

CHAPTER 8

NUTRIENTS

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CONTENTS

INTRODUCTION

1 UNDERSTANDING NUTRIENTS IN WETLANDS

- 1.1 Weeds
- 1.2 Plant litter
- 1.3 De-oxygenation
- 1.4 Nitrogen and phosphorus

2 HUMAN IMPACTS ON NUTRIENT REGIMES

3 RESTORING YOUR WETLAND

- 3.1 Developing a Wetland Restoration Plan
- 3.2 Determining wetland type
- 3.3 Understanding the site
 - 3.3.1 Using a reference wetland
 - 3.3.2 Restoration site nutrients
- 3.4 Setting realistic goals and objectives
 - 3.4.1 Keeping it legal

4 TIPS FOR WORKING WITH NUTRIENTS

- 4.1 Treatment wetlands
- 5 Monitoring

6 REFERENCES AND FURTHER READING

- 6.1 Useful websites



NUTRIENTS

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Excess nutrients are second only to hydrological disturbance as a cause of loss of natural character in wetlands. Unnatural nutrient enrichment occurs because human societies have historically managed their nutrient-rich wastes by discharging them directly into the environment with little treatment. Although much progress has been made in recent decades in pollution control in waterways, wetlands are very sensitive to the amount of nutrients they receive, and many New Zealand wetlands continue to suffer excess nutrient inputs. Managing the nutrient inputs and the nutrient availability in your wetland is therefore

essential in a wetland restoration project. It is a key aspect of achieving the goals of your project, such as getting the desired plant community, water quality and animal habitat. Failure to manage nutrients effectively will almost inevitably lead to a wetland that suffers from excess growth of undesirable plants, low plant species diversity, algal blooms in the water, weed invasion, and poor habitat value for many aquatic insects and native fish.

The case studies included in this chapter highlight the important roles wetlands play in the agricultural landscape.

**Previous page: Algal bloom at Lake Kainui, Waikato.
The lake is situated in an intensively farmed catchment.**

Photo: Monica Peters, NZ Landcare Trust



Mangarakau swamp flax community

Photo: Monica Peters, NZ Landcare Trust



Mangarakau swamp sedge community

Photo: Monica Peters, NZ Landcare Trust

The 400 ha Mangarakau swamp complex (Nelson/Tasman) showcases a range of wetland types, from flax communities in nutrient rich swamp areas to nutrient poor sedgelands in pakihi areas. Photo: Monica Peters, NZ Landcare Trust



1 Understanding nutrients in wetlands

Natural wetlands vary enormously in their nutrient contents, from very low-nutrient (called oligotrophic) to high-nutrient (called eutrophic) conditions. Nutrients enter wetlands from a variety of sources including streams, creeks and drains, in groundwater from the surrounding catchment, from the air in rainfall and spray drift. Once in a wetland, nutrients tend to stay there and accumulate, initially in the soil, then in the plants, and then in the surface water. Nutrients are essential in wetlands to support healthy plant growth, but can easily accumulate to excessive levels that cause problems. This is called eutrophication. The first consequence of eutrophication is that the plants begin to grow taller and denser. When this happens, the different species start to compete with each other for light and space, and so tall, fast-growing species like raupo and willow tend to out-compete smaller species by shading them and pushing them aside. Hence, nutrient enrichment usually causes loss of plant species, and the community to change from a diverse multi-species mixture to one that is dominated by one or two fast-growing competitors. Prolific vegetation growth can then block channels and increase sediment build-up and evapotranspiration rates, reducing the water

availability in the wetland and the aquatic habitat. A very common scenario in wetland restoration failure is where people spend a lot of time and money establishing the correct hydrology and planting an attractive, diverse plant community, only to see species like raupo, or exotic weeds, spread explosively and completely dominate the site. Too much nutrient is usually responsible for this.



