# Assessment of the Ecohydrological Functioning of Otakairangi Wetland, Northland

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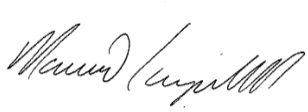

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# Executive Summary

Otakairangi is the largest wetland remnant on the floodplain of Northland's Wairua River near Hikurangi. Extensive peat deposits many metres deep accumulated over thousands of years on the valley floors of the Otakairangi and Riponui valleys, as they did elsewhere within the former Hikurangi "Swamp". The present-day Otakairangi Wetland, with an area of 2.6 $km^2$, represents around 20% of its former extent.

This report provides an assessment of the ecohydrological functioning of Otakairangi Wetland in its current state, based on information gathered during a field survey, discussions with landowners, and other sources. The wetland, which contains representative communities of rare peatland plants, is a good candidate for restoration, including re-introduction of the now locally extinct climax peatland plant species *Sporadanthus ferrugineus*.

Hydrological modification to Otakairangi over the past century has included a deep central drain that has largely eliminated the natural diffuse flows of the former Otakairangi Stream as it traversed the wetland, and lowered water tables. Deep drains bordering the wetland's south western and south eastern edges have also contributed to a modified hydrological regime. Over much of the past century water table lowering and frequent fires led to dominance by tall manuka, reduced peatland biodiversity, and severe peat degradation.

There is good evidence of fairly recent changes to Otakairangi's vegetation towards greater dominance, especially in the east, of the key peat-forming plant and ecosystem engineer *Empodisma robustum*, including vigorous growth of raw fibrous peat. As the dense manuka cover has declined, *Empodisma* and allied plants have been able to naturally colonise and spread.

Despite encouraging signs of some natural vegetation recovery within Otakairangi Wetland, there remain many unanswered questions about the trajectory of this recovery and the ongoing effects of drainage, as well as inundation by flood flows from the highly modified upstream catchment. Also, fire remains a constant threat that could reverse this trajectory. A number of key research questions are provided in this report that will guide the development of a research plan in support of ongoing restoration and monitoring efforts.

A number of restoration options are presented that should be considered at Otakairangi. These include minor to more major hydrological manipulations, which will require careful investigation and flow modelling in addition to working closely with affected landowners. As a first step, detailed surveys are required of drain invert levels and wetland and farmland surface levels. Monitoring of drain and wetland water tables should be initiated as soon as possible, to support research into wetland hydrological regimes and to further understand the spatial effect of water table lowering

adjacent to drains. Minimum water level controls should be established along the central drain to prevent further negative effects within the wetland.

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# 1 Introduction

Drainage, flow diversion and land development in the Hikurangi Swamp area have eliminated over 96% of the former extent of wetlands (Clarkson *et al.*, 2015) and, along with them, their values including biodiversity and ecosystem services.

Otakairangi Wetland is a 2.6 $km^2$ remnant peatland on the western edge of the former Wairua River floodplain that has been identified as having highly significant values and is recognised as being worthy of actions to ensure its protection and restoration. The wetland has been impacted by more than a century of modification by surrounding land drainage, internal drain excavation, and by fires.

Little is known about the historical or current state of Otakairangi Wetland or what its full potential for restoration is. This report provides an assessment of the present-day ecohydrology[1] of Otakairangi as a first step towards the development of a strategy for further research and monitoring to inform a restoration plan for this wetland gem.

## 1.1 Purpose and scope

Milestones for this project and report were:

1. Familiarisation and investigation of the ecohydrological functions of Otakairangi Government Purpose Wildlife Management Reserve (GPWMR), its surrounding catchment, drainage and flood management in the Hikurangi floodplain.
2. Produce and submit a baseline report of the ecohydrological functioning of the Otakairangi Government Purpose Wildlife Management Reserve (GPWMR) including long-term recommendations and monitoring regimes.

## 1.2 Report outline

This report is structured with an initial overview of peatland ecohydrological processes and restoration principles. The physical setting of Otakairangi Wetland is then described, including a brief consideration of the physical hydrology of its catchment, developmental history to its pre-settlement state, and the effects of land use, drainage and fires.

Following a brief description of field survey activities and methods, the perspectives of neighbouring farmers are reported. A section on assessment of present-day wetland condition based on observations and field measurements is then given.

[1] Ecohydrology is the interdisciplinary study of the interactions between water and ecosystems, recognising the often complex interdependencies between biota (plants, animals, and microbes), water, nutrients and carbon storages and flows.

A discussion section provides expert opinion on the trajectory of degradation and possible recovery of some more natural ecosystem functions, future risks, restoration options and challenges, and priority research needs from an ecohydrological and ecosystem functioning perspective in order to inform and monitor recovery and restoration success.

# 2 Peatland ecohydrology and restoration

## 2.1 Wetland types

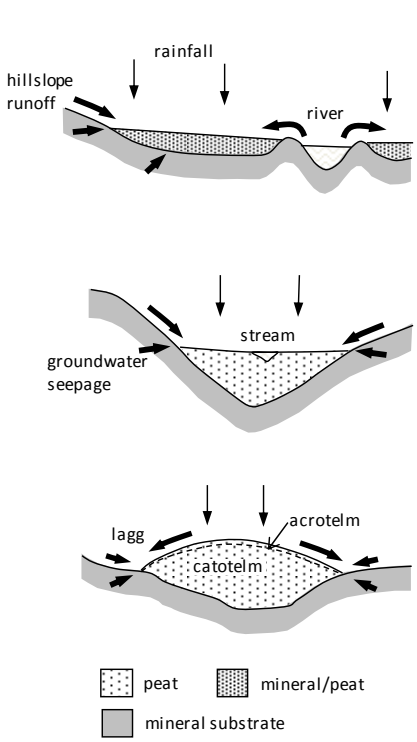
Wetlands occur in a wide variety of settings, from sea level to mountain top, and at almost all latitudes on a global scale. Otakairangi Wetland is an example of a *palustrine* wetland, because it exists outside of the normal boundaries of river and lake systems. The main types of palustrine wetland in New Zealand are swamps, fens and bogs (for a full classification refer to Johnson and Gerbeaux, 2004), which differ primarily because of their dominant water sources (**Figure 1**). Fens and bogs are the primary peat-forming ecosystems, referred to as *mires*, or simply *peatlands*.

**Swamps** are usually connected to river or lake systems and are frequently inundated with standing flood waters. Large inputs of mineral sediments and nutrients lead to eutrophic conditions and highly productive plant growth rates. Peat accumulation tends to be limited because most organic material decomposes rapidly.

**Fens** are peat-accumulating wetlands within which the main water and nutrient sources are from rainfall, groundwater and seepage from adjacent hillslopes.

**Bogs** have low plant productivity because their landscape position and depth of peat accumulation has isolated them from surrounding surface waters and groundwater. Their sole inputs of water and nutrients are from rain and atmospheric deposition. Incomplete decay of dead plant material causes nutrients to be bound within the peat and unavailable for plant growth. This causes bogs to have very low levels of the key plant nutrients nitrogen (N) and phosphorus (P). At their margins (lagg) they may be swamp-like or fen-like because other water and nutrient sources may be present. Only highly specialised plants such as (in New Zealand) members of the restiad (Restionaceae) family, *Empodisma spp.* and *Sporadanthus ferrugineus*, mosses, sedges, orchids and stunted shrubs can grow on the surface of true bogs. Bogs accumulate peat because decomposition of dead plant material occurs at a very slow rate, pH is low, and chemical compounds such as humic acids and phenolic compounds inhibit decomposer organisms.

All of these wetland types are now quite rare in developed landscapes because, once drained, they can be converted to productive agricultural land.




**Swamp**
Water and mineral sediments from rain, flooding rivers, hillslopes and groundwater seeps. Predominantly mineral substrate but peat may also be present. Raupo, sedges, flax, Kahikatea, willows. Highly fluctuating water tables, often inundated for long periods in winter.

**Fen**
Water from rain, hillslopes, small streams and groundwater. Peat substrate. Manuka, sedges, wire rush. Moderately fluctuating water tables.

**Raised bog**
Water solely from rain (ombrotrophic), but lagg areas at margins may be affected by mineralised runoff/groundwater (swamp or fen-like). Prominent peat doming caused by greater peat accumulation rates in the centre. Wire rush and cane rush (restiads), mosses, sedges, stunted shrubs. High stable water tables that usually remain below the peat surface.

**Figure 1** Swamps, fens and bogs differ from each other largely because of their water and nutrient sources. Fens and bogs tend to accumulate organic material in the form of peat because their higher, stable water tables and lower nutrient inputs provide the conditions under which dead plant material may be preserved. (Adapted from Campbell and Jackson, 2004.)

## 2.2 Peatland ecohydrology processes and feedbacks

There are three key interrelationships within peatlands: the relationships between vegetation, peat and water. In order for peat to form, plant material must be resistant to decay and it must accumulate in a saturated environment. The primary peat-forming conditions occur when the wetland water table is close to the surface and fluctuates only slightly, restricting decay without overly restricting the photosynthesis of peat-forming plants. There are a number of feedbacks that occur in peatlands that act to stabilise the water table regime. For example, in some peatlands the density, gas content, and elasticity of the peat enables it to shrink and expand in response to water table movement, a phenomenon referred to as peat surface oscillation (PSO). This property reduces the water table fluctuations relative to the peat surface because the peat surface follows the water table up and down. Fritz *et al.* (2008) devised a technique to measure PSO continuously and described the response of the peat surface to rainfall and water table fluctuations over the course of one year in a Waikato fen. The most responsive PSO sites occurred under *Empodisma robustum*. Under invasive willow, and at damaged or drained sites, PSO did not occur. *Empodisma* is thought to be New Zealand's keystone species, or "ecosystem engineer", responsible for bog formation (Hodges and Rapson, 2010).

The movement and storage of water in peatlands depends on the physical structure of peat. In undisturbed situations, the near-surface peat generally has large pore spaces and water moves relatively freely. As peat degrades the pore spaces reduce in size and hydraulic conductivity can reduce by 2–3 orders of magnitude. Particularly in bogs, a two-layer structure develops within the peat body (**Figure 1**). The upper, porous, layer of relatively young peat is termed the *acrotelm*, which may be 200–500 mm thick and is composed of living plant roots and buried plant material that is slowly decaying and becoming peat. The water table generally fluctuates within this zone, and most lateral water movement occurs here. Deeper, older and more highly decayed peat, which usually comprises the bulk of the mire, is termed the *catotelm*. Water movement is much slower, making the catotelm relatively hydrologically inert.

The importance of water table depth in setting the preconditions for important peatland ecohydrological processes has been demonstrated by many studies. In New Zealand, Clarkson *et al.* (2014) showed that plant material (leaves or culms and roots) decomposed slowest at sites with higher water tables, with decomposition rates decreasing exponentially as period of saturation increased, and that *Empodisma* roots decayed slower than other plant material.

