WETLAND NITROGEN REMOVAL MODULES IN OVERSEER®

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Abstract

Recent versions of Overseer include modules for estimating nitrogen removal by natural and artificial wetlands. The module for constructed wetlands is based on mature science and can be used with some confidence to scope potential mitigation. Nutrient removal by natural wetlands is variable and more difficult to estimate, but can be significant. To model natural wetlands, the user is required to input site-specific information based on their knowledge of flow pathways, wetland size, behaviour and vegetation. This enables the user to scope potential nitrogen removal. Expert advice is recommended concerning the enhancement and maintainence of natural wetlands, and the construction of wetlands.

Introduction

NIWA was contracted by AgResearch on behalf of the Overseer owners to develop modules that quantify nutrient removal by wetlands and filter strips prior to runoff leaving a property. This necessitated replacing the old hydrology module with a new daily time-step module. The old version of Overseer allows the user to quantify the effects of alternative farming practices on nutrient runoff. With the inclusion of the new modules the user will also be able to quantify the benefits of four on-farm mitigation measures: (1) natural wetlands, (2) constructed wetlands, (3) contour grass filters, and (4) riparian filters. This paper discusses the wetland modules – filter strip and hydrology modules are described elsewhere.

Wetlands

Water and nutrient are transported off the farm by several different flow pathways. Some pathways are amenable to on-farm mitigation using wetlands but others are not. Table 1 summarises the characteristics of wetlands and Table 2 the main nutrient attenuation processes.

Table 1: Summary of filter strips and wetland characteristics.

Location	flow convergence zones, often fed by ephemeral channels, usually feed permanent streams
Vegetation types	wetland grasses, rushes, sedges, raupo
Ssurface soils	black, smelly, organic, pugging damage by cattle
Sub-surface soils	low permeability layer
Standing water	visible most of the time
Response to rain	rapid flow increase/decrease
Baseflow	low, steady
Flow seasonality	may dry up in summer

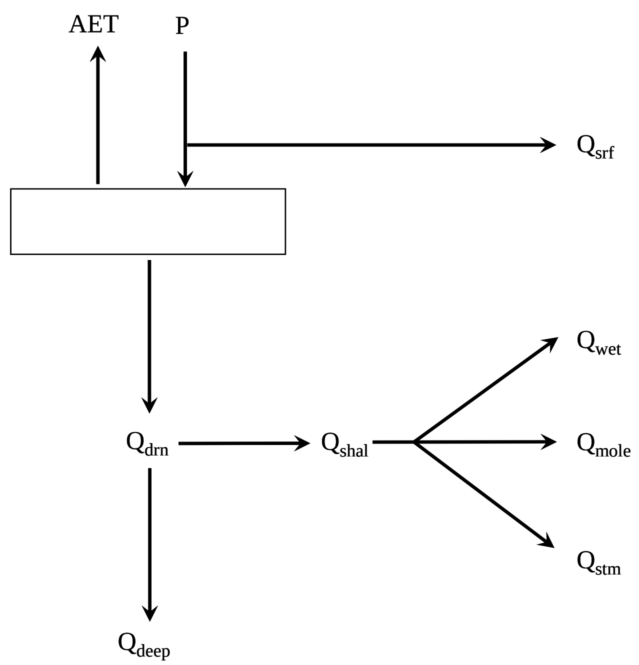
Table 2: Summary of main nutrient attenuation mechanisms in filter strips and wetlands.

Denitrification	permanent removal
Plant uptake of soluble nutrient	detritus remineralises to soluble nutrient
Settling of coarse particulates	may release soluble nutrient
Adsorption of soluble nutrient	soil & redox dependent
Adsorption of fine particulates	may release soluble nutrient

Flow through natural wetlands

The first step in quantifying existing and potential nutrient attenuation by wetlands is to quantify the rates of water and nutrient transport leaving the property by each flow pathway. The conceptual model used to do this is shown in Figure 1 and flow components in Table 3.

Figure 1: Conceptual model of flow pathways.



