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ALTERNATIVE WASTEWATER DISPOSAL METHODS

by

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EXECUTIVE SUMMARY

This report presents a summary of a number of papers dealing with alternative wastewater treatment systems. The number of papers covered by this topic is by no means exhaustive. The report is designed to allow conservancy staff to get a quick grasp of some of the literature on alternative systems and has been structured according to the main types of alternative treatment that are available. These are:

- Small scale or community based systems, usually using a scaled down version of one or more of the systems listed below, and often in conjunction with septic tanks for primary treatment
- Surface (overland) flow artificial wetlands where wastewater flows over the surface of the substrate and is treated by plants growing in the water
- Subsurface flow artificial wetlands in which plants grow hydrophonicly in a substrate which the wastewater is treated as it flows through it
- Discharge into a natural (existing) wetland. This is best used for small communities or as a polishing stage
- Land application where wastewater is applied to land that may be planted in crops, pasture, forest or bare. The wastewater is treated by nutrient uptake from plants and/or filtration through the soil

The final section deals with animal waste (from slaughter houses, dairy sheds etc.). The amount of nutrients in this type of waste can pose special problems in treating it on site. Oxidation ponds have generally shown poor performances and the discharges from them could be made cleaner with the use of one of the alternative systems described above in conjunction with these ponds.

The main advantages of these systems over conventional methods of treating wastewater are:

- They can be easily maintained and are cheaper to run
- They can be set up on a small scale so that even small communities can afford them
- They can be used in remote places
- These systems are based on relatively low technology
- Artificial wetlands may provide a new habitat for wildlife
- The nutrients in the wastewater, which is what gives it much of it's undesirable qualities, is put to good use as fertiliser and irrigation for pasture or forests

- Harmful bacteria rapidly die off over a period of up to two weeks so that a major health threat is removed.

- Local plants that are well adapted to the conditions may be used in such systems.

There are drawbacks with some of the systems:

- They all must be well maintained otherwise there is the risk that the system will fail though clogging or some other build up of nutrients and/or sediments

- All systems require some form of primary treatment and usually also secondary treatment of the effluent that they receive

- Some of the systems may not work in cold climates or areas where the slope or soil type is unsuitable

- Natural wetlands treatment can result in changing the ecosystem which could threaten some species. Constructed wetlands on the other hand may provide an alternative to this.

All of the treatment systems are very site specific and all designs should be reviewed on a site by site basis.

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INTRODUCTION - AIMS OF THIS LITERATURE REVIEW

The aim of the literature review is to provide a summary of current knowledge of the alternative wastewater disposal systems now available. This document is intended for use by Department of Conservation staff so that they can quickly get a grasp of the literature and research that is available. It will also allow the reader to locate key people within and outside the Department of Conservation who can advise them on specific matters.

The list of papers in this document is by no means exhaustive. Time and space has permitted that only a few key papers could be reviewed in each section. I have summarised the information so that conservancy staff can get a quick grasp of the facts - for more detailed reading it is recommended that the original documents are referred to. The papers also contain references to many other papers on the subject so that access to more detailed information is made easier.

I would like thank the various Department of Conservation staff members at Head Office -especially the Estate Protection Policy Division for their help in preparing this document and especially John Waugh and Marcus Simons, who gave considerable advise and helped with the proof reading. I would also like to thank Jeff Grigs of the Northland Conservancy Office for his helpful comments on the draft of this literature review.

SMALL SCALE SYSTEMS

These vary from single on-site systems for such purposes as polishing septic tank effluent up to the scale of small communities -especially resort communities where seasonal variations in use can be very high. There is often a need for small cost-effective systems that are easy to build and maintain. These are often areas of cold climates (South Island) and are locations where it is important to maintain a high quality of water in the waste water receiving area, eg: coastal areas, estuaries and beside lakes.

McNeil and Bradley (1988) gives a brief overview of some alternative wastewater treatment systems that have been in the South Island (mainly Otago, Southland and Canterbury Conservancies).

