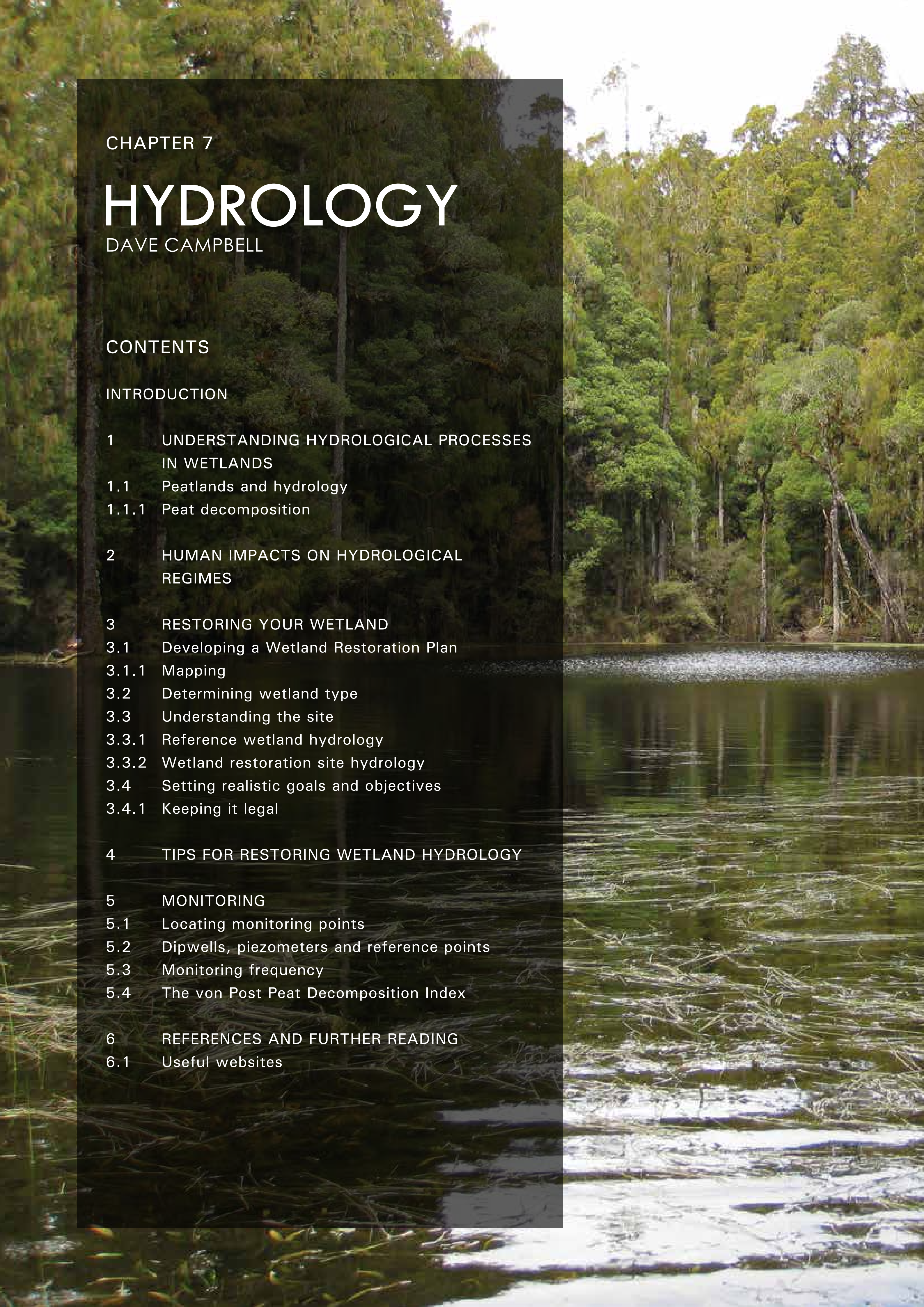

CHAPTER 7

HYDROLOGY

DAVE CAMPBELL

CONTENTS

HYDROLOGY

HYDROLOGY

DAVE CAMPBELL

When applied to wetlands, the science of hydrology is concerned with how the storage and movement of water into and out of a wetland affects the plants and animals, and the soils on which they grow. Most wetland scientists agree that the single most important factor determining both wetland type and function is hydrology. Consequently, changes in hydrology are the leading causes of wetland degradation or destruction. The two case studies in this chapter illustrate how water was returned to a previously drained lowland swamp and a peat bog and the effects on the vegetation communities. Both sites had been drained as further dry land was desired for farming and urban development, a common scenario throughout New Zealand.