## 2.3 Vegetation water use and feedbacks

Globally, deep peat deposits such as those found at Otakairangi and other northern New Zealand peatlands usually occur in cool, cloudy, moist climate zones. This is because the low nutrient bog environments within which peat accumulates most readily obtain their water input from rainfall (ombrotrophic), and to maintain a high water table year round requires seasonal rainfall totals to exceed evaporation rates most of the time. In the warm and windy climate of Northland, severe summer water deficits are common. McGlone (2009) pointed out the climatologically anomalous occurrence of northern New Zealand peatlands, and suggested that the conservative water use properties of *Empodisma* are likely to be a key factor in retaining water within the peat during drier months. Research by Campbell and Williamson (1997) and Thompson *et al.* (1999), on the summertime evaporation regimes of restiad bogs in the Waikato, demonstrated that *Empodisma robustum*-dominated bog vegetation communities have extremely low transpiration rates (**Figure 2**), and the dense standing litter layer of the *Empodisma* canopy acts as an effective mulch preventing drying of the peat surface. In bogs dominated by the taller, deeper-rooted restiad species *Sporadanthus ferrugineus*, including where shrub species such as *Epacris pauciflora* occur, evaporation rates are substantially higher than for *Empodisma* (Thompson *et al.*, 1999). These finding suggest that when a peatland ecosystem switches from *Empodisma*-dominated to shrub or tree-dominated (e.g. manuka), evaporation rates will increase and summertime water tables will likely decline. In contrast, if shrub and tree cover is replaced by *Empodisma*, water tables should recover. However, overall, the natural successional pathway for northern New Zealand peatlands like

Otakairangi is towards domination by the restiads *Empodisma* followed by *Sporadanthus ferrugineus* (Clarkson *et al.*, 2004).

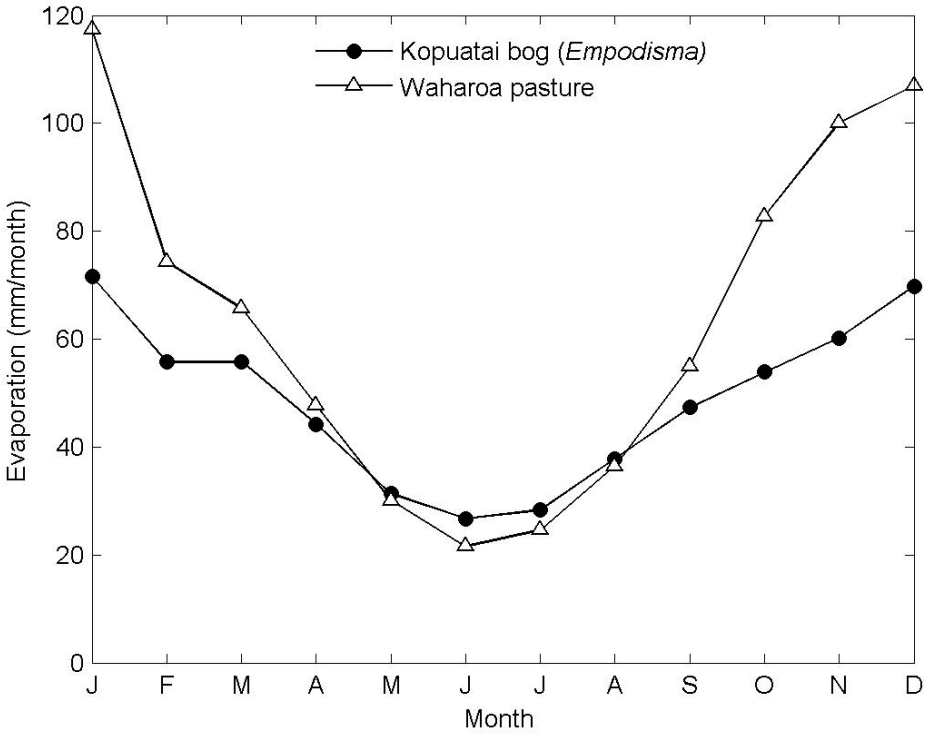



**Figure 2** Monthly total evaporation rates at Kopuatai bog (*Empodisma robustum*) compared to ryegrass/clover pasture. Data points are monthly averages across 2012–2015, derived from measurements made using the eddy covariance technique. Spring and summer evaporation rates were much lower at the bog site because of strong regulation of water loss by reduced plant transpiration and the physical mulching effect of the dense *Empodisma* canopy which is largely composed of standing dead litter. In winter, increased duration of wetting of the vegetation canopy by rain probably led to greater interception losses at the bog site, explaining higher evaporation rates from May to August. (Unpublished University of Waikato data.)

## 2.4 Peatland ecosystem services

There has been increasing recognition of the role that natural ecosystems play in human cultures and economies. Ecosystem services of peatlands can be grouped into (Clarkson *et al.*, 2013):

- provisioning services (e.g. food, fibre, clean water);
- regulating services (e.g. attenuating floods, carbon storage; water quality improvement);
- habitat services (refuges for wetland biota including habitat for birds, spawning areas for fish);
- cultural services (e.g. traditional values; bird watching).

New Zealand wetlands are important taonga to Maori as sources of food (birds, fish) and fibre (harakeke/flax).

At the catchment scale wetlands are important for their regulatory effect on water quality and quantity. Depending on the type of wetlands, their landscape position, size and internal hydrology they may either accelerate surface runoff during floods compared to similar areas of mineral soils, or

they may delay and attenuate flood peaks if they are linked to river systems and can act as overflow surface water storage areas.

At a global scale peat wetlands are important for their climate regulatory role. Over millennia peatlands have sequestered and stored enormous quantities of atmospheric carbon dioxide, which has had a net cooling effect on climate. In contrast, wetlands are the largest natural source of methane, a powerful but short-lived greenhouse gas. Over the long term, the climate-cooling effect of $CO_2$ sequestration overcomes the short-term warming effect of methane emissions (Joosten *et al.*, 2016). Recent research on the carbon balances and greenhouse gas exchanges of New Zealand peatlands has been summarised by Robertson *et al.* (2016).

## 2.5 Effects of drainage

Drainage of peatlands for agriculture requires closely spaced drains. Farm drains constructed adjacent to wetlands impact on wetland hydrological processes. This may be experienced as reductions in water table level and/or in the amount of water table fluctuation. Water table drawdown is greatest close to drains, and is usually only effective over a few tens of metres from the drains (Price *et al.*, 2016), although other studies have shown effects on peatland vegetation over much greater distances, e.g. 100–200 m (Landry and Rochefort, 2012).

Lowering water tables in peatlands or increasing the amount of water table fluctuation leads to increased aeration which results in accelerated peat degradation and peat surface subsidence (Pronger *et al.*, 2014). This may cause the hydraulic conductivity of near-surface peat to reduce by 2–3 orders of magnitude. Even by raising water tables, natural water table level fluctuations and subsurface water flows may not be able to re-establish until a significant layer of new, porous peat is able to accumulate, effectively creating a new acrotelm. This could take decades to centuries (Kotowski *et al.*, 2016).

Accelerated peat decomposition and mineralisation due to drainage or fire releases nutrients and other elements that had previously been locked up in plant material and peat. This may lead to wholesale ecosystem shifts, for example, dominance by shrubs and trees.

## 2.6 Peatland restoration

> *"Ecosystem restoration: the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed."*
> (Society for Ecological Restoration – http://www.ser.org/)

Ecosystem restoration takes place when environmental and ecological constraints, which prevent establishment and maintenance of natural process, are removed. Wetland-relevant examples include blocking drains to allow the water table and peat moisture regimes to recover, or removing trees and

shrubs to allow mosses and other natural ground covers to re-establish. For example, a focus of Waikato peatland restoration has been removal of willows by aerial herbicide spraying.

In peatlands degraded by drainage, the focus of initial restoration efforts is almost universally on rewetting by blocking drains and diverting water flows (Landry and Rochefort, 2012). Where natural peatland vegetation communities are already established, the chances of success are much more likely (Price *et al.*, 2016).

It is important to note, however, that when actively blocking drains and restoring wet conditions it may not be initially possible to restore a peatland to a desired state because of changed nutrient availability. Draining peat and burning lead to accelerated peat mineralisation and release of stored nutrients. Changes to groundwater and surface water inflow quantity and quality may also prevent a peatland from returning to its former state (Kotowski *et al.*, 2016). However, over time, the nutrient status of these peatlands should stabilise once the water table is restored, ensuring there are no other major sources of water with high contaminant loads.

## 2.7 Formulating restoration goals

It is not intended that this report be used as a restoration plan blueprint for Otakairangi wetland. Rather, it is an assessment of current condition based on limited data. The development of a full restoration plan should include a wide range of input from the community and relevant agencies. A useful starting point is the excellent *Wetland Restoration* handbook by Peters and Clarkson (2010), which includes chapters on restoration planning, hydrology, and monitoring, amongst other useful resources and case studies.

Active restoration such as hydrological manipulation requires careful planning within the context of restoration goal-setting. Formulation of restoration goals for Otakairangi is beyond the scope of this report, but examples could include the following:

- fully restore the ecosystem to the state it was prior to human intervention;
- restore significant areas of the remnant wetland, using techniques that minimise any adverse effects on adjacent landowners
- re-establishment of key functions and services such as active peat formation and a long-term carbon sink;
- establish self-sustaining populations of key wetland vegetation associations representative of a natural peatland;
- re-introduction of rare ecosystem components, including those that may have become locally extinct (plants like *Sporadanthus ferrugineus*; invertebrates and vertebrates).

A peatland may recover once sources of disturbance are removed or mitigated, although the timescale this occurs over can be highly variable. For example, ecosystems may follow a trajectory back to more natural vegetation communities many decades after fire (Clarkson, 1997). Also, peat degradation (due to drainage or vegetation change following burning) results in low hydraulic conductivity which may impede drainage and lead to higher water tables (Waddington *et al.*, 2015; Price *et al.*, 2016) and some amount of recovery.

Major restoration interventions such as drain blocking or water flow diversions should be delayed until there is clear evidence of need. This evidence should come from a sound information base and ongoing monitoring, for example monitoring of hydrology and vegetation combined with evidence for renewed peat accumulation. If a decision is then made to undertake active mitigation then this monitoring will have provided a valuable baseline against which to measure restoration success. However, if monitoring indicates that the wetland is on its own trajectory towards restoration then early monitoring will have removed the need for expensive mitigation and potential conflicts (Price *et al.*, 2016).

If the key sources of disturbances are not removed or mitigated (e.g. the main drain at Otakairangi) then the ecological impacts that these have caused are unlikely to be rectified and the ecosystem may remain in a degraded state.

# 3 Otakairangi Wetland physical setting and influences

## 3.1 Location and setting

The present-day Otakairangi Wetland (**Figure 3**) occupies ~2.6 $km^2$ (260 ha), around 20% of its former extent. There was once a continuous expanse of peatland filling the valley floors of the Otakairangi and Riponui streams, to the west of the Hikurangi Swamp. Much of the former extent of this large peatland has been reduced by artificial drainage and is now predominantly used for pastoral farming and supplemental cropping. The wetland lies within the boundary of the Hikurangi Swamp floodplain[2].