A Waikato wetland much degraded through the impact of agriculture — despite the fencing, the cows are on the wrong side of it! Photo: Fred Lichtwark, Whaingaroa Harbourcare



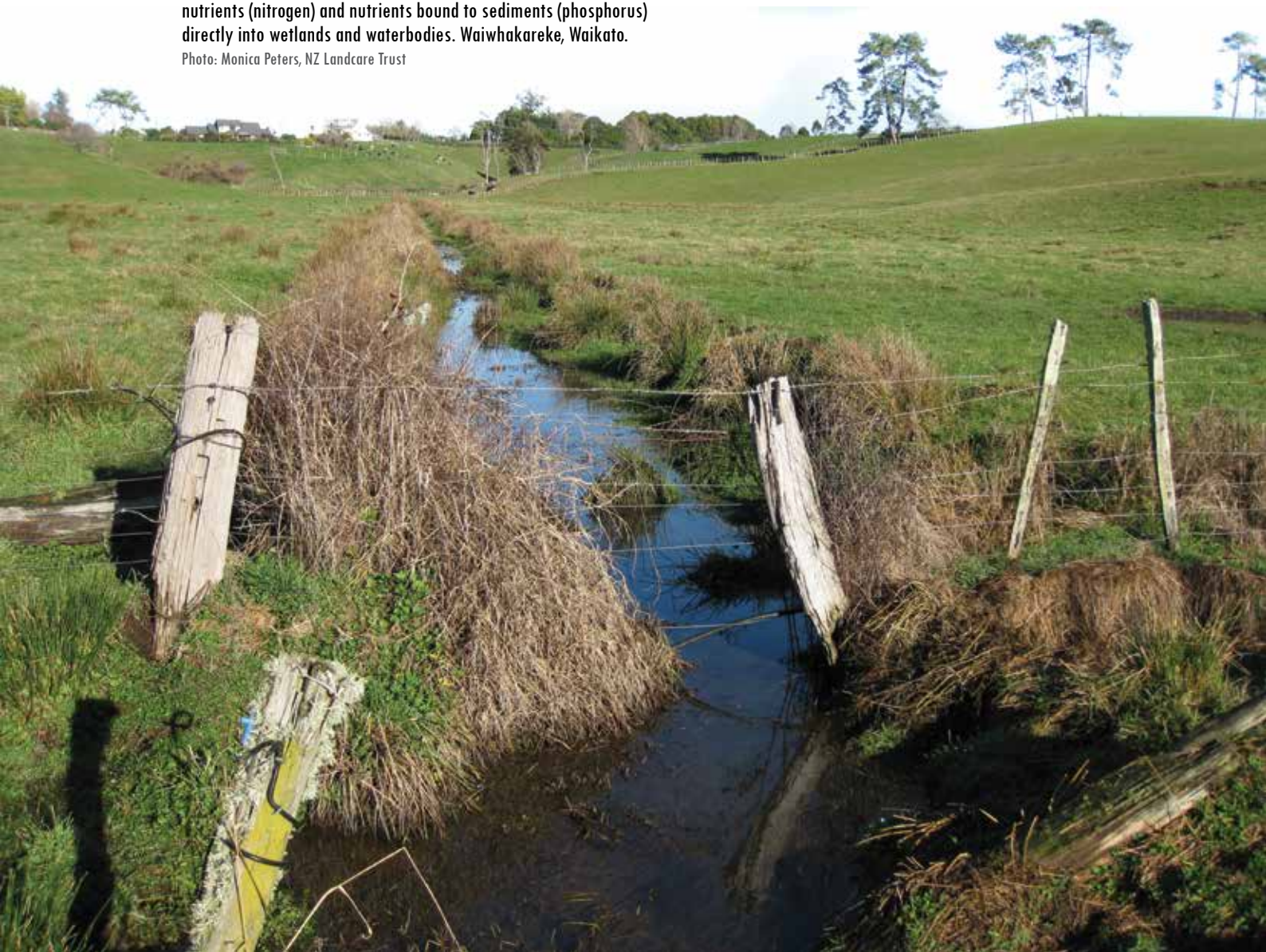
At Lake Kaituna (Waikato) raupo, an indicator of high nutrient levels is periodically removed to ensure it doesn't colonise too much of the shallow lake bed. Photo: Monica Peters, NZ Landcare Trust



Like raupo, sedges have high nutrient demands. Lake Hakanoa, Waikato. Photo: Monica Peters, NZ Landcare Trust

Point source pollution: farm drains frequently channel dissolved nutrients (nitrogen) and nutrients bound to sediments (phosphorus) directly into wetlands and waterbodies. Waiwhakareke, Waikato.