P = rainfall, *AET* = actual evapotranspiration, Q_{srf} = surface flow in heavy rain, Q_{drn} = total drainage, Q_{shal} = total shallow sub-surface flow that re-emerges on the property, Q_{wet} = flow that passes through wetlands, Q_{mole} = flow from artificial drains, Q_{stm} = groundwater flow direct to streams, Q_{deep} = deep drainage that does not re-emerge on the property.

Table 3: Conceptual model of flow pathways.

Symbol	Process	Comment	Mitigation methods
Q_{deep}	Drainage from root-zone to deep groundwater	Does not re-emerge on the property	By-passes filters and wetlands
Q_{srf}	On hillslopes, tracks etc. during heavy rain. Caused by low infiltration rate	Sometimes re-infiltrates on hillsides	Contour grass & riparian filters
Q_{shal}	Shallow groundwater that re-emerges on the property.	Occurs in ephemeral channels & on flat land during heavy rain. Caused by groundwater level rising to the surface. Includes ex-filtration & rainfall on saturated areas.	Fencing & stock management Wetland enhancement
Q_{wet}	Part of Q_{shal} that re-emerges in or upstream from natural wetlands & bogs.	Usually occurs at the bottom of hillslopes and on flat land close to streams.	Fencing & stock management Wetland enhancement
Q_{stm}	Part of Q_{shal} that flows direct to streams		By-passes filters and wetlands
Q_{mole}	Part of Q_{shal} that re-emerges as drainage from tile & mole to streams	Varies seasonally	Constructed wetlands

The estimation of the sub-surface flow that re-emerges within the catchment poses a serious challenge. Overseer estimates Q_{shal} based on information provided by the user: soil drainage class, depth to the aquitard, wetland type and wetland/catchment area. When wetland type and wetland/catchment area are known Overseer uses Table 4. When soil drainage class and depth to aquitard are known, Overseer uses Table 5. If only soil drainage class is known, Overseer assumes a default aquitard depth of 3-5 m. The relationships in Tables 4-5 are based upon our experience at a few locations within New Zealand and have not been tested throughout the entire country.

Table 4: Relationship between soil drainage class, aquitard depth and the proportion of total sub-surface flow that re-emerges within the catchment.

Wetland/Catchment area	<0.01	0.01-0.02	0.02-0.04	0.04-0.06	>0.06
Type A	0.05	0.15	0.20	0.25	0.30
Type B	0.03	0.10	0.15	0.20	0.25
Type C	0.02	0.03	0.05	0.10	0.15
Type D	0.01	0.02	0.03	0.05	0.10

	Water flow	Vegetation	Stock
Type A	Always flows.	Dominated by sedges and reeds. May contain flaxes, willows etc.	Easily damaged by mob stocking of cattle. Avoided by sheep.
Type B	Flows most of the year. Dry in droughts.	Dominated by sedges and reeds.	Moderate pugging if cattle have access all year. Avoided by sheep in winter and spring.
Type C	Flow in autumn, winter and spring. Dry in summer.	Abundant sedges and reeds. Some pasture grasses.	Pugging if cattle have access in winter. Grazed by sheep in summer and autumn.
Type D	Only flows after rain.	Dominated by pasture grasses.	Grazed by sheep except during wet periods in winter.

Table 5: Relationship between soil drainage class, aquitard depth and the proportion of total sub-surface flow that re-emerges within the catchment.

Aquitard depth	0-1 m	1-2 m	2-3 m	3-5 m	>5 m
Drainage Class					
Well	0.10	0.05	0.03	0.01	0.00
Moderate	0.15	0.10	0.05	0.03	0.01
Imperfect	0.20	0.15	0.10	0.05	0.03
Poor	0.25	0.20	0.15	0.10	0.05
Very poor	0.30	0.25	0.20	0.15	0.10

Overseer assumes that all the flow that re-emerges from the hillslope upslope from a wetland flows into that wetland. It is important to estimate precisely the area of the block which drains to the wetland because this determines wetland inflows. In addition water from mole/tile drains can be collected and piped into natural or more commonly constructed wetlands. Once in the wetland, some of the flow may pass quickly through the wetland in channels and thereby not come into contact with the anoxic, organic soils where denitrification occurs. The proportion of flow that by-passes the organic soils is quantified by the wetland condition factor *COND*. Rain falling directly on the wetland also passes through the wetland. A proportion of the infiltration-excess and saturation-excess surface flow may enter the wetland but a proportion may by-pass the wetland because of flow convergence and channelisation. Within Overseer the user is asked to classify flow convergence in and immediately upslope from the wetland and this information is used to estimate the untreated fraction as shown in Table 6.