Otakairangi Stream drains a catchment of around 20 $km^2$ of hill country and valley bottom land at the point it enters Otakairangi Wetland. The present-day stream course traverses the wetland along a deep drain approximately 2 km long that bisects the wetland from northwest to southeast, separating it into two roughly equal halves (**Figure 3**).

The hydrological connection through the wetland created by the central drain is artificial. Based in assessment of historical aerial photographs, it is possible that Otakairangi Stream formerly entered

[2] http://www.wdc.govt.nz/WaterandWaste/Stormwater/Documents/Hikurangi-Swamp-Map.pdf

the wetland near its present-day location, with water then fanning out into the swamp and fen areas. This is supported by observations of layers of clay and silt sediments preserved in the central drain cutting, and these sediments are evident underneath shallower peat deposits eastward of the drain. These layers likely represent former floodplain deposits. An outflow of the wetland is likely to have occurred at the southeast, but with some of the large central zone being predominantly rain-fed and not always connected to surface flows. In times of extreme flooding much of the wetland may have been inundated, similar to the situation at some Lower Waikato Valley peatlands (e.g. Whangamarino and Opuatia).

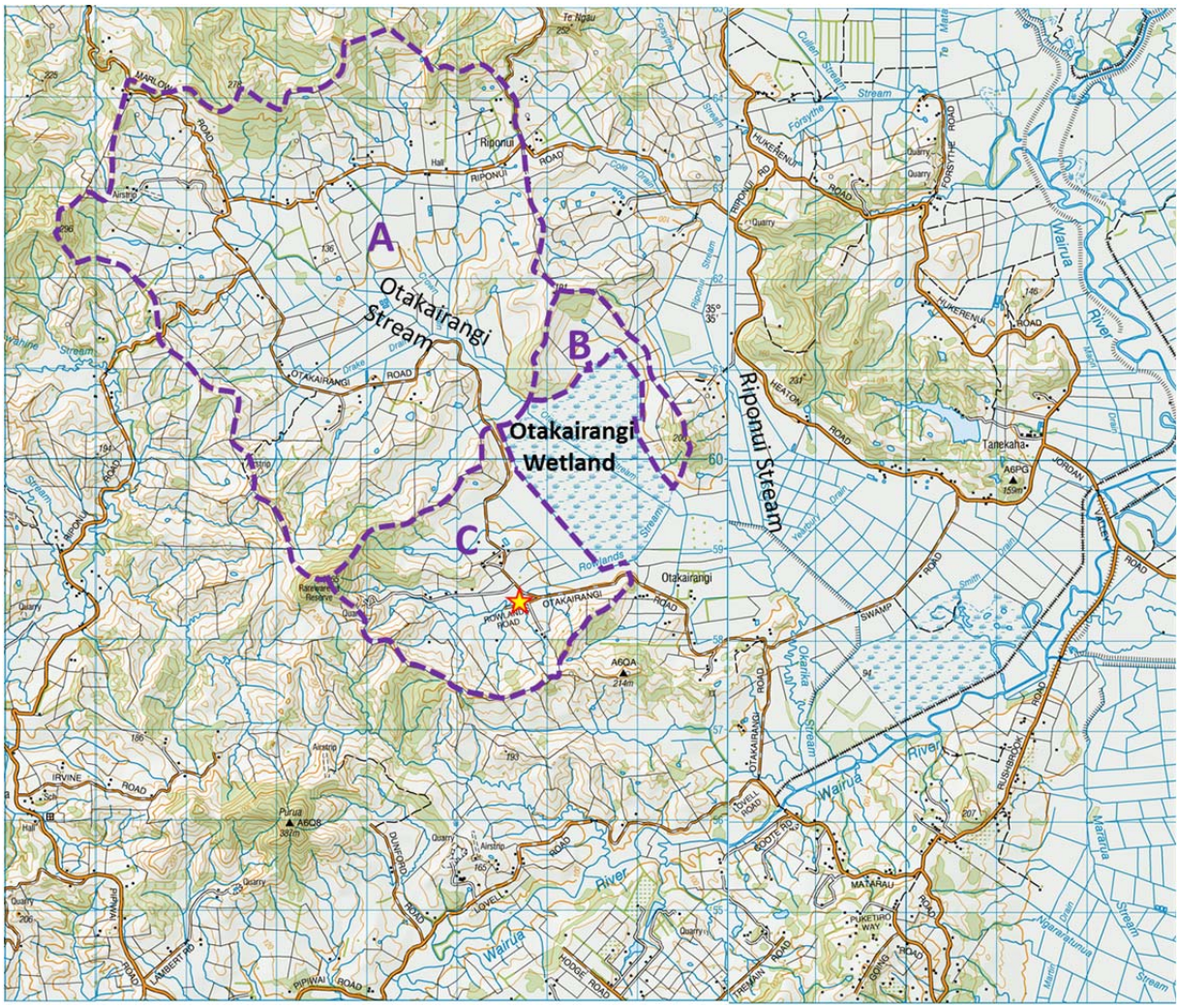



**Figure 3** Location map of Otakairangi Wetland with contributing surface water catchments delineated. A = Otakairangi Stream catchment as it enters the wetland's north western end; B = small hillslope catchment bordering north eastern side of wetland; C = Rowlands Stream catchment. Star symbol indicates position of NRC Rowlands Road rain gauge site. Base map parts of Topo50 series map sheets AW29, AW30 (LINZ).

In addition to the deep central drain, Otakairangi Wetland is now delineated by deep border drains around its south western, south eastern, and part of its north eastern margins. These drains intercept water flowing from adjacent hill country. In particular, the small Rowlands Stream catchment of ~5

km$^2$ to the southwest now discharge via drains around the southern end of the wetland but which would have formerly flowed into the wetland (**Figure 3**).

## 3.2 Climate and rainfall

Northland has a warm, humid, windy climate strongly affected by the proximity of the land to the relatively warm ocean. Summers are warm and winters mild, with only localised occurrence of ground frosts (Chappell, 2013). Mean annual temperature at Whangarei airport (1991-2016), 24 km from Otakairangi, is 15.9°C, with February being the warmest month (20.4°C) and July the coldest month (11.8°C).

Mean annual rainfall for the period 1990 – 2016, as recorded by the NRC rain gauge at Rowland Road, adjacent to Otakairangi wetland (**Figure 3**), was 1,287 mm/year. However, for this period annual rainfall varied between a minimum of 861 mm/year and maximum of 1,698 mm/year. **Figure 4** shows the pattern of monthly rainfall at Otakairangi. Mean monthly rainfall is lowest in February and November (75 and 66.4 mm/month respectively) and highest in July (175.5 mm/month). On a year-to-year basis monthly rainfall can be highly variable. While the lowest minimum monthly rainfall totals can be low at any time of year, the period from November to March are occasionally very dry. Coupled with high rates of potential evaporation over the summer, the shortage of rainfall can quickly lead to drought conditions causing depressed water tables in wetlands and increased fire risk. Highest maximum rainfall totals are more common in early winter. However, occasional intense rainfall totals can occur in summer caused by the passage of ex-tropical cyclones.

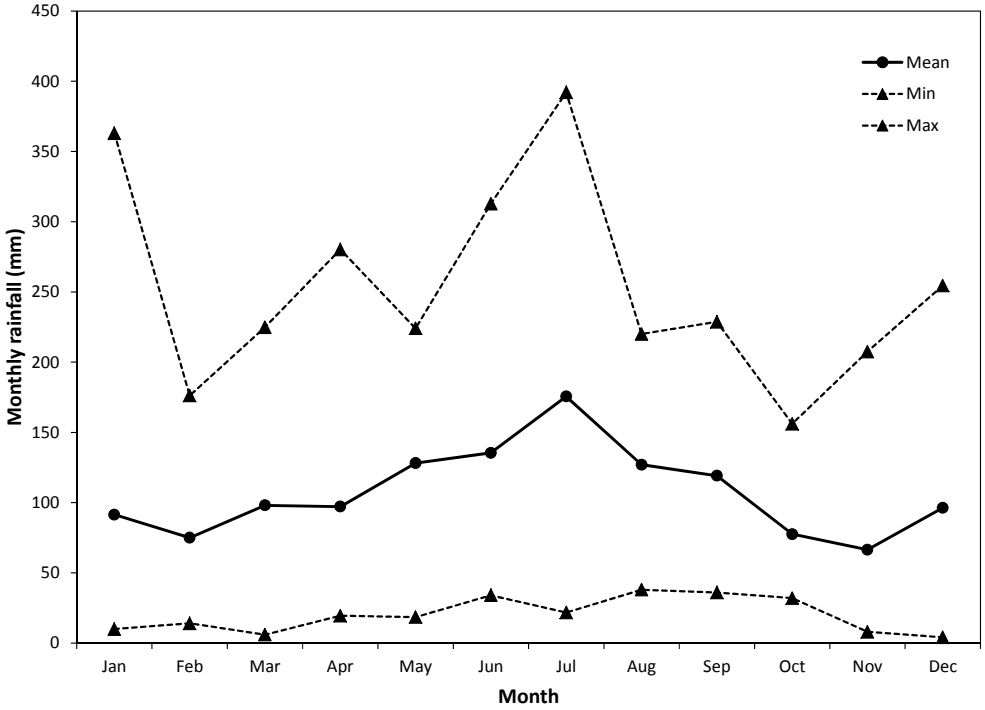



**Figure 4** Monthly rainfall statistics (1990–2016) from data collected by the Northland Regional Council at its rain gauge at Rowland Road, Otakairangi.

## 3.3 Physical hydrology

Because of its physical setting – straddling the floor of the Otakairangi Stream valley – the wetland would have always been affected by water, sediment and nutrient flows originating from the upper catchment, especially when the floodplain below the wetland was inundated by Wairua River flood waters. Unfortunately there are no flow records available for Otakairangi Stream, making it difficult to quantify the flow regime of the stream as it enters the wetland. However, drawing on flow statistics for the nearby Hikurangi River at the Moengawahine Bridge, 13 km to the southwest of Otakairangi, it is possible to calculate some approximate flow statistics for Otakairangi Stream (**Table 1**). The Hikurangi River has a predominantly forest-covered hill country catchment (comprising Moengawahine Stream and Kaikou River subcatchments) with an area of 189 $km^2$ but with farmed valley floors. It has a larger proportion of forest cover than the headwater hill country of Otakairangi Stream, meaning that estimated flows extrapolated to Otakairangi may be underestimated, because pasture country will generate larger discharges than forest. On the other hand, the generally higher hill country of the Hikurangi catchment would likely receive higher rainfall.

Based on simple catchment area-proportional adjustment of key flow statistics from the Hikurangi River, the mean and median flows of Otakairangi Stream are likely to be around 0.5 $m^3s^{-1}$ and 0.18 $m^3s^{-1}$ respectively, while the mean annual flood flow is estimated to be 24.5 $m^3s^{-1}$.