Photo: Monica Peters, NZ Landcare Trust



1.1 Weeds

Most exotic weeds are plants that like high nutrient levels. Weeds are discussed further in Chapter 9, but it's worth stating here that almost all of the problem weeds in New Zealand wetlands are strongly favoured by high nutrient levels, and that their impact can be minimised by paying attention to keeping nutrient levels down to low or moderate levels. Specific examples are reed canary grass and reed sweetgrass (both of which respond explosively to groundwater nitrate inputs in particular) and willows.

1.2 Plant litter

The next problem that develops is that too much plant litter accumulates. In a low-nutrient wetland, the plants retain most of the nutrients they take up in their live tissues, and only produce small amounts of dead litter. In a nutrient-enriched wetland, fast-growing plants shed lots of dead litter, that can build up and choke the site and that further inhibits the less-competitive plant species from establishing. Litter produced in eutrophic wetlands has more nitrogen and phosphorus in it than litter produced in oligotrophic wetlands, so bacteria decompose it easily and release the nutrients into the water. This is the next, and perhaps most undesirable, problem. Enrichment of the water with nutrients causes algal blooms, and changes the algal community from a slow-growing, diverse mixture into one dominated by problem algae like thick filamentous mats and blue-green algal scums. Recent research has shown that New Zealand's lower-nutrient wetlands are a treasure trove of desirable native algal biodiversity, but that nutrient enrichment causes the loss of most of these species and their replacement with a few common species.

1.3 De-oxygenation

The final negative consequence of nutrient enrichment is that all of this excess plant and algal biomass chokes the water and decomposes, causing de-oxygenation and anaerobic conditions. A de-oxygenated site with stagnant water is one that accumulates thick, smelly layers of mud, is prone to mosquito invasions, and may even lose all its plants as they become stressed and killed by lack of oxygen and build-up of toxic chemicals in the anaerobic mud. These are the kinds of negative perceptions of wetlands that are so pervasive in many people's minds and that can often be an obstacle to carrying out wetland restoration, so it's important to recognise that they can be mitigated or avoided by sound nutrient management.

1.4 Nitrogen and phosphorus

The two nutrients that usually need to be managed in wetlands are nitrogen and phosphorus. They are the two main growth-limiting nutrients for plants. Most plants need about ten times as much nitrogen as phosphorus, and they can take it up from the soil in the form of either ammonium or nitrate. In general, they grow best when given a mixture of ammonium and nitrate, rather than one or other alone. Because plants need much more nitrogen than phosphorus, nitrogen tends to be the most important growth-limiting nutrient in the more eutrophic wetlands, where plants are growing faster. Phosphorus is most likely to be limiting in the very oligotrophic wetlands, especially those that get most of their nutrient input from rainwater. In some low-nutrient wetlands, potassium is another nutrient that can become growth-limiting along with either nitrogen or phosphorus. Commercially available fertilisers are therefore usually sold with a specified ratio of these three nutrients (N:P:K ratio, where K is the chemical symbol for potassium) that provides for balanced growth of different types of plants.

Scum on the surface of Lake Kainui, Waikato.