Hydrologists often start their studies by defining the size and shape of a catchment, in other words, the area of land that contributes liquid water to a downstream location, either as surface water in streams or groundwater that may emerge in seepages or springs. Wetlands often occur in the lower parts of catchments where there is an excess of water input so that the water table is permanently or seasonally close to the ground surface. This includes valley bottoms, low-lying areas alongside streams and rivers, and down slope of seepages. Alternately, in very wet climates they can occur just about anywhere drainage is restricted. This means most wetlands are intimately connected to the upland parts of their catchments and restoration efforts may be stymied by water quality or quantity issues deriving from land-use practices considerable distances away. An integrated approach to whole-catchment water quality and quantity issues may be necessary for successful restoration, such as stream fencing and riparian planting upstream.

Previous page: Waihora Lagoon, Pureora Forest Park, Waikato.
Photo: Karen Denyer, National Wetland Trust

Most of the Waikato shallow lakes have been lowered through drainage. Further drainage is prevented by weirs that now establish minimum water levels.
Photo: Monica Peters, NZ Landcare Trust

Pooled water after heavy rain shows provides an indication of how far the wetland originally extended prior to clearing for pasture. Raglan, Waikato.
Photo: Monica Peters, NZ Landcare Trust

The seepage in this modified wetland clearly shows as bright green grass. Batlle Hill Farm Park, Wellington. Photo: Monica Peters, NZ Landcare Trust

1 Understanding hydrological processes in wetlands

Research has identified that the most significant problem limiting the success of wetland restoration projects is inadequate hydrological regimes. The hydrological regime or hydroperiod refers to the characteristic changes in hydrological variables over time, the most notable being water levels and water flows or discharge. It follows that getting the hydrology right is a key factor for successful wetland restoration.

Natural wetlands form because of landscape and hydrological interactions that lead to an excess availability of water or water convergence. If these hydrological conditions are provided a wetland will form, although it might not be the type of wetland you are setting out to establish. It follows that wetland restoration is only likely to be successful in locations where water flows already converge, unless you're prepared to carry out major engineering works. Any planned modifications to water flows such as blocking drains should aim to reinstate the natural degree of water convergence by slowing water flows rather than creating an artificially imposed hydrological regime, such as damming streams.

This intricate scroll plain in the upper Taieri (Otago) is the result of a river meandering across an area with a very low gradient.
Photo: Aalbert Rebergen, Otago Regional Council

1.1 Peatlands and hydrology

An intimate relationship exists between hydrology, plants, and the wetland substrate in peatlands. Peat forms because decomposition of accumulating plant matter is limited by low oxygen levels in saturated soils, and the dominance of low nutrient water sources (especially rainwater). Peatlands may begin to form during wetter climate conditions that promote high water levels, and many thousands of years are often required for significant layers of peat to accumulate. Once formed, peat itself restricts water flows and eventually true bogs may develop, where the wetland water table is raised above the regional water table and the bog becomes isolated from external water flows. When a peatland is drained the peat oxidizes and compresses, lowering the land surface, meaning it can be very difficult to restore a functioning wetland system. For this reason, peatland restoration poses very significant challenges.

Peat substrates in fens and bogs have the ability to expand and contract (and sometimes even float) in response to rising and falling water levels. This phenomenon is termed peat *surface oscillation*. It has the very important property of stabilising water level fluctuations relative to the surface, which may be a critical factor determining where particular plants will grow. For example, the jointed wire rush *Empodisma minus* will not grow well in situations where its roots are regularly flooded. There is some evidence that this plant forms peat that is capable of floating at high water stages, allowing the roots of the plants to remain moist but not flooded. Drainage activities, physical damage by stock trampling or vehicles, or weed invasion all lead to degradation of peat physical properties and destroy its ability to oscillate. Restoration of these peat functions is extremely difficult and may take a very long period of time.

1.1.1 Peat decomposition

A further consideration for restoration is the degree to which the peat is decomposed. Using a simple "squeeze test" a handful of undecomposed peat will show obvious plant structure and yield clear water. At the other end of the scale, well-decomposed peat will not show any plant structure and will ooze out between the fingers like toothpaste. The level of decomposition is closely linked to nutrient levels, hence to vegetation type. As undecomposed peat is lower in nutrients than well-decomposed peat, the plants selected for revegetation will need to be considered based on how decomposed the peat is. The von Post Index (included in the monitoring section of this chapter) is widely used to determine the level of peat decomposition.

