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BULLETIN

Constructed Wastewater Wetlands

Constructed wetlands are a low-cost way of treating wastewaters. This Bulletin describes the two main types and their performance in treating meat processing effluents.

Over the last decade, constructed wetlands have become popular world wide as a means of treating domestic, industrial, agricultural and mining effluents.

Two basic types of constructed wetlands are used: surface-flow and subsurface-flow.

SURFACE-FLOW

Surface-flow wetlands are shallow ponds or trenches that are typically 300-600 mm deep. The base of the wetland may be sealed with an impermeable membrane or clay, to prevent seepage to the groundwater.

A layer of soil is placed in the base of the wetland, in which appropriate plants are rooted, and the wastewater is treated as it flows horizontally through the wetland.

With some species of wetland plants, such as giant sweet grass, a floating layer of litter forms on the wetland surface. In time, all the plants become rooted in this organic layer, forming a dense floating mat detached from the soil base.

SUBSURFACE-FLOW

Subsurface-flow wetlands are also shallow, and may have an impermeable liner.

This type of wetland contains a layer of porous material like gravel in its base, 300 - 500 mm thick, in which the plants are rooted.

Wastewater is treated as it flows through this permeable material. The plants therefore grow "hydroponically" in the wastewater as it flows past their roots.

Usually water flows horizontally in subsurface-flow wetlands, but in some wetland designs, the water flows vertically.

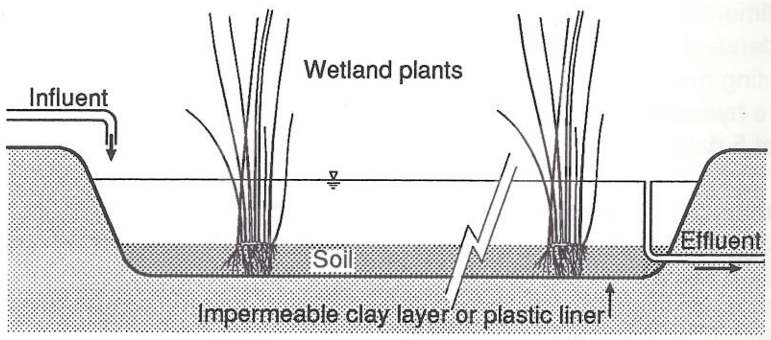
The figure below shows a surface-flow wetland and a subsurface-flow wetland. In New Zealand, subsurface-flow wetlands tend to have gravel as the base (these are called gravel bed wetlands) and horizontal wastewater flow. This wetland type is shown in the figure below.

WETLAND PLANTS

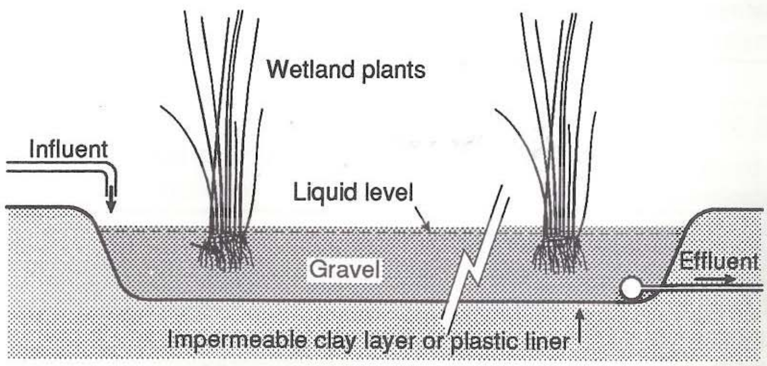
Throughout the world, various plants are used in constructed wetlands. The main species used in New Zealand include Raupo (*Typha orientalis*), soft-stemmed bulrush (*Schoenoplectus validus*) and giant sweet grass (*Glyceria maxima*).

Wetland plants play several roles in purifying the wastewater.

- In surface-flow systems, the plants act as baffles to slow flow and promote sedimentation; they also protect the liquid from wind disturbance.
- Plants shade the water. In surface-flow systems, this inhibits the growth of algae, whose presence can increase both the biochemical oxygen demand (BOD) and the total suspended solids (TSS) in the wetland effluent.