Photo: Monica Peters, NZ Landcare Trust



CASE STUDY



Hollow on farm in Lake Brunner catchment.
Photo: NIWA

WETLANDS ON THE FARM: POTENTIAL SOLUTIONS TO PROTECT LAKE BRUNNER

Farmers around Lake Brunner (Westland) often create a series of long ridges and valleys known as “humps and hollows” across their fields to cope with high rainfall and improve drainage. However, the public perception is that intensive farming coupled with humping and hollowing are increasing the nutrient runoff into the iconic lake. One of the key strategies to mitigate nutrient runoff proposed by NIWA scientists involves encouraging small wetlands at the end of the hollows to process some of the nutrients before they eventually enter the lake. This approach could be used where water is retained in the hollows situated on deep peaty soil, poorly drained heavy silts and clays. Where the hollows reach free draining material nutrients will directly enter groundwater. Most of the nutrient removal is associated with sediment accumulation, denitrification of N in the soil, and accumulation of plant litter in the hollow or further downstream.

Farmer perceptions: wetlands as positives

Farmers around the lake were interviewed to gauge whether they perceived wetlands to be a potential solution to nutrient runoff. For several farmers, wetlands in hollows were a reasonable solution because “there are wetlands there anyway, naturally”. In particular, this solution appealed to those who could not use the hollows because they were simply too wet for most of the year.

Farmer perceptions: wetlands as negatives

Leaving wetlands (or planting wetlands) in hollows was generally negative, as this would:

- Increase the spread of unpalatable, weedy plants, e.g, rushes “moving up the hollows”
- Increase hump and hollow maintenance
- Act as havens for pests such as possums and weeds such as blackberry and gorse
- Add costs and make paddock management more difficult
- Lead to the expansion of wetlands at the expense of pasture
- Increase area of pugging

Reaching potential solutions

Vegetated drains emerged as a possible system for nutrient mitigation. Almost all farmers interviewed had extensive drainage networks on their properties that they maintained, which are periodically deepened and cleared of wetland vegetation. They were quite happy to clean these out in sections and retain areas with wetland vegetation to act as filters “The water can sit there comfortably and won’t affect the pasture and you have to have drains anyway”. Overall, a range of solutions need to be developed so that farmers can select a suitable alternative that fits their beliefs and individual farming situation.

REF: maxa.maf.govt.nz/sff/about-projects/search/06-064/summary-for-farmers.pdf

2 Human impacts on nutrient regimes

Generally, human activities in landscapes lead to nutrient enrichment in downstream wetlands. Scientists have clearly shown in recent decades how urban and agricultural development in catchments increases nutrient run-off, for a number of reasons. Catchment development increases water flows and erosion, loading the in-coming water with nutrients. Many human activities involve fertilisation, for example, for pasture development, and this almost always involves increasing the flow of nutrients into downstream waterways. Managing nutrients in the catchment, and minimising nutrient inputs from the catchment, are therefore the most important strategy for protecting your wetland from excess nutrients. Wetland restoration projects need to be carried out in the context of which activities are taking place in the vicinity, and in cooperation

with other land users. Small projects on private properties need to take into account what else the property is being used for, and whether the planned project can be achieved, for example, in an agricultural landscape. Larger projects may require considerable planning and cooperation among adjacent landowners to manage nutrients effectively.

An intermediate level of nutrients – enough to support healthy plant growth, but not so much as to cause excessive production and nutrient pollution – is usually optimal for wetland restoration projects. Too little nutrient, for example if a sandy or clay-based substrate is used in the project and the site does not have a good water supply, may lead to sickly, sparse and unnaturally short plants that are prone to die-back and fail to develop good cover. Too much nutrient leads to the species loss, weed invasion and eutrophication problems discussed above.



3 Restoring your wetland

3.1 Developing a Wetland Restoration Plan

Your Wetland Restoration Plan should specify the type of soil and the water sources at your site. These two factors control the nutrient level of the wetland, and guide you as to what actions you should be taking to manage nutrients. See Chapter 2 – Restoration planning, for further information. Actions in your plan related to nutrients may include fencing (to exclude stock and create buffer zones), installing sediment traps, or harvesting plants (see Section 3).