**Table 1** Catchment and flow statistics for the Hikurangi River at Moengawahine Bridge (NRC; Land Air Water Aotearoa), with estimated statistics for the Otakairangi Stream at the point it enters the wetland, based on the ratio of catchment areas.

| Catchment/location | Catchment area $km^2$ | Mean flow $m^3s^{-1}$ | Median flow $m^3s^{-1}$ | Mean annual flood flow $m^3s^{-1}$ |
|---|---|---|---|---|
| Hikurangi at Moengawahine | 189 | 5.06 | 1.73 | 234 |
| Otakairangi at wetland | 20 | 0.535 | 0.183 | 24.5 |

## 3.4 Developmental history of Otakairangi Wetland

Newnham (1992) described the developmental history of the Otakairangi peatland based on pollen records obtained from a peat core extracted at a location just south of the present conservation reserve. Prior to 30,000 years BP a lake occupied the site, with aquatic sediments present as a distinctive blue clay deposit underlying the peat. Above this layer are alternating clay-peat laminations, probably representing gradual infilling or drying out of the lake. From 29,000 BP, pollen from New Zealand's key peat forming plant, jointed wire rush (*Empodisma robustum*), as well as tangle fern (*Gleichenia dicarpa*), sedges and manuka (*Leptospermum scoparium*) were all present, indicating the development of fen-like conditions. From this time onwards, *Empodisma-Gleichenia*

plant communities alternated in dominance with *Leptospermum*. From around 21,500 BP the peat contained records of the earliest fires, preserved as charcoal. Fires may well have been the mechanism driving the alternating dominance of wire rush/fern versus manuka. Between 13,600 BP and 7,820 BP charcoal concentrations were at a maximum, and *Empodisma-Gleichenia* communities were dominant, suggesting that bog conditions had developed. This suggests doming of the peat surface above the influence of mineralised runoff from surrounding hills. Between 7,820–2,400 BP plant assemblages suggested a return to more swamp-like conditions, perhaps as stream courses changed. Peat layers younger than 2,400 BP lacked *Empodisma* (although this is present now), while *Gleichenia* and charcoal concentrations were high, suggestive of drier conditions (Newnham, 1992).

Fires, as evidenced by the presence of charcoals preserved in the peat column, have been a natural feature at Otakairangi (Newnham, 1992) as in other New Zealand wetlands, which were a foci of fires in pre-historic New Zealand (Perry *et al.*, 2014). Newnham *et al.* (1995) estimated fire frequency at Kopuatai bog in Hauraki to have ranged from as low as 1 in 1500 years to 1 in 100 years prior to human settlement, increasing to 1 in 78 years in the period since Maori settlement.

The role of fires in restiad peatlands in New Zealand has been researched. For instance, intense fires in peatlands causing peat mineralisation may lead to cyclic dominance of manuka over restiads (Newnham, 1992; McGlone, 2009). Manuka located in North Island wetlands has retained fire adaptations, such as serotiny, which is the release of seeds in response to fire, an adaption which has been lost, or reduced, in manuka found elsewhere in New Zealand (Perry *et al.*, 2014). *Empodisma* tends to recover faster than *Sporadanthus* following fire (Clarkson, 1997) but it is possible that both may be shaded out by post-fire dense shrub covers.

## 3.5 What type of wetland was Otakairangi 100 years ago?

The types of wetlands previously occurring across the former Hikurangi "Swamp" floodplain were described by Clarkson *et al.* (2015), who noted that only 3.5% of the former wetland extent is still in existence today. Davoren (1978) surveyed and mapped peat depths across several peatland areas within the Hikurangi floodplain, including at Otakairangi.

Prior to major land use change and drain digging to improve drainage for agriculture, Otakairangi would most likely have been a mosaic of wetland types. One of the major influences on the wetland at this time would have been the course of the Otakairangi Stream as it flowed into the wetland, and its flooding regime. This stream drains a catchment of approximately 20 $km^2$ of what would once have been forested hills and low-lying wetlands filling the floor of the basin upstream of the present-day wetland (**Figure 3**). Most of the catchment is now farmland, consisting of steeper hill country used for grazing, rolling foothills and flatter valley-bottom land now used for intensive dairy farming and cropping. Only small remnants of original or regenerating native forest still exist.

Otakairangi Stream has probably occupied its present course where it enters the wetland for a long time. Its exact path through the wetland remains uncertain. There was an area of "lagoons" at the base of the now-regenerating bush-clad hill at the top end of the reserve, which may have been part of the original stream course (Pers. Comm. Greg Lovell). These are clearly visible on the 1966 aerial photograph. The original stream may have followed a number of diffuse paths through the wetland, which changed depending on stream flow, and depositing silt and clay in the wetland. This is evidenced by layers of silty material at various depths in the peat (Pers. Comm. Scott Bartlam, Landcare Research), and in-situ along the sidewalls of the present-day central drain. During times of flood, restricted water flows through the wetland vegetation would have led to inundation across large areas of the wetland, exacerbated by the backing up of floodwaters from the Wairua River itself.

Swamp vegetation consisting of flax, sedges, and kahikatea would have occupied areas along the old stream course and in over-bank areas frequently inundated by flooding. Farther away from the flooding influence of the stream, some parts of the wetland would have received most of their water supply from rainfall, causing gradients in nutrient supply affecting vegetation patterns and peat formation.

Another influence on water quantity and quality entering the wetland would have been small streams, overland flows and groundwater seepages at the base of the hills surrounding the wetland. To the north east, an embayment in the wetland was probably a classic fen, with fringes of more mineralised wetland containing flax and kahikatea.

Much of the wetland distant from the influence of Otakairangi Stream was probably fen-like, with raised bog areas dominated by *Empodisma* and *Sporadanthus*, where surface doming led to isolation from floodwaters and hillslope seepage.

## 3.6 Land use history and impacts

Drainage and flood control activities in the low-lying parts of the upper Wairua river catchment (the Hikurangi Swamp) have a long and somewhat chequered history. Early engineering works starting from 1919 focused on lowering the Wairua River channel at Mangere rapids at the downstream end of the Hikurangi Swamp basin, with subsequent diversion, lowering and widening of river channels farther upstream, and the construction of farm drains. With a lack of coordinated maintenance, much of the early flood control work fell into disrepair and by 1953 the flooding problem was similar to that in the period prior to 1919. Repairs were carried out between 1953 and 1962, then major construction works that led to the present-day system of pump drainage compartments, stop banks and control gates commenced from the late 1960's (Moores, 1968).

In the Otakairangi valley, early drainage works included the construction of the central drain sometime around the 1920's or 1930's. Northern Advocate articles from 1920 record some of the

efforts local landowners were undertaking to drain their "swamp" land (**Figure 5**). A dragline operated during the 1960's to deepen the central drain (Pers. Comm. Bill Lovell).

## OTAKAIRANGI

### CAPITAL AND ENERGY

While spending the best part of a day in the upper portion of the Otakairangi district with its outlet via Jordan and Hikurangi to Whangarei "your own" felt convinced that the possibilities of this district were distinctly bright. Some real good land is found here requiring a considerable amount of energy and capital expenditure to bring it up to anything like its possible standard of production. On the fringe of the swamp, where drainage on a small scale has been undertaken, sufficient evidence is at hand to indicate the great possibilities awaiting the progressive settler, who will devote the necessary attention to thoroughly bring this low-lying land under cultivation in place of allowing it to be a wilderness of ti-tree and rushes, etc. It is pleasing to note that the settlers are awakening to a more systematic style of farming their land judging by the various improvements under way on the different holdings, which tend to show that they are moving, possibly as far as general circumstances will permit. Cheap money is necessary to undertake the desired improvements and with labour a scarce and dear commodity it undoubtedly is much easier to suggest than to put into practice.

Northern Advocate, 20 January 1920

https://paperspast.natlib.govt.nz/newspapers/NA19200120.2.23

## RIPONUI

### SWAMP DRAINAGE.

Mr H. King has for some little time had a gang of Maoris engaged in drainage work affecting some two hundred acres of swamp land.. About a mile of deepening the old drains has been completed and a mile of new drains is under way, ranging from 5ft to 8ft wide and four feet deep, with a good fall for the water.

Mr King intends burning 100 acres off shortly with the intention of sowing down in grass. He has also had some fifty acres of tea tree felled and next season will possibly see this farm carrying milch cows.

Northern Advocate, 23 September 1920

https://paperspast.natlib.govt.nz/newspapers/NA19200923.2.3.2

**Figure 5** Newspaper articles from the Northern Advocate in 1920 reporting on swamp drainage activities by Otakairangi and Riponui landowners.

With the channelising and straightening of the Otakairangi Stream course leading to improved flows and lowered water tables, former areas of peat wetland and adjacent swamps were broken in, with farm drain networks established and progressively deepened. Aerial photographs show that by 1959 the line of the central drain was poorly defined. Most pasture and fence lines were limited to the elevated land to the west of the present-day wetland, and the wetland occupying the valley floor downstream was still undeveloped. By 1966, the wetland's central drain had been improved and was clearly defined in its present position. Between 1966 and 1979, land was developed for farming

upstream and downstream of the wetland, and a 240–320 m wide marginal strip on the western side of the wetland was in the process of being drained and converted to hump and hollow fields, largely completed by the mid-2000's.

According to neighbouring landowners, for much of the period of development through the 20th century, a dense cover of manuka dominated the wetland and fires occurred frequently, probably because of scrub burning on adjacent farmland. A 1966 aerial photograph indicates very patchy vegetation textures, possibly the result of partial burns.

By 2003, the wetland remnant was of approximately its present-day size. Deep border drains (**Figure 6**) have caused peat shrinkage and the development of relatively steep slopes along the peatland edge adjacent to the drains.

**Figure 6** Deep border drain at the south western corner of Otakairangi wetland. Fields contoured to hump-and-hollow to the left were planted in maize in December 2016, with seasonal adventives at the wetland edge, harakeke, manuka and tree ferns higher up on the steeply domed wetland margin.

**Figure 7** Drained peatland growing maize alongside Riponui Road, near the intersection with Heaton Road. The recently excavated drain shows a cross-section through peat, with a clay mound further along the drain forming the substrate under the low hill. This peatland was once continuous with Otakairangi.

# 4 Site survey activities and methods

## 4.1 Field visit schedule

The site visit and discussions with landowners and other stakeholders took place during 5–8 December 2016. A brief timeline of the week was:

5 December

- Accompanied Ben Herbert (DOC/LW) to Whangarei District Council offices and met with staff who provided an overview of the Hikurangi Swamp flood control scheme and WDC responsibilities for drain maintenance, and who described the ongoing issues with peat shrinkage. Provided maps and copies of 1968 NCC reports for historical context.
- Familiarisation tour with Ben Herbert around Hikurangi floodplain control works and overview of Otakairangi Wetland.

6 December

- Met with some of the landowners with land adjacent to Otakairangi Wetland, who were able to provide perspectives on historical and hydrological changes as they have affected the wetland and farming alongside it, including present-day issues.