Surface-flow wetland



Gravel bed wetland (example of a subsurface-flow wetland)

- Plant leaves and other litter provide a source of organic carbon, needed for denitrification.
- Active biofilms (bacteria growing in an organic film) develop on plant surfaces.
- Some wetland plants "aerate" their roots, supplying oxygen for root respiration. Oxygen that is not used can leak from the roots. This source of oxygen can result in an aerobic micro-environment around the root system for aerobic and facultative microorganisms. These organisms transform pollutants by reactions that require oxygen. Studies in the field and laboratory, however, indicate that this aeration is of doubtful importance for pollutant removal.

TREATMENT PERFORMANCE

In constructed wetlands, pollutants are removed by a variety of biological, physical and chemical mechanisms.

Suspended Solids Removal

Suspended solids are removed by sedimentation. This sedimentation is enhanced by the baffling effect of the plant stems in surface-flow systems and of the gravel in gravel bed systems.

Slow wastewater flow also promotes sedimentation. Surface-flow wetlands designed by MIRINZ and treating meat processing effluents have hydraulic retention times of at least 5 days.

Effluents from surface-flow wetlands tend to be slightly higher in total suspended solids than those from gravel bed wetlands, as gravel bed systems are more efficient at promoting sedimentation and at filtering out particles.

MIRINZ studies on both types of wetland have shown that neither the degree of prior treatment nor the hydraulic loading rate have much effect on TSS concentration in the wetland effluent.

Likewise, fluctuations in influent TSS concentration are unimportant, although very high influent TSS concentrations can affect wetland performance and longevity.

In gravel bed systems, solids accumulation and biofilm development in the gravel can block the flow through the gravel, particularly near the inlet end. Blockage can be minimized by selecting an appropriate gravel size and keeping the influent TSS concentration below about 100 g m^{-3}. There is considerable doubt about the sustainability of gravel bed systems treating meat processing effluents.

In surface-flow systems, the suspended solids form a sludge layer near the influent end. Although this sludge may not hinder flow, its build-up could reduce the useful life of the wetland. For good longevity, therefore, the influent to surface-flow wetlands should be kept below about 150 g m^{-3} TSS.

BOD Removal

Biochemical oxygen demand (BOD) arises from both settleable solids and soluble compounds.

The BOD associated with solids is removed by sedimentation, after which some will be removed by microbial decomposition in the sediment.

Soluble BOD is removed by microorganisms in biofilms that form on the many wetland surfaces (plants, substrate, sediment).

Usually, the oxygen demand of the wastewater is greater than can be met by oxygen diffusing into the water. Therefore, wetlands tend to be anaerobic.

However, some areas will be aerobic, particularly the surface liquid. Some oxygen may also be released from the plant roots, although it is doubtful that this plays an important role in BOD removal in wetlands.

Nitrogen Removal

In wetlands, nitrogen can be removed in various ways:

- Uptake by plants and incorporation into plant tissue.
- Storage in detritus, microbial biomass and sediments.
- Volatilization of ammonia (NH_3), with release into the air.
- Nitrification followed by denitrification, with nitrous oxide and nitrogen gases being released into the air.

Plant Uptake

Wetland plants take up nitrogen-containing compounds from the wastewater and incorporate them into their tissues. However, unless the plants are then harvested and removed from the wetland, their nitrogen eventually will recycle back into the system as the plant dies or leaves are dropped.

Treatment performance of a surface-flow and a gravel bed wetland and a facultative pond, all treating the same anaerobically treated effluent.

	Mean concentration in influent, g m^{-3}	Mean concentration in effluent, g m^{-3}		
		Gravel bed wetland	Surface flow wetland	Facultative pond
COD	247-261	78	124	161
BOD	105	n.d.	17	68
TSS	78-80	3	15	55
Total N	128-129	105	105	96
Total P	16-17	14	14	15

Normally, wetland plants are not harvested. If they were, under ideal conditions and on an annual basis, it is estimated that harvesting would remove no more than 0.5 g m^{-2} day^{-1} of nitrogen.

Storage

Some of the nitrogen taken up by plants may accumulate as "peat", which forms from plant litter. Nitrogen may also be stored as part of microorganisms' biomass and in accumulating sediment from settleable solids in the waste. A MIRINZ study showed that approximately 13% of the nitrogen removed by a wetland was due to accumulation within the wetland.