Farmers attending a workshop on effective nutrient management. The farm adjoins Lake Komakorau (Waikato), which is currently being restored, with weeds removed and drains ending in silt traps and vegetation filters. Photo: Monica Peters, NZ Landcare Trust

3.2. Determining wetland type

New Zealand is blessed with a wide variety of wetland types, with a correspondingly diverse range of plant communities and habitat types for animals. Much of this variation is due to the natural variation in nutrient availability. Different types of wetlands are characterised by different nutrient regimes, which is further reason to find out what type of wetland you are trying to restore before starting. In order of increasing nutrient availability, the main wetland types are bogs, fens, swamps and marshes, which reflect a gradient from being mainly fed by rainfall (rainfall has very low nutrient concentrations) to being mainly fed by surface water or groundwater. Within one wetland type, there can also be a range of different plant communities favoured by different nutrient ranges. See Chapter 3 – Wetland types for further information on wetland types and their characteristic nutrient regimes.



3.3 Understanding the site

3.3.1 Using a reference wetland

The reference wetland approach discussed in Chapter 4 – Site interpretation, will help identify the nutrient availability that is characteristic of wetlands in your local area, and the plant communities supported by it. Different levels of nutrient availability are suited to different plant communities, and to different vegetation structure. In general, it is much easier to restore wetlands to the type that was originally there, and this is especially true for nutrients.

Look at other wetlands that may still be present in the area, and historical publications or local knowledge, to define the target wetland you should be restoring. What type of wetland is or was common in this landscape? Features to look for include:

- Were the natural wetlands in this area typically forming peaty soils and relatively infertile (very likely in high rainfall regions)? In this case it will be especially important to keep nutrients low.
- Or are they depressions in the landscape with lots of tall and productive plants like harakeke/ NZ flax, cabbage trees, raupo and tussock sedges? In this case much higher nutrient levels can be allowed, although they still should be kept low enough to prevent eutrophication.
- Is there a river or stream in the site, with a good through-flow of water? This can help minimise stagnation and eutrophication, even when there are high nutrient levels.

3.3.2 Restoration site nutrients

The nutrient regime you should be aiming for in your project depends on how far along the bog-fen-swamp-marsh nutrient gradient the site should be. Most degraded wetlands that people want to restore have been subject to excess nutrient inputs, and these can be an obstacle to successful restoration. Look for changes that might have occurred in and around the wetland leading to nutrient enrichment. Things to look for include:

- Channelised water courses flowing into the wetland, especially if these appear to be sluggish and coated with oily or slimy biofilms (i.e. they've probably had wastewater flowing in them at some point).
- Extensive pasture development in the surrounding catchment, and especially if there has been a history of nitrogen fertiliser use. Also, other catchment activities that might be associated with point sources of nutrients: dairy sheds, roads, and waste dumps.
- Digging and clearing of unnatural deep, open ponds in the wetland, for example to create waterfowl habitat. These often become badly eutrophicated.

Further information on gathering information about your wetland can be found in Chapters 4 and 5 – Site interpretation.

3.4. Setting realistic goals and objectives

Nutrients are one of the biggest challenges in setting realistic goals in a wetland restoration project. Excess nutrients are perhaps the most common reason for a disappointing failure for a project to achieve the vision of the planning stage. When a restored site suffers from lots of weed invasion, or dominance by the wrong plant species, or turbid water with algal blooms, or anoxic water that kills fish, it is usually because the nutrient concentrations are too high. Considerations are as follows:

- If values associated with low fertility (e.g., clear open water, diverse plant communities, game fish habitat) are an important goal of the project, a source of clean, low-nutrient water is essential. This may require considerable time and/or money to achieve.
- If the project is taking place in a locality with very high fertility, it may be better to accept this at the start and produce a plan that works with the nutrients rather than wasting precious time and money trying to reduce them. As an extreme example, creating a low-nutrient bog featuring sundews and wire rushes is unlikely to be a practical proposition for a wetland in a depression at the bottom of a pasture valley used for dairy farming. Instead, a wetland more characteristic of high nutrient levels is a more suitable goal. It will also provide benefits for other aquatic habitats further downstream, as it will probably intercept and accumulate nutrients.

