trampling, grazing and eutrophication, and farm runoff. Reed canary grass *Phalaris arundinacea*, gorse, royal fern *Osmunda regalis*, grey willow and crack willow are listed as key undesirable species of palustrine wetlands (Clarkson *et al*., 2004a); these species are all present in the wetland in varying proportions.

7 Recommendations

7.1 General

Without adequate fencing, the health of Opuatia Wetland will deteriorate due to direct stock access, trampling and grazing of the wetland margins. Some adjacent farmland owned by Environment Waikato, and leased for grazing does not currently have alternative water sources for stock nor fencing to prevent stock access, causing the cattle to go to the wetland for water. During dry seasons stock walk deeper into the wetland in search of water. This poses a serious threat of nutrient enrichment from cattle effluent and severe trampling damage to vegetation and peat. Eutrophication can be a serious problem for wetlands as it has the ability to change the vegetation composition. It can also cause blooms of periphyton and phytoplankton, and stimulate microbes using up oxygen and producing soil phytotoxins, which puts vegetation under stress (Sorrell *et al*., 2004).

Fencing of the Opuatia peat bog was a conditional requirement of a resource consent granted to Environment Waikato to extend the existing Lower Waikato Flood Control Scheme, and was to be completed by February 2003 (Barnes *et al*. 2001). The importance of fencing Opuatia Wetland has also been given the highest rating ("*Priority 1 - to be mapped as Stock Exclusion Areas in the Regional Plan Maps"*) in proposed amendments to partially resolve references against Chapters 3.9 and 4.3.5 of the WRP[9].

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[9] Proposed Waikato Regional Plan References Amendments to partially resolve references against Chapter 3.9 and 4.3.5 of the WRP. Document # 982233.

Recommendation: that Environment Waikato land bordering the wetland is fully fenced before the summer of 2005/06.

The areas most vulnerable to weed invasion tend to be those associated with moving groundwater, which carries a supply of nutrients higher than that needed to sustain native wetland vegetation. Some form of willow control is essential, with particular attention given to the areas where willows extend out across the central fen and bog portion of the wetland, posing the risk of ecosystem fragmentation. Large intact wetland ecosystems possess functions which allow the system to resist modification. When these ecosystems become smaller in area due to fragmentation, the area to perimeter ratio decreases and edge effects become an increasing problem. Therefore, the size and shape of a wetland is an important determinant of whether or not a wetland will be substantially damaged through disturbance of ecosystem functions and habitat loss (Clarkson *et al.*, 2004a). Grey willow poses a much greater risk to the wetland at present than crack willow, which does not appear to be spreading significantly and has recently been damaged by saw fly. Additional weed control needs to be carried out on small patches of gorse and individual wilding pines, which are sparsely scattered through the wetland.

Recommendation: the removal of willows and other exotic species in areas where they extend out across the central fen and bog portion of the wetland.

The importance of managing nutrients in the Opuatia Wetland catchment has been given a high rating ("*Priority 2 - List of Priority Water Bodies For Nutrient Management*") in proposed amendments to partially resolved references against Chapters 3.9 and 4.3.5 of the WRP. Under this proposed amendment "*Environment Waikato will undertake and where appropriate encourage investigation into:*

1. *the adverse effects of fertiliser use and nutrients on water bodies*
2. *farm management techniques that make the most efficient use of nutrients inputs while minimising leaching*
3. *methods to prevent nutrient contamination of water bodies."*

Recommendation: landowners surrounding Opuatia Wetland are encouraged to undertake or investigate the above mentioned nutrient management options.

7.2 Restoration area

The restoration area north of the Opuatia Wetland study area is dominated by willows. Active management of the willows will be required to enable the establishment of native swamp vegetation. The removal of willows will also help to reduce transpiration rates and as a result help to maintain a higher water table. The measures used to control willow invasion and allow the natural re-establishment of native vegetation must be monitored to make ensure their effect is continual. If the removal of the willow results in the invasion of other undesirable exotic species it may be necessary to plant appropriate native species which cope well with a relatively high nutrient and competitive environment. The area must be protected from drainage or any activity which could lead to water table lowering. It is paramount to ensure that fencing is maintained to prevent stock access to this area and that other sources of water are available to stock grazing nearby. Nutrient runoff from agricultural land must be controlled or eliminated.

<u>Recommendation:</u> that vegetation monitoring is continued to identify if the amount of willows is reducing and being replaced with native species.

8 Conclusions

Opuatia Wetland is one of the last extensive wetland remnants in the Waikato Region and has a large range of ecohydrological characteristics, which are a result of it being a complex mixture of wetland types. Distinct landscape scale vegetation patterns identified from aerial photography relate to hydrology and nutrient availability. These vegetation patterns occur along a successional gradient, which is related to peat chemical and physical properties. Dominant vegetation species grade from higher nutrient species in the margins, where surface water flows are present, to low nutrient species in the centre, where rainfall has a much greater influence over the chemistry of the area. Pathways of surface water movement across the wetland have been proposed as well as a possible flow divide, which may separate the northern area of the wetland from the main body.

The wetland water table is generally shallow and stable; indicating that the wetland is in good health and with time may become a suitable area for the colonisation of threatened species such as *Sporadanthus ferrugineus*. However, Opuatia Wetland has been affected by invading exotic species. Grey willow poses a particularly serious threat and has increased its distribution since 1942 from almost zero to 30% of the present day wetland area. Without control it is possible that this species could increase to approximately 43% by 2024. Stock which graze on the surrounding hill slopes have direct access to the wetland margins, this as well as runoff from agricultural land, pose a harmful source of nutrients. The current agricultural use of the hills surrounding the wetland may not be appropriate due to the increased nutrient levels entering the wetland from fertilisers and stock waste. Opuatia Wetland requires active management to ensure its ecosystem health is maintained. Some of the management recommendations are:

- Fencing of Environment Waikato's land which is adjacent to the wetland before the summer of 2005/06
- That Environment Waikato encourages landowners surrounding Opuatia Wetland to undertake or investigate nutrient management options to reduce agricultural runoff
- The removal of willows and other exotic species in areas where they extend out across the central fen and bog portion of the wetland.

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