Table 6: Relationship between flow convergence and untreated fraction for surface flow entering wetlands.

Flow convergence	Untreated fraction
None	0.20
Little	0.35
Some	0.50
Moderate	0.75
High	1.00

Nutrient removal in wetlands

The dominant nutrient processes in wetlands are:

- denitrification of nitrate by organic, anaerobic soils;
- uptake of ammonium, nitrate and phosphate by aquatic plants;
- settling and infiltration of particulates;
- adsorption of fine particulates onto the surfaces of plants & detritus; and
- mineralisation of particulate organics to release ammonium, nitrate and phosphate.

Vegetation within wetlands reduces the velocity of surface flow and this aids the settling of particulates but Overseer does not currently simulate the trapping of particulates in wetlands. Wetlands are assumed not to remove phosphorus. Of the nitrogen processes listed only denitrification represents permanent removal and is the only process currently modelled in wetlands. Plant uptake, settling and surface adsorption represent temporary storage for the following reasons. First, senescent plant material (detritus) contains organic nutrient and unless this is removed (e.g., by burial, biomass harvesting, stock grazing etc.) will eventually be mineralised by bacteria back into soluble, bioavailable forms. This may happen in the wetland or in a downstream stream, lake or estuary. Second, inorganic sediments release adsorbed nutrient (notably phosphorus) under low redox (anaerobic) conditions. Third, clays that adsorb onto vegetation and detritus may re-mobilise when they dry and/or during subsequent high flows unless they become incorporated into the soil matrix. Fourth, aquatic plants leach dissolved organic nitrogen and phosphorus which has traditionally been considered to have a low bioavailability (i.e., is not taken up readily by aquatic plants). However, biofilms utilise dissolved organic nutrient and their detritus can be mineralised back into soluble, bioavailable forms. In addition dissolved organic nutrients may be hydrolysed by UV light thereby increasing bioavailability. These processes have been quantified in specific situations and some models exist. However, the available models are complex, remain largely untested and require substantial amounts of input data. They are not suitable for a tool such as Overseer. The recommended approach is to use a simplified model based upon our understanding of the dominant processes and supported by field observations of the overall performance of wetlands and filter strips.

Natural wetlands

Similar models are used for natural and constructed wetlands although the input data and coefficients differ. Guidance is provided to help identify natural wetlands. They include: damp, organic soils along headwater streams; saturated areas in paddocks at the head of stream channels or along the edges of channels characterised by wetland grasses, reeds and rushes (termed ‘pasture wetlands’); and fenced areas characterised by larger wetland species (e.g., flaxes, raupo etc.) (termed ‘riparian wetlands’). The ‘effective area’ of the wetland is the total surface area less the area of channels (where there are no plants or organic soils), and less areas that do not receive incoming flow. For most wetlands, channels are a small proportion of the total area. Areas isolated from the incoming flow include side arms and higher parts of the wetland where there are no springs. The principal diagnostic of ‘effective area' is that there is visible moving surface water part of the year and/or evidence of seepage inflow. The rate of denitrification is estimated as follows:

- The user specifies the 'effective area' of wetlands A_{wet}
- The user specifies the catchment area that drains to the wetland CA_{wet}
- Overseer allows a property to be sub-divided into several blocks whose nitrate yields may differ.
- Overseer estimates the annual specific nitrate yield *Yield* (kgN ha^{-1} yr^{-1}) for each block and then calculates the annual average nitrate drainage concentration for that block $C_{nitrate}$ as the ratio of yield to total runoff. Nitrate concentration is assumed to remain constant throughout the year.
- Overseer allows different areas, types and condition factors for wetlands in different blocks. Overseer also allows several blocks to contribute flow to a single wetland.
- Overseer calculates daily inflows to each wetland Q_{wet}. Daily nitrate input to the wetland is $INPUT = Q_{wet}C_{nitrate}$
- The user specifies a 'condition factor' *COND* for the wetland (0 < *COND* < 1) based on Table 7.
- Overseer assumes a specific denitrification rate for wetlands U_{wet} = 250 mgN m^{-2} d^{-1} at 15^{o}C which is a 'typical' value measured in studies at several wetlands in New Zealand and overseas. The removal rate varies with monthly air temperature but is independent of flow and concentration.
- Overseer then calculates the daily denitrification rate within the wetlands