Most of the wetlands that are being restored on private land in New Zealand are in fertile lowlands with extensive agricultural activity, and projects in such areas need to be realistic about these issues.

Occasionally, wetland restoration projects have been unsuccessful due to the nutrients being too low rather than too high. This occurs when a high yield of a productive, nutrient-demanding species like raupo is the aim of the project, for example, if harvesting for cultural purposes is an important value of the site. In these cases, careful consideration of the soil type and the feasibility of fertilisation without harming other values are the issues to consider in determining whether a higher yield is a realistic goal.

Nitrogen is almost always the lacking nutrient in these cases. Incorporating slow-release fertiliser into the soil can help, or using a nutrient-rich mud as the substrate. Avoid using the rapid-release types of fertilisers commonly used in garden projects (e.g., ammonium nitrate), as these are likely to wash through readily and pollute downstream waterways.

3.4.1 Keeping it legal

Most sites where people carry out wetland restoration activities will have some connection to other waterways, either via surface or groundwater. Most Regional Plans specify a number of rules to protect waterways from human activities. In particular, disturbance of riverbeds and discharges to waterways of sediments and nutrients are possible inadvertent side-effects of carrying out restoration activities. Contact your Regional Council as early as possible to obtain advice on the impact your project may have on waterways (usually classified as minor, more than minor, and significant), which will determine the extent to which you need to mitigate your activities or obtain a Resource Consent.



Wetland restoration success: this wetland on a farm in Marlborough highlights what can be done when appropriate native species are used and nutrient inputs to the wetland well managed. Photo: Doug Avery

The Howarth Memorial Reserve lies at the edge of the extensively farmed Hauraki Plains creating challenges for effectively managing nutrients entering the wetland from both the river and farm drainage networks Photo: Monica Peters, NZ Landcare Trust



An example of a low nutrient environment: the naturally peat stained waters of Lake Serpentine east, Waikato. Photo: Monica Peters, NZ Landcare Trust



CASE STUDY

TUTAEUAUA: MEASURING NITRATE REMOVAL WITHIN A NATURAL WETLAND

At 620 km², Lake Taupo is the country's largest lake. In spite of the Lake's size, nitrogen and chlorophyll concentrations have increased over the past 30 years. Soils are highly porous, allowing a high proportion of the rainfall onto surrounding catchments to soak to the groundwater, taking with it dissolved nitrogen. The nitrogen is mostly derived from surrounding urban and rural land. To maintain current lake water quality, a reduction of 20% in the nitrogen load from urban and pastoral land (the two major manageable sources of nitrogen) is predicted to be necessary. Wetlands comprise 0.7% of the Lake Taupo catchment area, and are commonly found in riparian parts of upland pastoral areas. These permanently wet features can exceed 1000 m² in size and are vegetated with sedges, rushes and NZ flax (*Phormium tenax*, a predominantly wetland species), although non-native pasture grasses dominate in some areas. Many of the wetlands are unfenced, allowing grazing by cattle, particularly during the summer months.

In 2004, the National Institute of Water and Atmospheric Research (NIWA) conducted two trials in wetlands in the Tutaeuaua catchment (located on the northern side of Lake Taupo) to determine how much nitrate was removed from water travelling through the wetland before eventually entering the Lake.

Methods

A tracer solution of nitrate nitrogen was added to 4 piezometers placed upstream. More piezometers were placed at intervals downstream, and at different depths to intercept surface and groundwater flows (see Chapter 7 – Hydrology for information on using piezometers). A well downstream also provided a convenient place to measure nitrate levels.