- Visited the north eastern portion of the wetland for a short recce on foot.
- Located the route established earlier that day by Scott Bartlam (Landcare Research), and carried out vegetation and peat inspection on the transect to the east of the central drain. Mapped the water table depth with distance from the drain.

7 December

- Accompanied Scott Bartlam and Ben Herbert to extend the eastern-Otakairangi survey into the north eastern portion.

8 December

- Walked the farm drains around the southern and south western edges of the wetland, to inspect the outlet of the central drain.
- Carried out vegetation and peat inspection along a transect to the west of the central drain, and mapped the water table depth with distance from the drain.

## 4.2 Methods

*Peat physical properties*

A small number of near-surface peat cores were extracted for quantitative and qualitative analysis. A sharpened, cylindrical stainless steel corer was used to cut peat samples of known volume for bulk density and volumetric moisture content analysis. Cores were stored in zip lock bags and refrigerated. Cores were subsequently weighed, dried at 105°C for two days then reweighed. Dry bulk density and volumetric moisture content were calculated.

A 100 mm diameter by 300 mm long PVC corer was used to extract longer peat cores for inspection and photography. These samples were replaced where they came from.

The von Post humification scale was used to assess the degree of peat decomposition. For this, a small sample of peat was obtained and squeezed by hand. The von Post "H-score" was determined by observing the colour of water or peat material squeezed out, residue texture, and visual evidence of plant remains. The von Post scale ranges from H1 (completely undecomposed peat, yields clear water) to H10 (completely decomposed, entire peat mass oozes through fingers when squeezed).

*Water table survey*

Water table depth was measured at sites spaced out along two transects, east and west of the central drain, approximately midway along the drain (**Figure 8**). To measure water table depth a PVC dipwell, slotted along its length, was pushed into the peat until 100 mm remained above the surface. After 2–5 minutes a "bubbler", consisting of a plastic tube and tape measure attached to a narrow garden stake, was inserted into the dipwell, while blowing air gently through the plastic tube. When

bubbling was first heard, the depth was recorded. Measurements were repeated several times to ensure the water level in the tube had stabilised. Following the measurement, the dipwell tube was extracted.

**Figure 8** Location of the water table transects and sampling sites. OTW = Otakairangi West transect, OTE = Otakairangi East transect. Image: Google Earth.

# 5 Landowner perspectives

## 5.1 Changes observed in the wetland

In the absence of documented evidence of changes in the wetland's hydrology and vegetation, the memories of landowners fill some knowledge gaps. Prior to the 1960's there were frequent fires across the wetland, but these have not occurred in recent decades. Many of these fires would have been associated with drainage and land clearance, as described by the 23 September 1920 Northern Advocate extract in **Figure 5**. Tall and dense manuka has been the predominant vegetation cover throughout living memory, but it was noted how the manuka cover had been opening up over recent years.

## 5.2 Flooding

While generally positive about the concept of restoring Otakairangi Wetland, farmers were also concerned about flooding and the ongoing efficiency of drainage on their farms. Farmland upstream of the wetland is prone to multiple days of surface inundation during floods in most years, leading to pasture damage. There is a feeling that the duration of inundation has increased in recent years and questions were raised about how well the wetland central drain is maintained. Peat shrinkage in

farmland will exacerbate the inundation problem and the situation will continue to worsen until the peat has completely oxidised. (Typical ongoing rates of peat shrinkage in the Waikato range from 19–26 mm per year (Pronger *et al.*, 2014).) Depending on the depth of peat remaining, this low-lying farmland may eventually become unproductive.

On the western side of Otakairangi wetland, slow drainage of water away from low-lying paddocks is a common problem. To counter this drainage limitation narrow hump-and-hollow fields have been formed, some of which were growing maize in December 2016 (**Figure 6**).

# 6 Assessment of condition of Otakairangi Wetland

## 6.1 Vegetation

*(These notes are informal observations only, not the result of a rigorous vegetation survey.)*

Otakairangi wetland contains native vegetation representative of the spectrum of wetland types from swamp to bog. The wedge of land at the north western end of the central drain had a dense cover of seasonal adventive weeds dominated by *Glyceria maxima* at the time of the field visit in December 2016. Limited inspection of the margins suggested some gorse, blackberry, privet, bracken, tree ferns, and the invasive wetland weed royal fern (*Osmunda regalis*). Grey willow, a serious wetland weed species in the Waikato, was not observed, neither is it a common wetland weed in Northland (Pers. Comm. Bev Clarkson).

The closest inspections of vegetation were along the east and west transects shown in **Figure 8**, as well as the area to the north of the eastern transect.

The eastern and western parts of the wetland appear to be at different stages along a trajectory towards recovery of wetland vegetation communities. In the east, close to the central drain, is a narrow zone containing tall harakeke (*Phormium tenax*), bindweed, *Coprosma tenuicaulis*, and *Blechnum* fern. Tangle fern (*Gleichenia dicarpa*) forms a dense ground cover in this zone.

With increasing distance from the drain harakeke reduces in size and become widely separated. Within the first 50 m from the drain, *Empodisma robustum* density increases from a few straggly individuals to a dense ground cover in association with *Gleichenia* and the sedges *Machaerina* spp. and *Schoenus brevifolius*. Frequent standing dead manuka are evident (**Figure 9**).

Extensive areas of *Empodisma* up to 1.5 m high have accumulated a dense canopy litter of dead stem material, with cluster roots evident at the peat surface, but not as tightly clustered as commonly seen at the wetter Kopuatai bog in the Hauraki, for instance. A single sun orchid (*Thelymitra* sp.) individual was encountered. Wetter zones were also common, with vegetation consisting of *Gleichenia* and dense sedges growing in the absence of *Empodisma*.

**Figure 9** Typical view of open *Empodisma/Gleichenia* vegetation near the eastern end of the eastern transect. Standing dead manuka are evident, with occasional harakeke, sedges *Machaerina* spp. and *Schoenus brevifolius*.

On the western side of the drain, beyond a zone of tall harakeke and manuka, was an extensive area of open *Gleichenia* with sedges interspersed with manuka and occasional harakeke and *Coprosma* (**Figure 10**).

A single patch of *Empodisma robustum* was encountered along the western transect, approximately 150 m from the central drain. This appeared to be expanding radially into surrounding *Gleichenia*.

**Figure 12** indicates the main areas of *Empodisma* cover at Otakairangi in 2016, with extensive areas to the east, and only scattered patches in the west, perhaps indicating that they originated as individual “pioneer” plants.

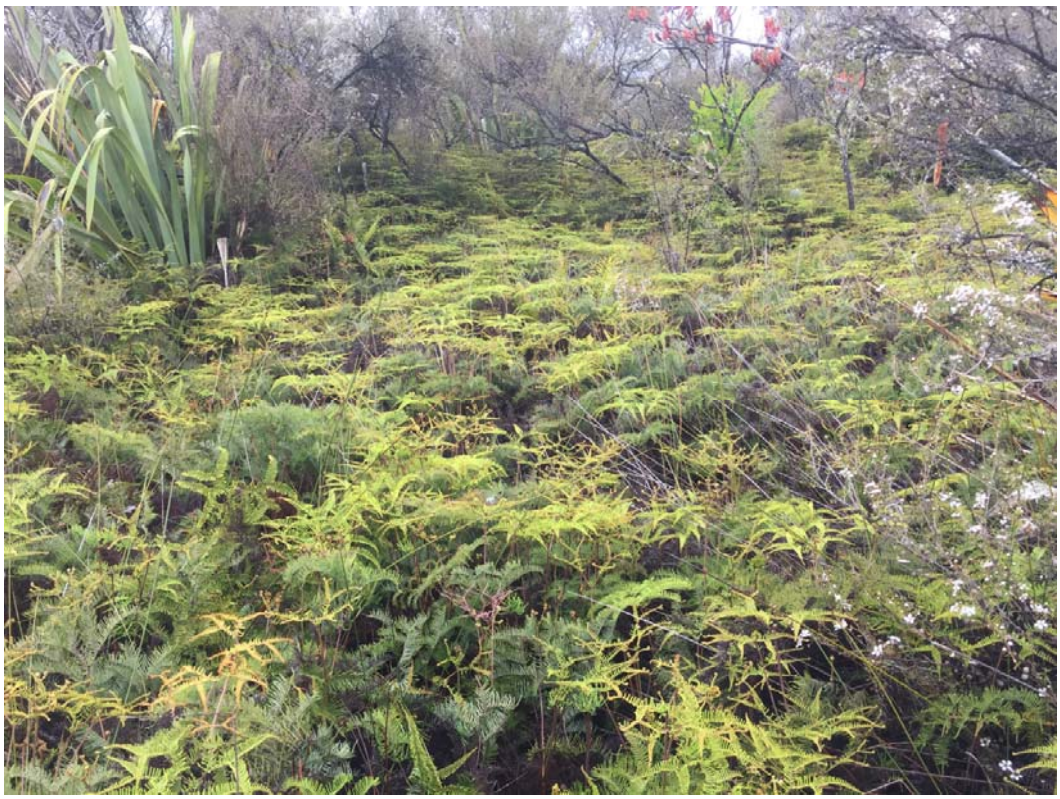


**Figure 10** Typical dense cover of *Gleichenia dicarpa* with sedges, harakeke, *Coprosma tenuicaulis* and manuka, near the western end of the OTW transect. A single tall royal fern (*Osmunda regalis*) individual is visible in the distance.

**Figure 11** Edge of the patch of *Empodisma robustum* encountered at site OTW 4. This appeared to be spreading into surrounding *Gleichenia* and had accumulated around 200 mm thickness of new "proto-peat" (**Figure 18**).

**Figure 12** Composite aerial photography map of Otakairangi Wetland compiled from drone images in 2016. Dotted yellow lines encircle zones of evident *Empodisma robustum* expansion. Credits: Imagery - FlightWorks Ltd.; GIS image - Landcare Research;

## 6.2 Peat condition

The peat substrate observed within Otakairangi broadly fell into two types – degraded and newly accumulating peat. Firstly, the peat under the extensive *Gleichenia/*sedge cover and flax/manuka predominating along the western transect but also present in the east was highly degraded, with von Post index around H7-H8 for the peat matrix, but with a dense network of living fern rhizomes (**Figure 18**, right panel). The matrix represents the state of the old peat, most likely burnt over several times and then decomposing for many decades under dense manuka before the present *Gleichenia* cover began to dominate. The water table was close to the peat surface in these areas (see Section 0). The dry bulk density (DBD) of a representative sample of this peat was 133 kg $m^{-3}$ and volumetric moisture content (VMC) was 77%.

In the eastern part of the wetland, and within expanding patches of *Empodisma* in the west, new peat raw material is currently accumulating to depths of up to 300 mm on top of the older, degraded peat (**Figure 13**, **Figure 18** left). Von Post H-scores ranged from H2-H4 for this material but with inclusions of more highly degraded material (**Figure 13**). This new peat had lower density (DBD ranging from 50–67 kg $m^{-3}$) and was drier (VMC 24%–47%). Compared to the large and relatively intact Kopuatai bog in the Hauraki Plains, the recent Otakairangi peat has a similar density but is much drier, probably because peat development has not progressed for long enough or over a wide enough area to develop the full range of restiad peat pore sizes and to be able to sustain a raised water table. This might take many more decades to develop.