$$\begin{aligned} REMOVE &= A_{wet}U_{wet} \qquad && if\ Q_{wet}C_{nitrate}COND > A_{wet}U_{wet} \\ &= Q_{wet}C_{nitrate}COND && else \end{aligned}$$

It is important that CA_{wet} exclude parts of the catchment that drain directly to streams without passing through a wetland. The best way to make this assessment is to observe surface flow pathways in the catchment during wet weather, in particular identifying the path taken by flow that re-emerges in ephemeral channels. It is recommended that each major wetland be inspected, A_{wet} and CA_{wet} estimated separately for each wetland, and then totals calculated for use within Overseer. During wet weather, daily nitrate inflow may exceed the removal capacity resulting in a low percentage removal. Conversely, during dry weather, the removal capacity may exceed the total inflow in which case outlet concentration is reduced to zero. Overseer reports wetland removal as a percentage of the nitrogen yield from the block. This is lower than the percentage of the nitrogen entering the wetland because not all drainage from the block enters the wetland.

Table 7: Condition factors for natural wetlands.

	Description	*COND*
Class 1	Fenced, well-vegetated, surface flow evenly distributed. No channelisation.	0.90
Class 2	Unfenced. Lightly grazed by sheep. No visible signs of pugging. Surface flow evenly distributed.	0.75
Class 3	Unfenced. Lightly grazed by sheep or by set stocked cattle in summer – not mob grazed by cattle. At most minor pugging. No major channels.	0.50
Class 4	Unfenced. Accessible by cattle. Signs of pugging damage. Signs of channelisation.	0.20
Class 5	Highly channelised wetlands even if fenced. Deeply incised. Inflowing water by-passes vegetated, organic soils.	0.10

Model calibration

Table 8 summarises measurements of potential denitrification rates (DEA) for a number of New Zealand wetland soils. These numbers demonstrate that organic, anoxic wetland soils have the potential to remove significant quantities of nitrate. This was confirmed by Burns & Nguyen (2002) who demonstrated that ~24-48 hours contact time was sufficient for almost complete nitrate removal from seepage flow containing ~0.5 gN m^{-3}. DEA measures potential denitrification – nitrate and often organic carbon are added to the soil samples during the test. DEA can, however, be used to estimate the maximum likely nitrate removal rate. Table 8 shows that in wetlands at Barkers and Whakarewarewa the hydraulic conductivity is highest in the top 10 cm of soil. Assuming that the top 10 cm removes nitrate at the measured DEA rate then these wetlands would have an areal removal rate of 1500 ± 300 mgN m^{-2} d^{-1} (mean ± standard deviation). However, the top few cm may not be anoxic – no denitrification occurs in the presence of oxygen although nitrate may be removed by plant uptake. Nitrate is carried across these wetlands in surface flow and then mixes vertically (Rutherford & Nguyen 2003). High nitrate surface flow may not mix as deep as 10 cm in which case denitrification rate at this depth may be lower than the DEA. Thus 1500 ± 300 mgN m^{-2} d^{-1} is a likely upper bound estimate of nitrate removal rate. Rutherford & Nguyen (2003) injected inert tracer onto the surface of Barkers wetland, Whatawhata, and knowing the flow and the time of passage of the tracer centroid inferred that tracer mixed to a depth of 4-5 cm at low flows and 10 cm at high flows – comparable with the depth of soil in which hydraulic conductivity is high. However, as stated previously, the top few cm may not be anoxic. Assuming that 50% of the mixing depth is anoxic then the likely nitrate removal lies in the range 300-700 mgN m^{-2} d^{-1}.