Ammonia Release

Under alkaline conditions, significant amounts of ammonia can be released. However, meat plant wastewaters are usually not alkaline enough for this to happen. Most have a pH of less than 8, and MIRINZ estimates that no more than 0.1 g m^{-2} day^{-1} of nitrogen will be lost from wetlands through ammonia release to the air.

Nitrification/Denitrification

This is by far the most important way that nitrogen is removed from wetlands. The nitrification and denitrification steps are carried out one after the other by different bacteria. These bacteria require very different conditions, which causes some problems and imposes some limitations regarding nitrogen removal.

With nitrification, ammonia is oxidized to nitrite (NO_2) and nitrate (NO_3) by nitrifying bacteria. These bacteria need oxygen and are inhibited by organic carbon.

With denitrification, bacteria reduce nitrite and nitrate to gaseous forms of nitrogen (N_2O and N_2), which are released into the air. These denitrifying bacteria need an environment free of oxygen and rich in organic carbon.

If a wetland is receiving effluent from anaerobic treatment, like an anaerobic lagoon, the incoming nitrogen will be present primarily as ammonia, as shown in the figure. Because wetlands tend to be mainly anaerobic, nitrification will be limited. This limits how much denitrification can occur, so nitrogen removal by this pathway will be relatively low.

In MIRINZ's experience with meat processing effluent, typically no more than 22% of the nitrogen in influent from anaerobic treatment is removed at hydraulic loading rates of 30-60 mm day^{-1}, and the presence of plants has little effect.

In contrast, effluent from aerobic treatment contains nitrite and nitrate, ready for denitrification in the anaerobic conditions of a wetland.

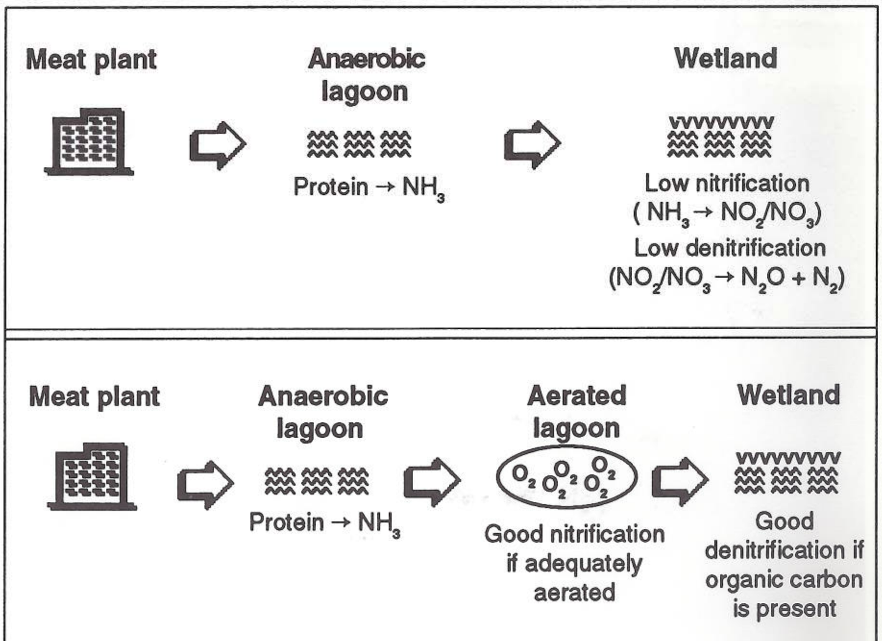
However, as well as requiring anaerobic conditions, the denitrifying bacteria also need organic carbon. Consequently, with nitrified effluents, the amount of organic carbon may limit denitrification and nitrogen removal.

One way to ensure a continuing source of organic carbon is to carefully select what plants are used. Plants that grow all year round and shed their leaves regularly are best. Giant sweet grass (*Glyceria maxima*) is one such plant.

Wetlands containing floating mats of this plant (and associated decaying litter) and treating a nitrified effluent from an aerated lagoon, removed twice as much nitrogen as a wetland that had a nylon mat in place of the plant mat (see table). Nitrogen removal in the planted wetland was more than twice as high as for similar systems treating anaerobic effluent.