Wire rush (*Empodisma minus*) with its dense mass of upward growing roots is a key peat forming species. Moanatuatua Scientific Reserve, Waikato. Photo: Monica Peters, NZ Landcare Trust

The fluctuating levels of the Waikato River (the result of power generation) have a pronounced effect on wetlands such as Hardcastle Lagoon. Photo: Monica Peters, NZ Landcare Trust

2 Human impacts on hydrological regimes

Human interventions in the landscape often result in "flashy" hydrological regimes in rivers and wetlands. For example, forest clearance and conversion to pasture will lead to higher rates of surface water runoff, which can cause scouring in downstream wetlands, or deposition of sediment, or both. For these reasons, upstream restoration may be the key ingredient for successful wetland restoration. This might only be feasible in small catchments, unless integrated catchment management principles are followed that involve entire communities and local government, as well as conservation groups.

Natural wetlands require water tables that fluctuate seasonally and in response to pulses of water inputs (e.g., from rainfall, tides, flooding rivers) – but not too much fluctuation, or too little. For example, artificial water control structures often result in unnaturally stable or high water tables. On the other hand, extreme water table lowering caused by artificial drainage or drought will challenge the survival of some wetland plants and animals, and may allow dryland weeds to invade.

The Taieri River (Otago) is a highly modified system – with many wetland areas in the catchment drained, severe flooding can result after heavy rainfall. Photo: Gretchen Robertson, NZ Landcare Trust

3 Restoring your wetland

3.1 Developing a Wetland Restoration Plan

A Wetland Restoration Plan is extremely useful for gathering information about the restoration site, clarifying goals and objectives and guiding restoration activities. Either use an existing template (see the Useful websites section at the end of the chapter) or create your own based on the steps outlined in Chapter 2 – Restoration planning.

3.1.1 Mapping

A useful starting point for developing a Wetland Restoration Plan is a sketch map. A bird's-eye view sketch map is important as it helps summarise knowledge about the natural and man-made character of the restoration site. It is a practical tool for defining, for example, management zones and locations of permanent plots for monitoring. The map can be hand drawn using a range of resources such as aerial photos, topographic maps, and Google Earth, combined with your own knowledge.

The following features should be included:

- Vegetation types
- Water sources and outflows, hydrological modifications, water level
- Soil type
- Man-made, natural and cultural features

For more detail on what to include, see Chapter 2 – Restoration planning.

3.2 Determining wetland type

An important step for developing a Wetland Restoration Plan is to determine the wetland type of the restoration site. This will also help with finding an appropriate reference wetland. Freshwater wetland types and the features that characterise them are outlined in Chapter 2 – Wetland types.

3.3 Understanding the site

Use maps and aerial photographs to locate a reference wetland or enlist help from agencies such as the Department of Conservation. To be useful, any reference wetland should be in a similar landscape position to the one you are intending to restore, at a similar point in its catchment, and with similar water flows. To take an extreme example, an extensive peat bog will not provide a suitable reference for the restoration of a valley bottom flax swamp because the types of water and sediment sources are completely different. Further information on reference wetlands can be found in Chapter 5 – Site interpretation 1. For more in-depth information on historical aspects of the wetland, see Chapter 6 – Site interpretation 2.

Two key steps will guide your Wetland Restoration Plan by informing you about hydrological factors. First, determine what the natural hydrological regime would once have been at the restoration site. Second, determine what changes have occurred to alter the natural regime. A reference wetland can help with the first step, and can then provide a yardstick against which to judge the success of any restoration efforts over time. The key questions to ask are:

Why is this reference wetland more pristine than the one we are planning to restore?

How does the hydrology differ between the reference and the restoration wetlands?

3.3.1 Reference wetland hydrology

Make a careful evaluation of the factors affecting the hydrological regime at your reference wetland(s), particularly those that affect water quantity and quality. The questions below provide a useful starting point. Additionally, tapping into the local knowledge of adjacent landowners could be very helpful.

What are the primary sources of water for the reference wetland?

- If the wetland is at the toe of a slope, seepage is likely to be important, even if you can't see any springs.
- If there are streams flowing into the wetland then there are likely to be strong linkages between the stream water and the wetland, so surface water inflows will be important, as will the water quality.
- If the wetland is alongside a major river, flooding by the river may be a major factor, or the level of water in the river will likely control the level of water in the wetland.
- How often will flooding of adjacent large and small streams and rivers impact on the wetland – several times a year, or maybe only one year in 10?
- Is the wetland affected by tidal water flows?
- Is the wetland predominantly rain fed?

What factors affect the quality of water flows into the reference wetland?

- Is the land upstream or upslope forested?
- If forested, is it native or exotic?
- If the land is used for agriculture, what type and intensity of agriculture?
- Are there any signs of erosion such as landslips, turbid stream water, or fresh deposits of silty material?

How do water levels vary in the reference wetland?

To answer this fully requires a detailed monitoring programme carried out over one or more years; however, there may be clues you can obtain from a site visit.