Results

- Results from the routine monitoring and the tracer experiment both demonstrate that the wetland was attenuating significant amounts of nitrogen from entering the stream, and along with other potential nutrient removal areas such as riparian zones, was acting as an important buffer protecting stream water quality. The role of wetlands in reducing fluxes of nutrient and sediments to downstream surface waters is well known; however, the significance of this function differs depending on what proportion of water in streams has passed through these zones.
- 95% of the nitrate was lost between the upstream piezometers and the down stream piezometers/well.
- Most of the nitrate removal occurred in the first 24 hours.

Conclusions

Wetlands and stream-bank riparian zones typically will remove significant amounts of nutrients, particularly nitrate, so long as there is effective contact between groundwater and the organic rich sediments within these zones.

- Wetlands can reduce the flux of nitrate into streams within short time frames and over short distances, due to the sponge like capacity of plants and soils, and the microbial processes within the ecosystem.
- Excluding stock from wetlands prevents damage to the plants and soils, therefore protecting wetland function.

REF: Sukias, J. P.S., Long Nguyen, M., Collins, R. and Costley, K. 2004. *Nitrate removal within a natural wetland in the Taupo catchment*. Limnological Society Conference, Waiheke.



Experimental set up with piezometers Photo: James Sukias, NIWA



Well-fenced riparian area protecting the wetland values. Photo: James Sukias, NIWA

4 Tips for working with nutrients

If very low fertility is needed, the only certain method is to collect rainwater in tanks and ensure that this is the only water source for the wetland. A lining in the soil may be necessary to isolate the site from nutrient-enriched groundwater.

Low fertility sites need to be protected from adjacent human activities. Wide buffers (minimum 5 m width) around the wetland from which stock are excluded may be necessary if a healthy, low-nutrient wetland is the target.

If the site is badly nutrient-enriched at the start (you can see this if there has accumulated a lot of dead plant material, or dark smelly mud), time and effort will have to be put in to dig or pump out the accumulated material, and possibly re-contour to an appropriate soil and water depth for the plants and animals you want.

The following methods can be used to reduce the nutrient load into wetlands when low fertility is an important goal for the project outcomes:

- Treat agricultural products such as effluent and silage leachate on the property before it has a chance to enter streams that flow into the wetland. Protect streams that flow into the wetland from catchment nutrients by fencing and riparian strips, and planting buffer zones around the margins to absorb nutrients before they enter the wetland.
- Use sediment traps in streams that flow into the wetland. Many Regional and District Councils have staff that can assist with the design of sediment traps.

When moderate to high fertility is unavoidable at a restored site (most often the case), the following practices can help minimise its impact:

- Avoid having too much water or the water too deep – reduce the rate of in-flow if necessary. Lots of deep, nutrient-rich water will probably kill your plants and will certainly produce algal blooms.
- Instead, having a reasonable rate of water through-flow (lowering the residence time of water in the wetland) will reduce problems such as algal blooms, sedimentation and oxygen depletion.
- When planting, choose species that have high nutrient demands and retain nutrients in their vegetation. Harakeke/NZ flax, tussock sedges such as purei, raupo and lake club rush are all species that thrive in high nutrient regimes.
- In landscaping the wetland, consider planting nutrient-loving species furthest upstream to intercept the nutrients, which will allow you to have areas of lower-nutrient communities and open water further downstream.
- Avoid having large areas of deep, open water, as algal blooms and de-oxygenation are likely.
- Use shade to reduce algal growth – plant faster-growing flood-tolerant trees (e.g., kowhai, manuka) at the margins of the wetland and use shady native plants like cabbage trees, harakeke/NZ flax and purei (all of which do well in fertile environments) in the wetland.
- Remove dead plant litter regularly and compost it off-site, away from the wetland. This can be done at any time of the year, but the best time to do it is winter.