Table 8: Summary of published denitrification enzyme activity (DEA) and soil properties in New Zealand wetlands.

depth cm	bulk density g cm^{-3}	DEA mg kg^{-1} h^{-1}	porosity	hydraulic conductivity cm d^{-1}
Barkers Wetland, Whatawhata (Burns & Nguyen 2002)				
		5.7 ± 1.8		
Barkers Wetland, Whatawhata (Rutherford & Nguyen 2003)				
5	0.14 ± 0.03	4.1 ± 0.3	0.86 ± 0.04	89.4 ± 38.4
10	0.15 ± 0.03		0.79 ± 0.05	33.2 ± 45.8
15	0.22 ± 0.04		0.79 ± 0.04	3.8 ± 0.1
25	0.29 ± 0.05		0.74 ± 0.05	0.2 ± 0.1
Whakarewarewa (Rutherford et al. 2000)				
5	0.16-0.42		0.55-0.82	7.4 ± 2.4
10	0.18		0.76	6.5 ± 1.3
15	0.32		0.59	2.8 ± 0.6
20	0.20		0.69	3.1 ± 0.5
25	0.60		0.33	3.7 ± 0.2
30	0.25-0.28		0.64-0.68	8.1 ± 1.5
45	0.27		0.67	12.0 ± 1.5

mean ± SD

Table 9 summarises areal nitrogen removal rates. Included are measurements of *in-situ* denitrification rate (e.g., using the acetylene block method) which are the most reliable estimates of permanent removal. Table 9 also contains removal rates inferred from the differences between inlet and outlet nitrate or total nitrogen concentration, or from changes in the ratio of nitrogen/tracer following artificial injection. A drop in nitrate concentration is not proof of permanent loss by denitrification – nitrate can drop as a result of uptake by plants and/or reduction to ammonium. Net removal rates for total nitrogen are typically an order of magnitude higher than for nitrate which may reflect the trapping of particulates. One striking feature of the published denitrification rates is the very large range (11-8100 mgN m^{-2} d^{-1}). Cooper (1990) found that the highest rate in Table 9 (8100 mgN m^{-2} d^{-1}) occurred at the upstream edge of the riparian zone where high nitrate (640 mgN m^{-3}) seepage flow first encountered organic rich and anoxic wetland soils. Close to the stream where nitrate concentrations had been reduced by denitrification (13 mgN m^{-3}) *in-situ* denitrification rates were very low (<2 mgN m^{-2} d^{-1}). At an intermediate site both nitrate concentration (218 mgN m^{-3}) and denitrification rate (6100 mgN m^{-2} d^{-1}) were lower than at the top site, but higher than near the stream. Schipper et al. (1993) showed that *in-situ* denitrification decreased with decreasing nitrate concentration and denitrification enzyme activity. These results indicate that in places where conditions are optimal (viz., high nitrate concentration, high organic carbon and low oxygen) wetland soils can remove nitrate at rates of 950-8100 mgN m^{-2} d^{-1} – rates comparable with the upper bound estimate of 1500 ± 300 mgN m^{-2} d^{-1} estimated earlier from DEA measurements and mixing depths.

Table 9: Summary of relevant published nitrogen removal rates in wetlands and riparian buffer strips.

	Denitrification by in situ measurement		
		$mgNO_3N\ m^{-2}\ d^{-1}$	Comment
Cooper (1990)	organic riparian soils	6100-8100	Highest where g/w enters
Schipper at al. (1993)	organic riparian soils	950-1120	organic zone, decrease as nitrate conc drops
Groffman et al. (1991)	grassland buffer	11-288	
Groffman et al. (1998)	grassland buffer	27	
	Nitrate removal by tracer or inflow/outflow studies		
		$mgNO_3N\ m^{-2}\ d^{-1}$	
Nguyen & Downes (1997)			Pukemanga
ML Nguyen (pers. comm.)		20-30	Howie, Toenepi. Class 2-3
Sukias & Collins (in press)	pasture wetland	5	RC, Taupo. Class 4-5
Rutherford & Nguyen (2003)	pasture wetland	120 ± 80	Barkers, Hamilton. Class 3
Vellidis et al. (2003)	pasture riparian wetland	7	
Hanson et al. (1994)	poorly drained forest	11	
Pinay et al. (1993)	riparian forest	15-29	
	Nitrogen removal by tracer or inflow/outflow studies		
		$mgTN\ m^{-2}\ d^{-1}$	
Mander et al. (1997)	floodplain wetland	270	
Brusch & Nielsen (1993)	stream valley fen	55-164	
Vellidis et al. (2003)	pasture riparian wetland	26	