- Are the summer (low) water levels above or below the surface in different parts of the wetland?
- Are there any signs left of high flood stages (e.g., debris in fences or trees)?

Opposite page: Pukio/purei (*Carex secta*) is typical of swamps. Lake Koromatua, Waikato. Photo: Monica Peters, NZ Landcare Trust

3.3.2 Wetland restoration site hydrology

Given the critical nature of hydrology for wetland restoration success, you should clearly identify all the hydrological changes that have affected your restoration site, either directly (e.g., excavation of a network of drainage ditches) or indirectly (e.g., conversion of catchment headwaters from native forest to dairy farms that have increased water, nutrient and sediment inputs to the wetland).

Rank these factors according to their likely importance in creating the situation as it now exists.

Which of the highly ranked factors might feasibly be changed to return the system closer to its natural state?

Moanatuatua Scientific Reserve (120 ha) is a rain-fed bog remnant situated close to Hamilton (Waikato): The original bog covered an estimated 7500 ha. Photo: Monica Peters, NZ Landcare Trust

The following is a list of possible hydrological effects from factors that may be impacting on your wetland:

- Increased water flows due to upstream forest removal
- Reduced water flows and improvements to water quality by forest planting or reversion to scrub
- Pulses of sediment from the natural adjustment of forest streams
- Sediment and nutrient runoff increases due to land-use intensification. Crops have very high fertiliser inputs, dairy moderately high, while sheep and beef are comparatively low
- "Flashy" runoff and reduced low-flows through urbanisation – impervious paving and roofs prevent infiltration through the soil and groundwater recharge. This may lead to scouring and/or reduced summer inflows to downstream wetlands
- Lowered water tables though drainage (e.g., tile drains, ditches), which also leads to drier soil, oxidation and shrinkage of organic soils, and invasion by dry-land species
- Faster water flows and reduced local flooding by artificial straightening of stream channels, which may also exacerbate flooding downstream
- Unnaturally long flooding regimes in flood detention areas through flood protection works such as stop banks
- Isolation of wetlands from natural periodic inundation by flooding rivers through flood protection works such as stop banks
- Heavily impacted natural system functions by weed invasion
- Unnaturally stable and high water tables by damming, which also leads to very narrow wetland zones around aquatic habitat
- Soil types, e.g., peat or mineral

The vegetation of this dune lake on Matakana Island reflects changes in salinity as the narrow barrier separating the wetland from the sea is periodically breached. Photo: Monica Peters, NZ Landcare Trust

The Lower Kaituna Wildlife Management Reserve (BoP) is bordered by stopbanks and drained farm land, creating a "perched" wetland with water management problems. Photo: Environment Bay of Plenty

CASE STUDY

OTAIURA/HANNAH'S BAY WETLAND: RESTORING & RETAINING HIGHER WATER LEVELS

Near Rotorua lies a remnant of a swamp significantly reduced in size due to the development of the surrounding lands for agriculture, residential settlement and the Rotorua Regional Airport. Drainage allowed the colonization of a wide range of introduced species such as willow, hawthorn, pampas, blackberry and Himalayan honeysuckle.

Thorough planning

A restoration strategy was first developed by Wildlands in 2000 (Shaw et al.) with an implementation plan produced in 2005 (Wildlands Contract report #1197). The highly degraded state of the wetland, restoration constraints imposed by its location, and a variety of conflicting community interests meant significant planning was required before beginning on the ground works.

Key activities

- Identification of an ecologically acceptable route for a stormwater channel to pass through it
- Liaison and supervision of the earthworks contractor
- Meetings with all affected parties
- Large-scale weed control
- Restoration planting over 5 seasons (>27 000 plants)
- Restoration updates produced for on-site bulletin boards
- Water levels monitored using a staff gauge and 4 piezometers
- Restoration progress documented from photo points and vegetation monitoring plots

Restoration goal

The goal of the restoration is to re-establish and maintain the natural ecosystem processes and the indigenous character of the Otauira wetland. From a hydrological perspective, this meant restoring and retaining higher water levels within the wetland by redirecting surface runoff and other airport-derived water and by "fixing" other areas where water was being lost. Resource consents were required for the development of bunds in low-lying areas, stormwater channels and a weir to control water levels within the wetland. Today, water levels in the wetland area have been raised significantly by blocking off two culverts formerly draining the wetland and by redirecting water from the airport into the wetland through the newly developed stormwater system. Funding for the hydrological works was covered by the Rotorua Regional Airport as mitigation for the loss of wetland habitat due to runway extension.