Fisher (1988) looks at a Surface Flow Wetland system at Richmond, New South Wales but the article has been put in this section because if the good section of a small scale site system at Kamina, Papua New Guinea.

Northland Regional Council (1990) gives a very brief descriptive summary of several community scale operations in Northland (Northland Conservancy)

McNeil, P. and Bradley, J. W. (Royds Gardens), 1988. Alternative Waste Treatment Systems in Southern New Zealand in *Alternative Waste Treatment Systems.* Elsevier Applied Sciences, London. Pages: 241 - 249

Wastewater treatment systems must be cost effective and accommodate the particular physical site constraints, waste characteristics and environmental concerns of the project. Southern New Zealand poses a unique challenge when considering the type and level of technology to be applied to the physical and environmental conditions encountered. The paper gives a general overview of the technology but is not specific about the relative financial costs about each system.

Common Requirements

Cost effective, easy maintenance, high level of treatment in environmentally sensitive areas. South Island has a low overall population and population density, pristine areas with a high demand for preservation of water quality. Holiday population is extremely transient.

Types of Systems

On-site systems

Conditions often unsuitable for the septic tank and absorbtion field system -is of relevance to small communities with medium to high dwelling densities where a lack of absorbtion causes unsanitary conditions and illegal discharges off properties. The use of PVC pipes has produced significant cost savings. Long pipes may be laid which can link communities.

- Low cost treatment alternative
- When processed by a facility for solids removal can accomplish excellent reductions in BOD, suspended solids and bacteria. Treble Cone (Canterbury Conservancy) - IBSF system constraints:
- Limited space, high quality of effluent required, high altitude -cold, raw effluent varies widely in quality and quantity, no permanent power, personnel and available for significant operation & maintenance activity, no trained personnel, winter operation only.

The system is protected against the harsh climate and heated. Good removal of suspended solids and BOD reduction.

Aerated Lagoons

Similar to oxidation ponds but oxygen is introduced by mechanical means. It is often used prior to oxidation pond treatment. There is little or no structural work in digging out the shape of the lagoon. The technique can be used to reduce holiday peak loads. It is cost-effective compared to conventional systems.

Rotating Biological Contactors

Simple operation, ability to handle high shock and variable loads -holiday and weekend communities. The paper gives no specific information about this system.

Oxidation Ditches

Used on small sites where land is at a premium - has been used for Alexandra. Odour production is minimal due to completely mixed aerobic environment in which wastes are degraded. Compact versions of the type of treatment can be made unobtrusive.

Land treatment and Disposal

- Advanced "polishing" (final treatment stage) of effluent.
- Palmerston -oxidation pond grass plot overland flow system. Grassed application areas are sequenced while sheep are grazed in between applications.

Fisher, Peter J. 1988. Wastewater Treatment using Aquatic Plants in *Alternative Waste Treatment Systems.* Elsevier Applied Sciences, London (pp. 34 – 44)

This paper has two case studies on wastewater treatment using aquatic plants in constructed wetlands.

Richmond (New South Wales)

A large scale pilot plant was located near Richmond (New South Wales) on which had a two year study on seven plots receiving secondary treated waste was conducted. The aim was to test low cost, low maintenance, energy efficient methods. Treatment potential of aquatic macrophytes (large aquatic plants) in either natural or constructed systems was assessed. It was established in 1983. Macrophyte and two control trenches without plants (1 open water, 1 gravel) with dimensions 100 m by 4 m, 0.5 m deep were used with an application rate of 0.1 -1.8 ML/ha (Million litres/ha?) per day.