Denitrification rates from overseas studies (11-288 mgN m^{-2} d^{-1}) (Groffman et al. 1991) were measured in riparian soils where soil moisture, available carbon and redox conditions differed from the New Zealand studies, and it would be unwise to use these rates. Rutherford & Nguyen (2003) injected nitrate and bromide onto the surface of a rectangular section of Barkers wetland (1.5 m long x 1.06 m wide, area 1.6 m^2) isolated by plywood sheeting. By measuring flow and concentrations at the outlet they found that 1.1 ± 0.2 g was removed (24%). Reworking these data yields an average removal rate of 120 ± 70 mgN m^{-2} d^{-1}. Barkers wetland is Class 3 with moderate flow convergence. Correcting for condition factor gives a maximum removal rate of 240 mgN m^{-2} d^{-1}. Removal rates inferred from changes in nitrate concentration between inlet and outlet of large wetlands lie in the range 3-30 mgN m^{-2} day^{-1} and are typically 2 orders of magnitude lower than the *in situ* denitrification rates measured by Cooper (1990) and Schipper et al. (1993). The rates inferred from concentration changes apply to much larger areas of wetland (typically 10-1000 m^2) than the *in situ* denitrification measurements (typically 0.01-0.1 m^2 chambers). The difference suggests that there are localised 'hot spots' within wetlands where denitrification rates are very high (e.g., where high nitrate groundwater first encounters organic, anoxic soils) and areas where denitrification rates are low (e.g., because nitrate has been depleted or the soils are well aerated). Note that measured DEA values are commonly high throughout such wetlands but DEA measurements are made with added nitrate thereby allieviating shortages that may exist in the wetland due to poor mixing. At a constructed wetland in Toenepi, near Hamilton, Sukias et al. (2006b) found that annual average nitrate removal rates ranged average 253 ± 79 mgN m^{-2} day^{-1} (mean ± standard deviation) for the 4 years 2001-2005. TN removal rates were higher but more variable 414 ± 236 mgN m^{-2} day^{-1}. At the RC wetland near Taupo Sukias & Collins (in press) measured an average nitrate removal rate of 5 mgN m^{-2} day^{-1}. This wetland is Class 4 or 5 which, using the condition factors in Table 10, implies that the maximum removal rate is 25-50 mgN m^{-2} day^{-1}. Nguyen (pers. comm.) measured nitrate removal rates of 25 mgN m^{-2} day^{-1} in the Howie wetland, near Hamilton. This wetland is Class 4 which, using the condition factors in Table 15, implies that the maximum removal rate is 125 mgN m^{-2} day^{-1}.

The very high denitrification rates reported by Cooper and Schipper are not used in Overseer because they apply only to parts of the wetland, and the user has no way of estimating where such high rates occur. If plug flow were to occur everywhere in the wetland then these high rates could be used safely. Where nitrate first enters the wetland it experiences a high removal rate and is reduced to zero over a short distance. Thereafter there is no further nitrate removal. Only if the inflow rate exceeds the capacity of the wetland (wetland area times removal high) does any nitrate reach the outlet. However, it would be dangerous to assume plug flow because there is evidence that parts of the wetland are not continuously supplied with nitrate and these parts exhibit a low removal rate despite having a high DEA. If the location of these areas could be determined the wetland area could be reduced and the high removal rate applied to the remained. However, currently reliable ways to determine the area of active soils (viz., to determine mixing rates) do not exist. The maximum removal rate estimated from studies of entire wetlands is used in Overseer because these account for spatial variability. The removal rate used is 250 mgN m^{-2} day^{-1}. This value closely matches the value published by Sukias et al. (2006b) of 253 ± 79 mgN m^{-2} day^{-1} for constructed wetlands at Toenepi and the value of 240 mgN m^{-2} day^{-1} estimated for Barkers wetland from data published by Rutherford & Nguyen (2003). However, it is higher than rates inferred from measurements at the RC (Taupo) and Howie (Waikato) wetlands which lie in the range 25-125 mgN m^{-2} day^{-1}.