Positive outcomes

The raised water levels have resulted in the die back both of introduced plants and native species (e.g., tree ferns and karamu) not well adapted to standing water. Over time these native species will be replaced by wetland plants better adapted to the new conditions. More important, elevation of water levels coupled with sustained weed control and an extensive planting programme have restored the quality and quantity of wetland habitats that formerly characterized this area.

REF: Wildland Consultants Ltd. 2005. *Otauira (Hannah's Bay) Wetland Ecological Restoration and Development Plan*. Wildland Consultants Contract Report No. 1197. Prepared for the Rotorua District Council.

Culvert with removable concrete inserts to enable further hydrological manipulation when required. Photo: Wildland Consultants Ltd.

Native plant regeneration inside the wetland view from the boardwalk. Photo: Monica Peters, NZ Landcare Trust

Hannah's Bay/Otaiura wetland is situated on the shores of Lake Rotorua. Photo taken in 2006 showing stormwater channel.
Photo: Wildland Consultants Ltd.

3.4 Setting realistic goals and objectives

Setting realistic goals is the key to success in wetland restoration (See Chapter 6 – Goals & objectives). Hydrological goal setting is one component of the overall restoration goals, with more or less importance depending on the situation at hand. For instance, if you are dealing with a wetland where weed invasion is the key challenge, but there has been little hydrological modification, your hydrological goals might be focused on improving upstream water quality, for example, keeping stock out of streams and improving riparian planting. Your goals and objectives will help you develop a monitoring programme to determine the success of your restoration activities.

Make a list of the main challenges confronting your restoration plans. Do they include water quantity and/or quality? Weed infestations? Erosion or deposition of sediments? Significant soil shrinkage?

Evaluate the role hydrology might play in these challenges, and decide whether you can feasibly overcome them. Over-ambitious or unrealistic goals are a recipe for failure in wetland restoration. Examples include situations where large-scale engineering works are required, or where the effects of drainage over large areas have caused a wholesale shrinkage of the land surface, common in drained peatlands. Restoration in these situations may be unfeasible or lead to long-term and expensive maintenance commitments.

Opposite: A kahikatea swamp forest in good ecological condition. Kopuatai Peat Dome, Waikato. See overleaf for a nearby remnant that has been drained. Photo: Monica Peters, NZ Landcare Trust

For any restoration project there should be multiple goals, but identify one major goal. Hydrological goals may include: enabling ecosystem functions; improving water quality; providing wildlife habitat. Specific objectives linked to these goals may be to:

- install a weir to establish minimum water levels
- modify inflow drain design to include silt trap for improving water quality
- raise water levels by 30 cm to flood broom infestation
- create suitable habitat to reintroduce mudfish

CREATING AREAS OF OPEN WATER

"It is not a good idea to create areas of open water by excavating material out of, or damming, existing wetlands. Areas of open water can be difficult to keep free of weed and algae in summer and dams can block fish access. Often wetlands do not have sufficient water flow to support good ponds. If you want to create open water for wildlife (e.g., for hunting), choose bare paddocks or badly degraded areas. Include gently sloping irregular shorelines as well as areas of water three metres deep. This allows birds, particularly waders, chicks and ducklings, easy access to and from the water and will extend the belt of reeds and rushes growing around the edge. Note that you may need a Resource Consent for pond construction."

– Northland Regional Council

3.4.1 Keeping it legal

If you are planning to divert water courses, alter water levels or impound water you should first check with your local authority. Any work you carry out that causes changes to water levels on neighbouring properties or floods an area of 1 hectare or greater is likely to require a resource consent, as will any earthworks close to flowing water courses. Construction or alteration of any structure that will impact on minimum water or bed levels of existing rivers, lakes or wetlands are likely to be controlled activities, and appropriate advice and consent must be sought.

Your local or regional council may also suggest an appropriate expert with whom you can discuss your restoration plans. You will need to ensure any proposed works do not block fish access, and the Department of Conservation should be consulted in these cases. You should also consult affected parties such as surrounding landowners. Consider whether there will be any downstream effects, such as changes to stream flows.

4 Tips for restoring wetland hydrology

- Plan any hydrological works for minimal maintenance and allow for nature's ability to self-design.
- Avoid over-engineering with rigid structures and channels where these do not occur in nature. They will result in unnatural water velocities (possibly leading to erosion), unrealistically high and stable water levels or excessive amounts of open water.
- Drains should be filled with locally sourced materials (e.g., original excavations). Filling entire lengths of drains may be preferable to plugging drains at one or two locations as open, flowing water can develop considerable erosive power during floods. The greatest maintenance issues will occur where water flows steepen and accelerate, potentially "blowing out" any earth plugs – see the case study on Dunearn peat bog.
- Utilise the natural energy of water rather than fight against it. Wetlands form in parts of the landscape where water flows naturally converge. Wetlands adjacent to rivers or estuaries will be linked to them, and pulses of water into and out of wetlands may be dominant natural drivers of nutrients and sediments.
- Natural ecosystems have resilience to cope with cyclic and extreme phenomena. In a hydrological context, water stored in a wetland (reflected by wetland water levels) will have seasonal highs and lows, and extremes associated with floods and droughts. At the extremes, plants may die, weeds may invade, and erosion may occur. A resilient restored ecosystem should be able to recover from these impacts given enough time. Remember that wetlands, like other ecosystems, are always changing.