Peat condition around the margins of the wetland was not assessed in the limited time available. Also, nutrient analyses have not been undertaken as part of this assessment. However, peat samples were collected for this purpose by Landcare Research colleagues.

**Figure 13** Section and core of *Empodisma* root mat "proto-peat" at site OTE 4. Pale coloured patches are *Empodisma* roots, with white living cluster roots visible at top of the larger section. Darker zones are comprised of more highly degraded material.

## 6.3 Central drain observations

The central drain was walked for almost half its northern length within the wetland. Observations showed that the drain has eroded its base since it was last mechanically cleared because buried logs are presently suspended up to 0.5 m above the drain bed (e.g. **Figure 14**). It is likely that this erosion has been caused by progressive drain deepening in farmland downstream of the wetland and "nick point" erosion subsequently progressing upstream.

The main drain was inspected at the point it exits the southern end of the wetland (**Figure 15**). At this location it has been excavated into clay sediments and two deep border drains feed in from the east and west.

According to WDC, the central drain has not had any maintenance for several years, but has been sprayed for weed control during the present summer. The drain was last mechanically "cleaned" with an excavator around 15 years ago.

**Figure 14** View south along the Otakairangi central drain (Otakairangi Stream) close to the OTW and OTE transects (**Figure 8**), showing an ancient log suspended above the present base of the drain.

**Figure 15** View northward along the central drain where it exits the south eastern end of Otakairangi wetland. At this point the drain is excavated in clay sediments.

## 6.4 Water table variation within the wetland

The water table survey along transects into the wetland east and west of the main drain (see **Figure 8** for locations) took place on 6 and 8 December as a *point in time survey* with the results shown in **Figure 16**. It was expected that the water table would be deep close to the central drain and shallower with increasing distance away. Repeat measurements were made at some locations on 8 March 2017 by Scott Bartlam (LCR).

Water table depth below the surface was variable along the eastern transect and, in contrast, very consistently shallow along the western transect. The only evidence of a deep water table close to the drain was found at the eastern site 7.5 m from the drain, where the water table was 1,100 mm below the surface. At the site 45 m east of the drain a 500 mm deep water table was recorded in December, although this may have been an anomaly caused by a clogged dipwell since the water table at the same site was much shallower in March 2017. The closest site to the drain on the western transect was 45 m away, and water table depth there was not noticeably lower than at other points further west of the drain.

The re-survey of water table depths carried out in March 2017, prior to a major storm cycle, may well represent the lowest water tables of that summer. A similar, but slightly deeper pattern of water tables was evident.

Water table depth below the surface appeared to be explained by the dominant vegetation type at each site. In the east, shallow water tables 100–120 mm from the surface were only found in areas dominated by *Gleichenia* and *Machaerina*, while in the west there was a very uniform and dense cover of *Gleichenia* above consistently shallow water tables. The eastern transect passed through many areas of dense *Empodisma* cover, and these had more variable water table depth, averaging 315 mm. In the west, the only patch of *Empodisma* traversed, 146 m from the drain, was 5–8 m in diameter and the water table was markedly deeper (260 mm) than at an adjacent *Gleichenia* site less than 5 m away (100 mm depth).

**Figure 17** illustrates why the water table is deeper below the peat surface under *Empodisma* "mounds" compared to neighbouring *Gleichenia*-dominated areas, with the young peat material accumulating under *Empodisma* raising the peat surface further above the horizontal water table. *Empodisma* prefers sites where the water table remains permanently below the surface (Fritz *et al.*, 2008). In a restoration experiment at the cut-over Torehape peatland (Hauraki Plains) Schipper *et al.* (2002) demonstrated that restiad vegetation recovered faster on artificially raised mounds of peat. It appears that, at Otakairangi, *Empodisma* creates its own mounds in order to establish the hydrological conditions it prefers. **Figure 18** shows an example of the distinctive fibrous young peat accumulating at these sites, overlying older, highly degraded peat. Under adjacent *Gleichenia*-

dominated sites the surface peat was highly degraded. At site OTW 4 *Empodisma* appeared to be invading into *Gleichenia* (**Figure 11**), and a dome of young peat composed of *Empodisma* root material had formed up to 200 mm thick. At this site the water table was 260 mm below the surface under *Empodisma* and 100 mm deep under neighbouring *Gleichenia*. Over such short distances the water table is horizontal, so the differential water table depths shown in **Figure 16** are largely caused by surface doming under the *Empodisma*, which has created its own micro "raised bogs".

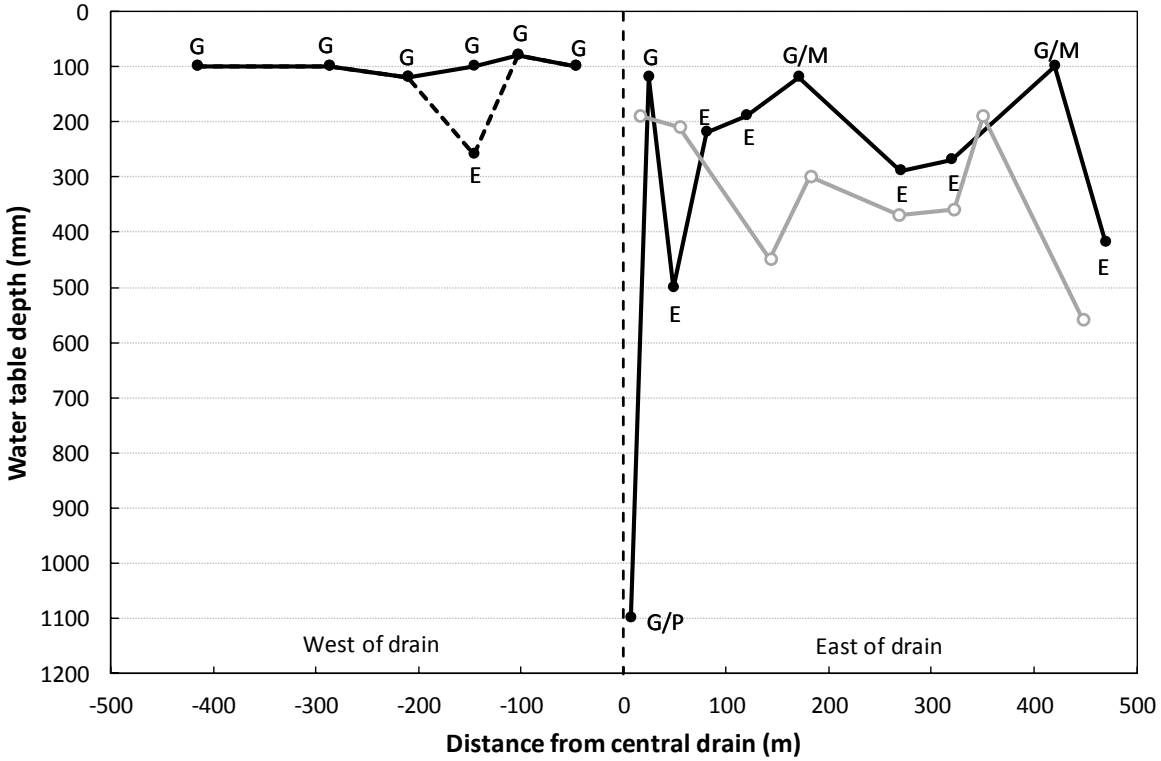



**Figure 16** Water table depth below the peat surface along the east and west transects at Otakairangi peatland, 6 and 8 December 2016 (black points and lines) and 8 March 2017 (grey). Letters indicate dominant vegetation type: E = *Empodisma robustum*; G = *Gleichenia dicarpa*; M = *Machaerina* spp.; P = *Phormium tenax*. At the site 146 m west of the drain, adjacent *Gleichenia* and *Empodisma* communities had different water table depths.

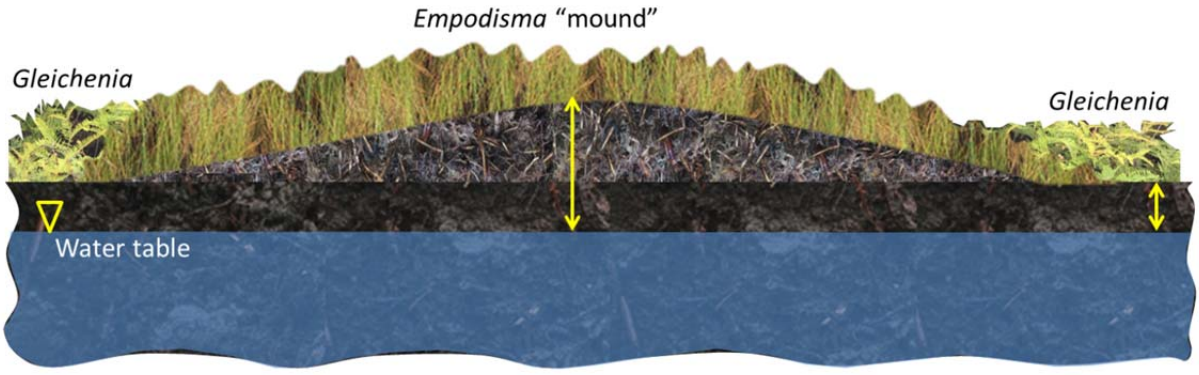



**Figure 17** Conceptual diagram of recent *Empodisma robustum* peat growth forming a mound of new "proto-peat" over the top of degraded peat, resulting in greater water table depth (yellow arrows) underneath *Empodisma* compared to neighbouring *Gleichenia* which is not contributing to peat growth. This sketch is modelled on observations made at site OTW 4, with peat cores shown in **Figure 18**.

**Figure 18** Left - peat core extracted at site OTW 4, 146 m west of the central drain, from near the centre of a small patch of *Empodisma robustum.* Very fibrous material consisting of *Empodisma* rhizomes and cluster roots (white patches) formed a layer 200 mm thick over the top of highly degraded peat containing *Gleichenia* rhizomes. Right – peat core extracted at the *Gleichenia*-dominated site at OTW 1. Peat matrix was highly degraded but interwoven with a dense network of fern rhizomes.

## 6.5 Ecohydrology

With such a short visit to Otakairangi it was not feasible to carry out a full assessment of all of the influences on the ecohydrology at Otakairangi under present-day conditions. The water table patterns, along with observations about flows along the drains, could only be made at point-in-time. Never the less, some observations and opinions are recorded here.

In early December 2016 water tables were generally close to the peat surface, roughly within the range of depths found in more intact bogs and fens. The central drain did not seem to be drawing down the water table to any great distance into the wetland on either side.

A major unknown at present is the extent and duration of inundation of the wetland during the severe flooding conditions that were described by landowners. Floodwaters backing up into the wetland will transport mineral sediment and nutrients into sensitive ecosystems that are on a pathway to recovering more ombrotrophic (rain fed) characteristics. Similarly, seasonal inundation of the wetland margins is likely around the north eastern side adjacent to pasture hillslopes, especially where drains are absent.