Constructed wetlands

Constructed wetlands most suitable for treatment of surface and sub-surface drainage are shallow (0.2-0.5 m) surface-flow marshes vegetated with emergent herbaceous species such as raupo and tall-growing sedges. Denitrification in the flooded soils and accumulated plant litter in the water column is the dominant, sustainable removal process for nitrogen. Plant, algal and bacterial uptake is important in maturing wetlands and can seasonally provide periods of uptake. Once the wetland has matured much of the assimilated nutrients will be gradually re-released within the wetland during senescence and decomposition. However, a proportion of the assimilated nutrients will be stored in recalcitrant plant litter and organic soils. Nitrate removal rates are based on New Zealand and overseas field data from a wide range of mature wetland systems treating flows in which nitrate is the dominant form of nitrogen (>80% of TN). Performance is calculated as a function of the areal hydraulic loading rate on the wetland, influent nitrate concentration, temperature, and estimated wetland hydraulic efficiency class.

Wetland performance data relevant to treatment of nitrate-rich tile drainage from intensive dairy pastures has been collected under New Zealand conditions for constructed wetlands in Northland (3 years), Waikato (5 years) and Southland (3 years), and for an array of small experimental wetlands in Waikato (Sukias et al. 2006a; Sukias et al. 2006b; Tanner et al. 2003a; Tanner et al. 2003b; Tanner et al. 2005a; Tanner et al. 2005b; Tanner et al. 2005c). These studies show that newly constructed wetlands take a number of years to reach maturity, and that treatment levels vary with year-to-year differences in seasonal drainage patterns. In particular, N removal performance is better in warm than in cold seasons and when residence times are extended (i.e., when influent flows are spread out relatively evenly over a period rather than arriving as a few large events). Nutrient budgets over 5 years for the longest-running wetland at Toenepi in the Waikato comprising ~1% of a 2.6 ha drainage area (without supplementary irrigation) showed TN removals from 40-406 g m^{-2} y^{-1} (16-65% of influent loads, Figure 3). Typical TN removals of 100-120 g m^{-2} y^{-1} (30-45% removal) were measured for the mature systems (2003/4-2005/6) receiving loads of 250-350 g m^{-2} y^{-1}.

Wetland treatment nitrogen removal performance has been assessed using a first-order, kinetic model (Kadlec & Knight 1996, Kadlec 2005). Mean removal rates and modified Arrhenius temperature coefficients for nitrate-N removal derived from a comprehensive recent review of available international (65 systems; Kadlec 2005 and pers. com.) and from New Zealand field data were used to calculate nitrate removal rates. Denitrification rates are significantly influenced by temperature and so seasonal variations in percentage nitrate-N removal for the sites were predicted using mean monthly temperatures as an estimate of drainage water temperature. This assumption may need to be modified where the inflow being treated is predominantly groundwater-derived spring-flow, and water temperatures are likely to be relatively constant year round. In this case, average annual air temperature or the measured temperature of the spring should be used. Daily drainage flows and nitrate concentrations derived from Overseer are used to calculate wetland hydraulic loadings, with expected removal rates calculated from Table 9 (assuming wetland inflows = outflows).