Opposite: Drainage has left this Waikato kahikatea remnant high and dry, destroying its wetland character. This photo was taken only a few kilometres away from the photo on the previous page.
Photo: Monica Peters, NZ Landcare Trust

CASE STUDY

BLOCKING DRAINS TO RE-WET THE DUNEARN PEAT BOG

The 60-ha Dunearn peat bog in western Southland is an excellent example of a raised peat bog system. The site was bought by the Department of Conservation (DOC) in 2003 through the Nature Heritage Fund. To develop the surrounding land for agriculture, deep drains c. 2.5 m wide and 2 m deep were dug through the wetland remnant and around the periphery. Key indicators for the declining health of the wetland took the form of peat shrinkage and the dieback of wire rush – a key peat-forming species. Hydrological restoration took the form of blocking the drains with sods of peat at 100-m intervals in order to raise water levels to prevent further peat degradation and encourage wetland plant recovery.

Monitoring change

Environment Southland have been monitoring the condition and trend of the Dunearn peat bog in collaboration with DOC. To monitor changes in the groundwater regime dip wells were installed in February 2003 when the hydrological restoration work began. Along with a transect through the bog, 21 2 x 2 m plots were established for annual vegetation monitoring. A series of photo points are used to record general vegetation change over time.

Seeing results

From 2004 wire rush coverage climbed 27% to an average of 68% cover in 2008, clearly showing that the raising of the water table was resulting in a rapid increase in wire rush cover. Furthermore, those plots closer to the drains responded more than those furthest away (c. 24% vs c. 7% increase) showing that the low water table around drains had further impacted on total wire rush cover. These results are preliminary and better statistical analyses are needed to strengthen findings and model future trajectories.

Plot 8 in 2003. Photo: Crown Copyright, Department of Conservation

Plot 8 remeasured in 2009. Photo: Crown Copyright, Department of Conservation

Challenges

In October 2007, water pressure build up behind the peat sods used to block one of the drains resulted in a "blowout", again lowering the water table in one part of the peat bog and damaging adjacent farmland. An excavator was originally used for blocking the drains. Along with almost getting stuck in the soft substrate, the excavator transported weeds into the wetland through seed lodged in the tread of its tracks. This highlights the challenges (and associated costs) of restoring wetland hydrology in highly modified environments. DOC and Environment Southland are now investigating alternative ways of re-blocking the drains.

REF: *Dunearn peat bog: The restoration of a wire rush peat bog through the raising of its water table.* Dept of Conservation internal report DOCDM-367540

With drainage species tolerant of drier conditions were able to colonise areas formerly dominated by wire rush (*Empodisma minus*).
Photo: Crown Copyright, Department of Conservation

Aerial view of the Dunearn peat bog remnant clearly showing the network of deep drains . Photo: Crown Copyright, Department of Conservation

Standing away from piezometers when collecting data from sites with high water tables prevents water surging in and out of the sampling zone.
Photo: James Sukias, NIWA (with permission from DOC)

5 Monitoring

If you are considering making modifications to the hydrology of your restoration site, it is a good idea to carry out hydrological monitoring before, during, and after modification, so the effect of the modifications can be evaluated. Prior and parallel monitoring at a reference wetland can help set restoration goals, provide a basis for comparison, and inform decisions about restoration success.

Hydrological monitoring in wetlands often focuses on measuring water levels at representative locations, although water quality and water flows are also important aspects of hydrology. Rainfall should also be measured. A local farmer, NIWA or the regional council may already do so at a nearby site, and there are good long-term records available in most regions. Changes to water levels in a wetland reflect the changes to water storage, and also highlight the sensitivity of the wetland to external influences such as rainfall, floods and droughts. It is important to monitor water levels for several years to build up knowledge of typical and extreme patterns.