Treatment performance of two surface-flow wetlands treating an aerated meat processing effluent in which 61% of the nitrogen was in the nitrate or nitrite forms. The planted wetland contained a floating mat of giant sweet grass; the other wetland contained a nylon mat in place of plants. Hydraulic loading rate was 57 mm day^{-1}.

		Mean concentration in effluent, g m^{-3}	
	Mean concentration in influent, g m^{-3}	Planted wetland	Nylon mat wetland
COD	411	134	143
TSS	330	13	36
Total N	199	100	149



Nitrogen transformations in meat plant waste treatment systems with wetlands as the final stage.

INDICATOR ORGANISMS

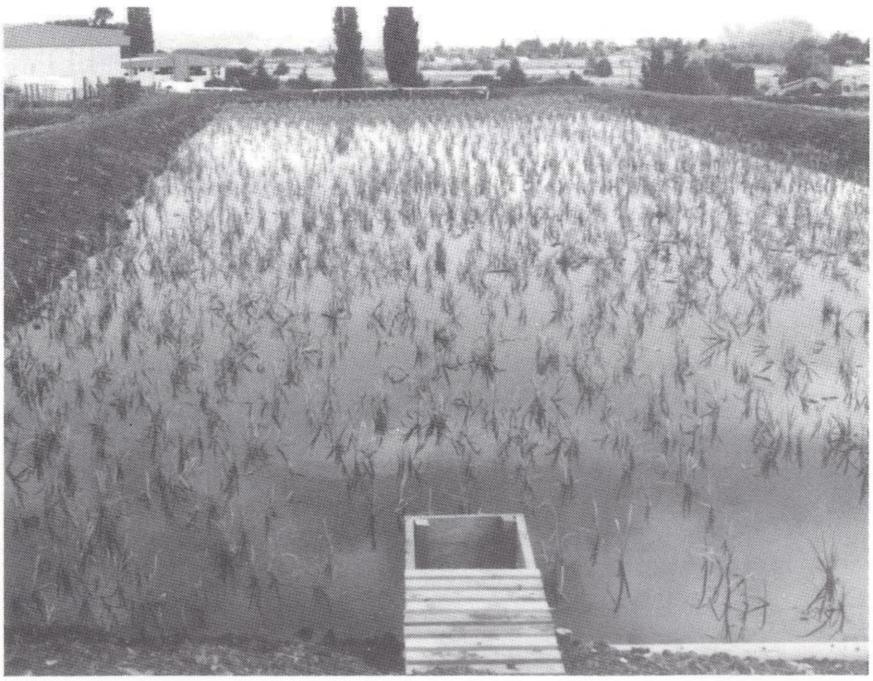
MIRINZ studies have shown that for surface-flow wetlands treating meat processing effluents, the number of faecal indicator organisms is reduced typically by one or two orders of magnitude, and the die-off rates were similar to those in pond systems treating the same effluents.

The actual die-off of indicator organisms in aquatic treatment systems is difficult to determine, however, since waterfowl can re-introduce these organisms.

The main removal mechanism is probably sedimentation, followed by die-off.

IN SUMMARY . . .

- Primary-treated meat processing effluents are too high in BOD and suspended solids to allow successful treatment by wetlands over the long term. Wetlands are best used as a final polishing stage after anaerobic or (preferably) aerobic secondary treatment.
- For a surface-flow wetland to have a long life, the incoming waste should contain less than about 150 g m^{-3} TSS. Gravel bed wetlands are best suited to treating effluent with low suspended solids concentrations, such as from a surface-flow wetland.
- As a tertiary stage after anaerobic treatment, wetland systems remove about 10 - 20% of the influent nitrogen. At least twice as much nitrogen can be removed with influent from aerobic treatment, where much of the nitrogen is in the oxidized form. With aerobic effluent, for good nitrogen removal, organic carbon must be present.
- Gravel bed wetlands give slightly better BOD and TSS removals than surface-flow wetlands.
- Both types of wetlands give better removals of BOD, COD and TSS than ponds treating the same type of effluent.
- Surface-flow wetlands are substantially less expensive to build and maintain, and are much less affected by sludge accumulation than gravel bed wetlands. For these reasons and because treatment efficiencies are similar, surface-flow systems are usually preferred.



A full-scale surface-flow wetland during establishment.

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