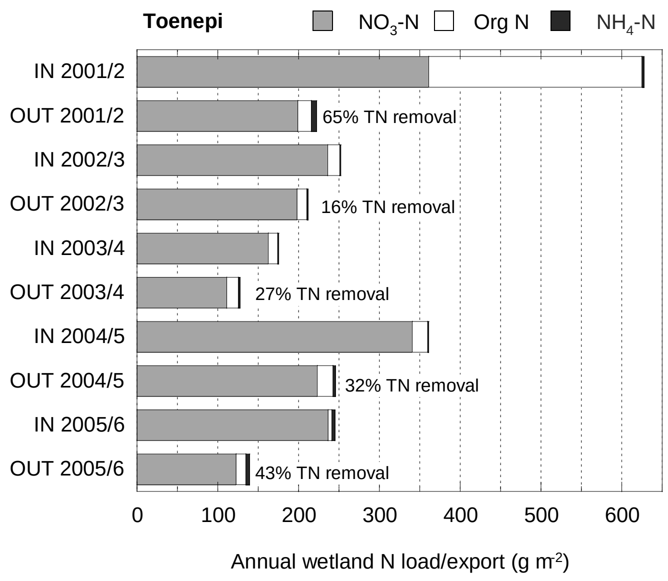


Figure 3: Comparison of annual nitrogen budgets (1 April - 31 March) for a wetland treating pastoral subsurface drainage in the Waikato (Sukias et al. 2006b). Year to year differences in N removal broadly reflect variations in the magnitude and seasonal timing of flow events.

Nutrient attenuation in constructed wetlands is estimated as follows:

- Overseer estimates the average nutrient concentration in drainage flow from annual nutrient yield and annual total drainage flow.
- Overseer estimates daily flow in the artificial drains Q_{mole} using Eq. 35. The daily delivery rate of drainage to the wetland is critical to determining the wetland's ability to attenuate nitrate loads.
- Daily flow in the artificial drains Q_{mole} (m^3 day^{-1}) is divided by the wetted area of the wetland A_{cons} (m^2) to calculate the areal hydraulic loading rate q ($m\,d^{-1}$).
- The internal flow efficiency of the wetland is characterised as:
- Type 1: Flow path length to width ratio >5 (2 or more stage wetland, with even elongated channel or serpentine path created using internal bunds), well vegetated with good dispersion and even flow through the majority of wetland and minimal channelisation or dead-zones.
- Type 2: Single stage wetland with flow path length to width ratio >3, well vegetated with even flow through majority of wetland and minimal channelisation or dead-zones).
- Type 3: Single wetland with length to width ratio <3. Still well vegetated with even flow through majority of wetland, but with greater potential for short-circuiting.
- *COND* in the natural wetland model is equivalent to *Type* used here.
- Based on the water temperature and the hydraulic efficiency class of the wetland, the areal hydraulic loading q is used in the appropriate logistic equation in Table 18 to calculate the percentage reduction in nitrate concentration after passage through the wetland.

Table 9: Relationships for calculating nitrate removal for constructed wetlands treating farm drainage for various water temperature ranges.

Water temperature °C	Fraction of nitrate removed		
	Type 1	Type 2	Type 3
23-24.9	$0.143q^{-0.6471}$	$0.1408q^{-0.6281}$	$0.1367q^{-0.5959}$
21-22.9	$0.1203q^{-0.6864}$	$0.1191q^{-0.666}$	$0.1165q^{-0.6317}$
19-20.9	$0.1011q^{-0.7228}$	$0.1005q^{-0.7017}$	$0.0989q^{-0.6663}$
17-18.9	$0.0849q^{-0.7564}$	$0.0846q^{-0.735}$	$0.0838q^{-0.6993}$
15-16.9	$0.0712q^{-0.7869}$	$0.0712q^{-0.7659}$	$0.0708q^{-0.7305}$
13-14.9	$0.0598q^{-0.8144}$	$0.0598q^{-0.7942}$	$0.0597q^{-0.7598}$
11-12.9	$0.0501q^{-0.839}$	$0.0502q^{-0.8199}$	$0.0503q^{-0.7869}$
9-10.9	$0.0421q^{-0.8609}$	$0.0422q^{-0.843}$	$0.0423q^{-0.812}$
7-8.9	$0.0353q^{-0.8801}$	$0.0354q^{-0.8637}$	$0.0356q^{-0.8348}$

q = wetland areal hydraulic loading in $m\,d^{-1}$. The predictions given are only valid for areal hydraulic loading rates into the wetland between 0.05 and 0.8 $m\,d^{-1}$.

Conclusions

Natural and constructed wetlands have the potential to reduce nitrogen exports from agricultural land. New modules have been included within Overseer that are suitable for scoping potential removal. Site specific information is required to run these modules which requires the Overseer user to walk the farm and be familiar with the data input requirements of Overseer. If the user concludes that natural or constructed wetlands have the potential to reduce nitrogen exports, it is advisable to seek expert advice about construction and maintenance.

Figure 4: Three examples of natural wetlands, and one example of a constructed wetland.

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