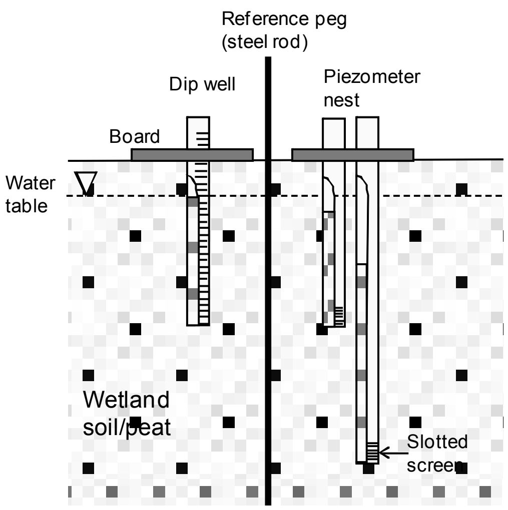

Figure 1. Setting up a dipwell and piezometer nest.

5.1 Locating monitoring points

Hydrological monitoring should encompass the major ecosystem types in your wetland, and sites are often best set up along a transect. Access to monitoring sites can be a problem, especially during high water stages, and vegetation and soil damage can result from frequent site visits. Choosing the appropriate number of monitoring sites depends on wetland size and complexity. Don't be too ambitious.

5.2 Dipwells, piezometers and reference points

Installing a dipwell is an inexpensive way of measuring the water table elevation. A dipwell usually consists of a plastic tube 30–60 mm in diameter with small holes or 1–2 mm slots cut along its length, sealed at the base with an end-cap and wrapped in a geotextile such as shade cloth, to prevent fine material clogging the tube. Because wetland soils are usually very soft, dipwells can often be pushed in by hand, otherwise a hand auger may be used. Dipwells need to extend deep enough to intersect with the water table in very dry spells. Piezometers have a similar construction except that the section with holes or slots is at a specific depth, and they are mainly used in groundwater studies to determine the direction of vertical water movement.

The textile is folded over the top of the well to prevent the build up of algae inside. Photo: James Sukias, NIWA (with permission from DOC)

Water-level measurements must be referenced to a known elevation. In many wetland studies this is simply the local ground surface adjacent to the dipwell because this best describes the conditions experienced by plants. If there is a need to determine the water-table slope or variations relative to adjacent water bodies or groundwater systems, it is important to measure water levels relative to an absolute datum, commonly sea level, or to a fixed benchmark on an adjacent hillside. The skills of a land surveyor are probably needed to do this. At each dipwell site a reference peg can be inserted through the wetland soil and into underlying stable ground (Figure 1). Each time the water level is manually read, the vertical distances between the top of the reference peg and the top of the dipwell, and from the top of the dipwell to the water table inside the tube, should be measured. A simple tape measure is usually sufficient where the water table is shallow, but a specialised water contact sensor might be needed to access deeper water tables.

5.3 Monitoring frequency

While manual measurements of water levels are relatively cheap, they are costly in time, although they can be combined with other regular tasks. No matter how frequently manual measurements are made, they will always yield an incomplete record and inevitably the full range of water level fluctuations will not be captured. Automatic methods for measurement are ideal, but the costs can be considerable. Relatively cheap electronic sensors are available (a few hundred dollars each – see equipment supplier at the end of the chapter) but inevitably you get what you pay for. Even when automatic sensors are used, frequent manual check-measurements are required to ensure good quality data. Figure 2 shows how monitoring frequency can have a big impact of interpretation of water level data. Weekly and monthly spot measurements lead to smoothed water level trends and extreme minimum and maximum levels are less likely to be recorded, compared with automatic measurements.

Manual measurements do not need to be equally spaced in time. Over long dry periods monthly measurements may be sufficient, weekly when the wetland is "wetting up", and immediately following large amounts of rain. You should aim to record the baseline water levels during rain-free periods in each season as well as the response to typical and large rainfalls.

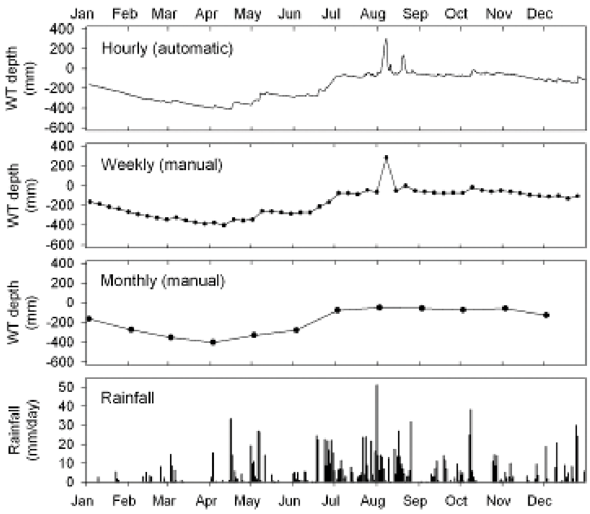

Figure 2. Measurements of water table elevation at Opuatia wetland in 2008. Peat surface is at 0 mm, negative depth is below the surface. Measurements were made automatically (top panel), weekly and monthly manual measurements are simulated. Daily rainfall totals in bottom panel. Graph: Dave Campbell, University of Waikato