Nutrient rich sediment harvested from a silt trap can be reused away from the restoration site. Lake Kaituna, Waikato. Photo: Monica Peters, NZ Landcare Trust

At Lake Kainui (Waikato) a shallow vegetated excavation at the end of a drain enables some nutrient removal prior to water entering the lake
Photo: Monica Peters, NZ Landcare Trust



4.1 Treatment wetlands

The well-documented ability of some types of swamps and marshes to accumulate large amounts of nutrients and still remain healthy ecosystems has led to considerable interest all over the world in using wetlands as a method for pollution control. Restored wetlands of this type can be useful amenities in the landscape provided they are designed well, as they can help protect the local water quality in streams and small lakes. Some artificial wetlands are specifically designed as treatment wetlands, constructed with linings and artificial substrates that allow them to receive and treat large amounts of nutrient-enriched wastewaters. Creating a treatment wetland on your property can be a very useful way of generating a clean water source that you can use to feed a more natural restoration project. Talk to your local Council about the benefits of treatment wetlands and their applicability to your project. Science organisations such as NIWA have considerable research experience with treatment wetlands and can provide advice on designing and constructing them.

To prevent further nutrient enrichment of the 30 ha Lake Okaro (Rotorua), a 2.3 ha treatment wetland was constructed to capture and processes diffuse farm nutrients from the surrounding catchment.

Photo: Environment Bay of Plenty





Lake clubrush (*Schoenoplectus tabernaemontani*) is commonly planted in NZ constructed wetlands. Photo: Kerry Bodmin, NIWA



Marsh clubrushes (*Bolboschoenus medianus*— pictured, and *B. fluviatilis*) are useful species for providing seasonal diversity in treatment wetlands. Photo: Kerry Bodmin, NIWA



Once mature, the Lake Okaro wetland is predicted to be able to remove around 40–50% of the total nitrogen intercepted. This will complement nutrient reduction from riparian restoration and improved farming practices as well as provide wildlife habitat, enhance biodiversity, landscape and public amenity values.

Photo: Environment Bay of Plenty



5 Monitoring

Most private land-owners and community groups involved in wetland restoration do not have the financial resources to carry out regular chemical monitoring of nutrient levels in wetlands.

However, the height and density of the vegetation in a reference wetland give an indication of the nutrient regime you should be aiming for, and towards which your monitoring should be aimed. What is the height and density of the plants in the reference site? Monitor the height and density at your restoration site after completing your restoration actions. Make sure you do this at permanently fixed points, so that it's a genuinely comparable set of measurements (see Chapters 9 – Weeds and 10 – Revegetation for monitoring methods). If the plants stay much lower than you expected, then some (careful) fertilisation may be needed. However, if the plants begin to exceed the reference site, then you probably have too many nutrients and these need to be reduced. Methods include removing excess litter, digging out any accumulated sediment, and looking at practical ways of reducing nutrient inputs (see previous section).

There are also other inexpensive, indirect indicators of excessive nutrient enrichment that you can use to monitor eutrophication at your site. Things to watch for include:

- Filamentous green algae. All wetlands, even the most nutrient-poor, have some flocculent algal growth in them. However, if the more still and sheltered water in your wetland starts to develop tangled mats of long, bright green filamentous algae, this is a sure sign that eutrophication is occurring.
- Build-up of dark, black, smelly sediment – especially if there is a strong smell of hydrogen sulphide (rotten eggs).



Low nutrient pakihi community, Milnthorpe Park Scenic Reserve, Nelson. Photo: Monica Peters, NZ Landcare Trust.

6 References and further reading

Tanner, C., Caldwell, K., Ray, D. and McIntosh, J. *Constructing wetlands to treat nutrient-rich inflows to Lake Okaro, Rotorua*. Presentation at the South Pacific Stormwater Conference, Auckland, May 2007.

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Wheeler, B. 2002. Restoration of freshwater wetlands. In: Perrow, M., Davy, A. (Editors), *Handbook of Ecological Restoration: Volume 2, Restoration in Practice*. Cambridge University Press, U.K.

Zedler, J. 2000. *Progress in wetland restoration ecology*. Trends in Ecology and Evolution 15: 402-407.

6.1 Useful websites

Constructed wetlands

New Zealand constructed wetland planting guideline

www.waternz.org.nz/

Category?Action=View&Category_id=106

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.