A full assessment of seasonal and annual variations in the water table at key locations in the wetland is needed, along with a full understanding of the effect of seasonal flows and extremes of water levels in the central drain.

Aside from potential inundation by floodwater, it is likely that the two halves of Otakairangi Wetland have been able to continue natural succession to some degree and develop some bog-like characteristics, with increasing reliance on rainfall for water and nutrient supply. The areas of *Empodisma* are accumulating new peat mounds which will function to hold the peat surface up above the surrounding wetland water table, providing the "dry feet" conditions preferred by this ecosystem engineer (Fritz *et al.*, 2008) and perhaps giving it a competitive advantage. Peatlands dominated by *Empodisma robustum* are known to have drastically reduced evaporation compared to other peatland vegetation (Campbell and Williamson, 1997; Thompson *et al.*, 1999) and pasture (**Figure 2**), which will contribute to the wetland retaining more water, and eventually to a higher water table as a more continuous and natural peat layer develops over the older degraded peat.

# 7 Discussion

## 7.1 Ecological pathway of degradation and possible recovery

There are no known records of the condition and composition of Otakairangi Wetland's historical vegetation dating back to a time prior to the earliest drainage activities. Even before drain digging commenced in earnest the ecosystem may have been disturbed by fires originating from the clearance of hill country for early farming, and also by infrequent natural fires.

Fire is always a dominant agent of wetland disturbance and increased fire frequency (due to human arrival) is likely to have contributed to degradation of wetland condition at Otakairangi, and this may have been repeated again and again throughout the first half of the 20$^{th}$ century. Fire-adapted manuka would have recovered quickly each time, and shaded out ground cover species. Underneath the dense manuka cover the peat degraded because of the absence of fire-sensitive peat-forming species, and possibly because of a deep water table caused by the higher evaporation rates (transpiration and interception loss) from the dense manuka. *Gleichenia* fern seems to be reasonably well adapted to shady conditions underneath tall manuka, so it has probably been a dominant ground cover. As the peat degraded, its hydraulic conductivity declined to the extent that water would have perched near the surface for large parts of the year. This may have been a stress factor contributing to the eventual collapse of the manuka across much of the wetland.

Accompanying the thinning and collapse of the manuka canopy came the opportunity for *Empodisma* to invade and expand. Though all the decades of fire and drainage, there must have been remnant populations of key peatland plants including *Empodisma robustum*. This was probably in the eastern

part of the wetland where it has now recovered over the largest area, whereas it has only recently started to spread into the western side (**Figure 12**).

Where *Empodisma* has established, a new surface layer of proto-peat has accumulated, up to 300–400 mm thick. This lies directly on top of older, highly degraded peat. Although this is an encouraging sign, there is some way still to go along the trajectory towards a healthy/functioning peatland ecosystem. The samples of recent peat material collected during fieldwork had relatively low moisture contents, and the water table was always below this zone. Until *Empodisma* covers large enough areas and its peat consolidates sufficiently to develop a full range of natural peat pore sizes, the hydrology will remain under the control of the degraded peat beneath.

## 7.2 Future risks to Otakairangi

The major risks to ecosystem recovery at Otakairangi Wetland may be grouped into fire, flooding, drainage work, pest plants and animals, and climate.

*Fire*

Fire has been an important agent of change at Otakairangi and has contributed to peat degradation. New Zealand peatland vegetation is fire-prone and the risk of future fires can never be eliminated, particularly under seasonally dry conditions. Resetting of successional pathways by infrequent natural fires is a part of natural peatland developmental processes. The major risk in future would be that very large and intense fires could burn recently accumulated peat and destroy seed sources across large areas of the wetland, resetting the restoration trajectory back many decades. Careful management of fires on neighbouring privately owned land is essential, particularly where areas of scrub and gorse adjoin the wetland.

*Flooding (and associated transport of nutrients/sediment)*

Inundation of sensitive low nutrient parts of the wetland by floodwaters derived from intensively farmed land brings sediments and nutrients into the wetland. Very infrequent flood events may not have such a serious impact, but if this inundation is an annual or more frequent occurrence then the impacts will be cumulative. Retirement of steep hill country, fencing of waterways and riparian planting, restoration of headwater wetlands, and sensitive nutrient and effluent management – all of which practices should be happening anyway – will improve the situation and also relieve flooding pressure on low-lying farmland. Identifying the natural or human-induced flood ponding zones within the wetland will also help to determine the spatial extent of future risks to the wetland.

*Drainage works*

Conflicts exist between agricultural land use and wetland ecosystem requirements. Drains have been established around the margins of Otakairangi Wetland in order to enable efficient water runoff

during wet periods and to maintain deeper water tables in farmland to improve pasture and crop growth, which has also led to soil development capable of supporting heavy animals and farm machinery. Farmed peat soils may have shrunk by up to several metres and will continue shrinking by 2–3 cm/year until remaining peat is fully oxidised. This shrinkage process inevitably leads to a renewed cycle of drain deepening encouraging accelerated shrinkage. Over time, the wetland surface becomes ever more elevated relative to surrounding farmland. This results in steep wetland marginal slopes (**Figure 6**) and fosters deeper water tables within the wetland, which encourages peat degradation, ecological shifts favouring weed species, and increased fire risk.

The construction of the deep central drain at Otakairangi undoubtedly would have led to deepened water tables through the heart of the wetland and played a role in ecological shift favouring manuka, which appears to have dominated the wetland's vegetation for much of the past century. As the peat degraded and held up water tables, it appears likely that the lateral effect of the drain may have been somewhat reduced. However, WDC is under pressure from upstream farmers to clear this drain to alleviate perceived flow restriction. Any deepening, from mechanical digging or erosion, will likely lead to a renewed cycle of water table lowering in adjacent parts of the wetland.

Drain deepening through farmland south of the wetland is a likely cause of the drain bed erosion observed within the wetland. While the central drain clearly has to manage extremely large discharges of floodwater, it should be managed in such a way as to maintain dry season water tables as high as possible. Surveying of current invert levels (drain base) should be undertaken and, ideally, installation of minimum invert level controls be investigated.

*Weeds and feral animals*

Drains are vectors for weed invasion. The central drain passes through the most sensitive parts of the wetland so weed control programmes need to be maintained. Inundation of floodwater into the wetland also provides a vector for weed invasion, but this is likely mitigated by the very dense vegetation adjacent to the drain filtering out floating material and slowing water velocity causing suspended material to settle. Dissolved nutrients in floodwater will penetrate further into the wetland. At present, there is no information on the extent of surface inundation with distance away from the central drain, and this should be part of a hydrological investigation.

Feral animal populations also present risks to wetland recovery. Recently, a mob of wild pigs was present in Otakairangi, although these appear to have been eradicated. In the Waikato feral deer cause tracking and trampling through sensitive wetlands, but deer have not been reported at Otakairangi.

*Climate risks – drought*

The New Zealand climate will continue to warm and rainfall patterns may change. Eastern and northern regions are expected to become drier. In Northland, annual rainfall is expected to decline under high greenhouse gas emissions scenarios, with drier conditions especially in spring (MfE, 2016). Warmer and drier conditions will lead to reduced water tables in wetlands, with consequent impacts on ecosystem functioning.

Peatlands researchers are concerned about the effects of changing climate on the ability of peatlands globally to continue to function as sinks for atmospheric carbon (a carbon "sink" is an ecosystem that takes up more atmospheric carbon in the form of $CO_2$ than it releases in all forms – $CO_2$, methane, dissolved organic carbon and, long term, through fires). Some Northern Hemisphere studies have found that, under drought conditions, peatlands turn into net carbon sources (Lund *et al.*, 2012). Research in Kopuatai bog (Hauraki) shows that this large restiad peatland remains a strong carbon sink in years with severe drought (Goodrich *et al.*, 2017). The Moanatuatua remnant restiad peatland (Hamilton Basin) was a strong $CO_2$ sink in the early 2000's despite abnormally low water tables (Campbell *et al.*, 2014). New Zealand restiad-dominated peatlands appear to be reasonably resilient carbon sinks during drought. However, lowered water tables caused by reduced rainfall or drain deepening favour growth of shrubs such as manuka, leading to higher evaporation rates and a positive feedback towards deeper water tables. In addition, manuka domination leads to loss of biodiversity, e.g. specialised peatland plants such as orchids, lycopods, and sundews (Pers. Comm. Bev Clarkson). The late-successional restiad *Sporadanthus ferrugineus* also has higher evaporation rates than *Empodisma* (Campbell and Williamson, 1997; Thompson *et al.*, 1999).

## 7.3 Restoration options and challenges

### 7.3.1 Restoration goal-setting

As described in Section 2.7, it is critically important to establish goals for restoration prior to active interventions such as hydrological flow modification. These goals should be agreed between agencies and the community, and be informed by sufficient baseline research so that the recovery trajectory of Otakairangi wetland and the present-day hydrological regime are clearly understood. The remainder of this section discusses some of the challenges and options that should be considered as part of a restoration plan.

### 7.3.2 Challenges and opportunities

*Challenges posed by Otakairangi Wetland's setting*

Otakairangi Wetland straddles the Otakairangi Stream valley and is surrounded on three sides and up-valley by intensively managed, low-lying farmland, which all relies on efficient drainage through a

network of drains that border and pass through the wetland. The deep central drain, at the point at which it enters the wetland, drains a catchment of around 20 $km^2$, and likely has to cope with annual flood flows >20 $m^3s^{-1}$ (**Table 1**) and extreme flows far greater than this. This drain has undoubtedly had a strong influence over hydrological and ecological processes within the wetland for nearly 100 years. Many of these changes may take decades or longer to reverse. When the drain was first constructed and later deepened, it would have lowered the water table along a wide band within the adjacent wetland, triggering accelerated peat degradation and compaction, and vegetation change. The drain also split the wetland into two entirely separate halves. The two (nearly equally sized) wetlands that exist now seem to have taken slightly different ecological trajectories in recent times, with the eastern wetland having far more extensive areas of *Empodisma robustum* (**Figure 12**). These two wetland halves probably have subtly different hydrology and nutrient regimes, which may explain their different trajectories. They may also have had different fire histories, which have influenced vegetation and peat degradation patterns. These differences represent an opportunity for restoration research and monitoring, potentially for paired trials.

*Working with the community*

Ecosystem restoration is a community endeavour. It will be important to develop a shared vision for the future of Otakairangi Wetland between communities (including iwi), landowners, government agencies, industry and scientists. Current engagement examples include school visits and the Living Waters initiative, which has already prioritised Otakairangi for its restoration potential. Forming effective community partnerships will assist with identifying trade-offs in the restoration planning process that can help to avoid conflicts.