5.4 The von Post Peat Decomposition Index

The amount of decomposition is gauged in the field by assessing the distinctness of the structure of plant remains and colour, determined by squeezing a handful of wet peat. The following standards (Table 1) are based on those of von Post (Clymo 1983).

von Post 2: almost decomposed; plant structure distinct, yields only clear water coloured light brown. Torehape peat mine, intact bog. Waikato. Photo: Richard Lowrance, USDA, Georgia, USA

von Post 8: very strongly decomposed; about two-thirds of peat escapes like toothpaste between fingers. Torehape peat mine, degraded margin. Waikato. Photo: Richard Lowrance, USDA, Georgia, USA

Table 1. Level of peat decomposition and characteristics

1. Undecomposed Plant structure unaltered. Yields only clear colourless water
2. Almost undecomposed (see photo) Plant structure distinct. Yields only clear water coloured light yellow-brown
3. Very weakly decomposed Plant structure distinct. Yields distinctly turbid brown water; no peat substance passes between fingers, residue not mushy
4. Weakly decomposed Plant structure distinct. Yields strongly turbid water; no peat substance passes between fingers, residue rather mushy
5. Moderately decomposed Plant structure still clear but becoming indistinct. Yields much turbid brown water; some peat escapes between the fingers; residue very mushy
6. Strongly decomposed Plant structure somewhat indistinct but clearer in the squeezed residue than in the undisturbed peat. About half of the peat escapes between the fingers; residue strongly mushy.
7. Strongly decomposed Plant structure indistinct but still recognisable. About half of the peat escapes between the fingers
8. Very strongly decomposed (see photo) Plant structures very indistinct. About two-thirds of the peat escapes between the fingers; residue consists almost entirely of resistant remnants such as root fibres and wood
9. Almost completely decomposed Plant structure almost unrecognisable. Almost all of the peat escapes between the fingers
10. Completely decomposed Plant structure unrecognisable. All of the peat escapes between the fingers.

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6.1 Useful websites

Wetland restoration templates

Waikato Regional Council Wetland Restoration Plan templates

www.waikatoregion.govt.nz/PageFiles/5799/Wetlandtemplate1.pdf

www.waikatoregion.govt.nz/PageFiles/5799/Wetlandtemplate2.pdf

Wetland restoration guides and factsheets (New Zealand)

Northland Regional Council

www.nrc.govt.nz/upload/2217/Wetland%20Restoration%20Guide%20(second%20edition%20Feb%2009).pdf

Auckland Regional Council

www.arc.govt.nz/albany/fms/main/Documents/Environment/Plants%20and%20animals/wetlandsfacts2.pdf

Waikato Regional Council

www.waikatoregion.govt.nz/Environment/Natural-resources/Water/Freshwater-wetlands/

Hamilton City Council

www.gullyguide.co.nz/index.asp?pageID=2145821537

Bay of Plenty Wetlands Forum

www.doc.govt.nz/upload/documents/conservation/land-and-freshwater/wetlands/wetland-restoration-guide.pdf

Greater Wellington

www.gw.govt.nz/a-beginner-s-guide-to-wetland-restoration/

Department of Conservation Protecting Natural Areas Design Guide

www.doc.govt.nz/publications/getting-involved/volunteer-join-or-start-a-project/start-or-fund-a-project-/nature-heritage-fund/protecting-natural-areas-design-guide/

Wetland restoration guides (International)

USA Environmental Protection Agency

www.epa.gov/owow/wetlands/pdf/restdocfinal.pdf

Understanding wetland hydrology

www.gw.govt.nz/assets/council-publications/wetland_hydrology.pdf

Creating ponds

www.gw.govt.nz/so-you-re-thinking-about-a-pond/

Technical resources

Hydrological instruments, monitoring advice and training

www.scottech.net/

National climate database

cliflo.niwa.co.nz/

Note that regional council websites also have information on climate

Reports

Ecohydrological characterization report Opuatia wetland, Waikato

www.waikatoregion.govt.nz/Services/Publications/Technical-Reports/Ecohydrological-characterisation-of-Opuatia-wetland-and-recommendations-for-future-management/

Note that many of the resources above are available as hard copy from the respective organisations. There is also a CD containing all above hyperlinks at the back of this Handbook. If you are using the online version of the Handbook and having problems with the hyperlinks above, try copying and pasting the web address into your browser search bar.