If major restoration works are proposed, especially if these will modify or redirect water flows, including blocking drains, it is critical that affected landowners are engaged with early on and their input sought. Negative perceptions of impacts on their farming operations (real or imagined) can generate distrust. It has already been noted that flooding inundation of farmland upstream of the wetland is perceived to be worsening so the causes of this, and the implications of any drain modification within the wetland, should be fully investigated in partnership with farmers. It is likely that continued peat shrinkage under long-term agricultural management is contributing to the increased duration of inundation, which will continue to exacerbate the problem in future. Working with farmers so they can understand and "own" the problem will help them plan for future use of this land. Shrinkage of land down-valley from the wetland also contributes to the problem, with drain deepening a likely contributor to erosion along the central drain.

### 7.3.3 Hydrological restoration options

Most peatland restoration projects worldwide initially focus on rewetting because drainage has removed water—leading to lowered water tables and accelerated peat decomposition. Rewetting is

usually achieved by drain blocking or diversion. A thorough description of common techniques was given by Landry and Rochefort (2012). However, Otakairangi Wetland's position in the centre of its valley poses significant challenges to this approach since the central drain regularly carries large flows of water (**Table 1**).

Hydrological restoration options at Otakairangi should be thought of in terms of restoring more natural wet season/high flow conditions and dry season/low flow conditions.

*Wet season/high flow*

Otakairangi Stream once flowed into the wetland where sediment and nutrient inputs would have created a complex mosaic of wetland types. It is likely that most of the former minerotrophic (swamp) parts of the wetland have long been isolated from catchment inflows except under the most extreme flooding events. Restoring a more natural hydrological regime under high flow conditions would be technically very demanding, but could be a possibility if the central drain was relocated around the outside of the wetland and overflows diverted into the wetland.

Diversion of the central drain/stream around the western side of the wetland, followed by blocking the drain and ponding water within it would be an ideal restoration scenario because it would more effectively separate the need to efficiently drain farmland from the natural hydrology of the wetland. Unfortunately, this would be very costly and potentially affect existing farmland and drains to the west. The longer flow path and consequent reduced slope may also lead to increased flooding duration upstream of the wetland, depending on the flow capacity of the bypass channel. A sophisticated diversion design could incorporate overflows into the wetland in order to mimic the more natural hydrology that formerly existed, except that water flow volumes, as well as sediment and nutrient concentrations of these floodwaters, are probably significantly higher than in pre-settlement times. The possibility of passing the central drain through a long culvert pipe traversing the wetland could also be investigated but, again, this is likely to be extremely costly and create severe upstream flooding if hydraulic capacity of the pipe were exceeded during high-flow events.

*Dry season/low flow*

The central drain is 2–3 m deep and under low-flow conditions there is an extreme hydraulic gradient between the adjacent wetland water tables and the drain water levels. A prolonged period of peat degradation and consequently lowered hydraulic conductivity in the many decades since the drain was first excavated, as well as vegetation change and fires, may have led to a degree of self-mitigation where water tables are held up close to the peat surface within a few tens of metres from the drain. However, the effectiveness of this needs to be carefully researched.

Certainly, it is critically important that the central drain invert levels (base of drain) are not deepened or allowed to erode further. At a minimum, current invert levels should be surveyed along the full length of the drain and minimum water level controls should be installed to prevent bed erosion.

The best dry season restoration outcome would be achieved by complete drain blocking, but the challenges to achieving this are very significant.

### 7.3.4 Maintaining the status quo as an initial restoration option

Price *et al.* (2016) recommended delaying major drain blocking or water flow diversions until sufficient evidence of need is accumulated (Section 2.7). There is an urgent need for research and monitoring to answer basic questions about Otakairangi's ecohydrology and the status of drainage impacts (Section 7.4) on its hydrology, prior to undertaking major capital works. Surveying of central and marginal drain invert levels and establishment of minimum water level controls should still be undertaken during this initial phase.

### 7.3.5 Recommended hydrological mitigation and restoration actions

Minor interventions such as minimum water level controls could be constructed in the short term without exacerbating flooding during high flow events. Major interventions such as diversion of the central drain will require significant engineering design and flow modelling, as well as working closely alongside affected land owners and the community.

1. Best-practice land use and riparian management within the Otakairangi Stream catchment should be undertaken as a major mitigating strategy to slow down water flows, and to reduce sediment and nutrient runoff.
2. Mapping extent and depth of farmed peat soils surrounding the wetland and working with farmers to implement best practice to minimise ongoing shrinkage.
3. Surveying of current central (and marginal) drain invert levels.
4. Design and construction of central drain minimum water level controls to prevent ongoing bed erosion and maintain slightly higher minimum water levels. These should be staged along the drain, informed by surveying, and careful consideration given to preventing erosion around these structures under high flow conditions.
5. Work with WDC, DOC and landowners to establish agreed drain maintenance protocols that do not lead to negative outcomes for the wetland.
6. Feasibility of relocating the central drain around the western side of Otakairangi Wetland, along with blocking the central drain at multiple locations should be further investigated, requiring engineering design and flow modelling.

## 7.4 Research needs

This assessment report is based on impressions from field visits, discussions, photographs, and a limited number of spot measurements. Wetlands are dynamic ecosystems, with changes that occur across a spectrum of space and timescales. Wetland science is, by its very nature, interdisciplinary, calling on the skills of ecologists, hydrologists, and biogeochemists. There are many knowledge gaps about Otakairangi Wetland that limit our ability to chart its future trajectory, and to plan, implement and monitor the effectiveness of restoration efforts.

This section provides an overview of priority research themes and questions that should be investigated. Many of the research questions will be interrelated and knowledge advances will be best gained where opportunities are taken to integrate and collaborate across themes.

### 7.4.1 Seasonal and annual water table regimes, and surface flooding

The water table regime (variations over time) is a key indicator of wetland type and wetland health because it affects so many aspects of ecosystem functioning. It is also relatively easy to measure using reliable and accurate self-logging water level probes. The key is to design a well thought-out monitoring network that contributes to multiple goals.

Key questions/goals to address are:

1. What are the annual and seasonal ranges of the water table depth in representative vegetation communities?
2. How far does the influence of the central drain on water tables extend across the wetland, during wet and dry times of the year?
3. During flood events leading to surface inundation, how far into the wetland does inundation occur, and what are the return periods of these events?
4. To what extent does downstream flooding (from the Wairua River) affect Otakairangi Wetland?
5. Map the spatial distribution of hydrological regimes across the whole wetland.
6. What is the hydrological relationship between the older, degraded peat (typical of *Gleichenia*-dominated areas) and the new “proto-peat” forming underneath *Empodisma*? Is the degraded peat “holding up” the water table in summer, or are the *Empodisma* “islands” becoming isolated from the water table?

Contributing towards mapping the distribution of hydrological regimes, a detailed aerial LIDAR survey would be invaluable.

### 7.4.2 Colonisation and expansion of *Empodisma* and associated fen-bog species

*Empodisma robustum* is the key peat former in northern New Zealand, and its recovery at Otakairangi is an indicator of a trajectory towards more natural fen/bog conditions. There has clearly been significant expansion of areas dominated by *Empodisma* in the eastern part of Otakairangi while colonisation and expansion appears to be at an earlier stage in the west. However, expansion of *Empodisma*-dominated vegetation associations is only a first step towards ecohydrological recovery and renewed peat formation, and it is likely to be at severe risk from ongoing drainage management and fire. As yet we don't understand enough about this recovery trajectory, and Otakairangi presents a unique opportunity to follow its progress.

1. What is the rate of colonisation and expansion of *Empodisma* and associated fen/bog species?
2. Are the larger *Empodisma* areas to the east of the central drain having a significant effect on ecohydrological processes (e.g. water table and peat moisture regimes; decomposition rates) compared to the west?
3. What is the rate of proto-peat accumulation under actively colonising *Empodisma*, and will this eventually lead to renewed formation of "normal" restiad peat?

### 7.4.3 Spatial variation of water and nutrient inputs to the wetland

Detailed peat and vegetation nutrient sampling and analyses, coupled with improved understanding of the spatial variation of hydrological regimes, will allow better delineation of the major wetland types within Otakairangi, and provide a baseline for targeted restoration efforts. An example study from Whangamarino Wetland (Lower Waikato Valley) is Blyth *et al.* (2013) (MSc thesis Blyth (2011) is available online[3]). Examples of application include better identification of areas for re-introduction of *Sporadanthus ferrugineus* (Clarkson *et al.*, 2015), and targeted weed control.

1. Which areas of the wetland are predominantly rain-fed (ombrotrophic or bog-like conditions)?
2. What is the evidence for, and patterns of, groundwater and hillslope runoff influences along the eastern margin (mesotrophic or fen-like conditions)?
3. Which areas receive nutrients and mineral sediments from inundation?
4. What was the most likely former path of Otakairangi Stream through the wetland prior to excavation of the central drain, and is re-creation of natural swamp habitat feasible?

### 7.4.4 Ecosystem functioning

Micrometeorological methods have been used to improve understanding of ecohydrological and carbon cycling processes in Waikato peatlands, e.g. Kopuatai (Campbell and Williamson, 1997; Goodrich *et al.*, 2015; Goodrich *et al.*, 2017) and Moanatuatua (Thompson *et al.*, 1999; Campbell *et*

[3] http://hdl.handle.net/10289/5344

*al.*, 2014). Also, a key indicator of healthy peat formation under *Empodisma* communities is seasonal adjustment of peat surface level, or peat surface oscillation (Fritz *et al.*, 2008).

1. What is Otakairangi Wetland's present status as a carbon sink?
2. What are the key drivers of Otakairangi's carbon balance and how resilient will it be under changing conditions (hydrology, climate change).
3. How sensitive is the water balance (especially evaporation rates) to vegetation association?
4. How do the major vegetation associations differ in their water and carbon exchange properties and how is this driving change in the wetland's ecohydrology?
5. Does the newly-forming peat have peat surface oscillation characteristics similar to more intact New Zealand restiad peatlands?
6. Development of carbon and hydrological models, based on ecosystem functioning research, to forecast future trajectories for the wetland's ecohydrology and carbon sink-peat formation.

# 8 Conclusions

New Zealand has a tragic history of wetland loss, and the vast mosaic of wetlands that formerly existed on the floodplains of the Wairua River (the Hikurangi "Swamp") has also been largely replaced by intensively managed farmland, stop banks, drains and pump stations.

Otakairangi Wetland has a remarkable tale to tell of survival, resilience and potential recovery in the face of overwhelming odds for very many decades. It has been severely reduced in size, subjected to drainage and damaged by fire. Yet it retains key elements of its peatland biodiversity and there is evidence that significant recovery has taken place in recent years, probably resulting from reduced fire frequency and positive feedback of severe peat degradation leading to higher water tables.

The continued trajectory towards ecosystem recovery—potentially even the resumption of active peat formation over much of the wetland area—will likely depend on assistance in the form of best practice catchment land and drainage management, weed control, and some degree of hydrological manipulation.

Quantitative research and ecological and hydrological monitoring are now needed to provide both a baseline against which to measure ongoing recovery and restoration success, and to answer critical questions prior to expensive and potentially risky hydrological manipulation. Alongside this effort, it will be necessary to engage with and seek the support of landowners, industry, government agencies, and the community including iwi.

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