In the open water region of trenches algal blooms blocked the down stream interface, significantly reducing effluent flow. Gravel filled macrophyte trenches -suspended solids and BOD were effectively removed -rapid drop in levels over the first 10 to 20 m were due to filtering and sedimentation within the gravel. Nitrogen (N) removal was poor due to slow development of nitrifying bacteria populations in the trenches. N removal occurred with 5 to 10 days retention time. Only limited accumulation of oxidised nitrification - if oxygen can be transferred via plant roots into the trench systems, then nitrification and denitrification will readily follow. Little phosphorus (P) removal. Gravel control comparable removal of BOD, N, P. Suggests filtering and sedimentation of particulate matter was a significant nutrient removal mechanism. Gravel based aquatic macrophyte systems had a high die-off rate of faecal coliforms – Combination of sedimentation and natural die-off, supplemented by ultra violet radiation.

Kamina (Papau New Guinea)

A remote site (pop. approx. 150 people). 198516 -aid project to build a health clinic with reticulated system to remove solids. Pit dimensions were 15 m by 4 m, 0.5 m deep.

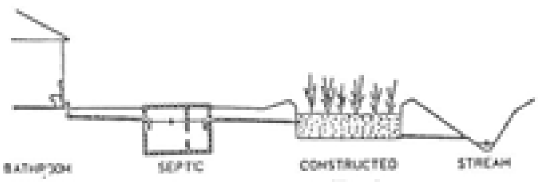


Figure 2: Details of Kamina sewerage project.

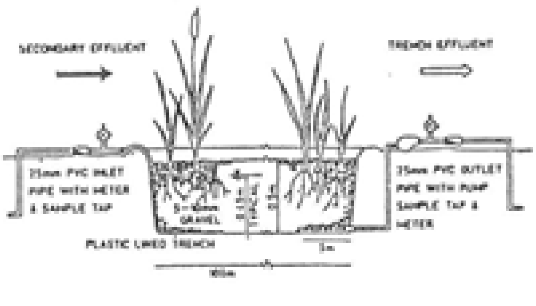


Figure 1: Typical trench longitudinal section.

Effluent percolated through the gravel to the outer pipe. Effluent level was below gravel surface level which minimised algal growth that could clog the gravel and prevented surface ponding that could act as a breeding ground for mosquitos. The system was a low cost, low maintenance method of polishing and upgrading the qualities of wastewater -it can produce a very high bacteriological standard of effluent.

The main design considerations are: simple design, no complex energy consuming equipment and an aquatic plant system that requires little technical backup.

Northland Catchment Commission, 1988. Wetland Sewage Treatment in Northland. ***Water and Wastewater Treatment Plant Operators 26 (4):*** **pp: 11 - 23**

This is a summary of a report that briefly outlined a number of community alternative sewage treatment systems that are being used in Northland. The more interesting projects are described below. The paper gives a brief description of each operation, but does not go into any detail and does not tell the reader where these places are.

Awanui Township

Activated sludge extended aeration plant (the reader is not told what this is) -large fluctuations in water quality recorded, but over last 10 years balanced effluent easily achieved using constructed marsh treatment systems for tertiary treatment. Low maintenance and skill required.

Ahipara

Previously septic tanks and surface irrigation on to fields but soakage inhibited by 1 m deep pan. Borewater extensively used which indicated a pollution problem. Now uses aerated lagoon and then pumped 2 -3 km to a cultivated marsh system. 4 cells irrigated alternatively. 100 cubic metres/day maximum discharge - effluent is absorbed into the ground within 200 m of the discharge.

Hihi Beach

Activated sludge plant. Waiuwa Stream -faecal contamination from failing soakage fields -intends a constructed marshland for tertiary treatment before disposal to a natural marsh at Hihi Beach.

Whangaroa

Some foreshore pollution -activated sludge aerated plant lead to reduced bacterial levels. Constant attention is required. Sand filtration to be installed which will require constant attention but there is no land available to construct a conventional marsh system.

Kerikeri

Steady rise in pollution in Kerikeri Inlet since 1976. Proposed primary and secondary treatment with effluent pumped into a large marsh in Waitangi Forest for disposal and tertiary treatment. October, 1989 was on line - marsh was monitored for three years beforehand to determine base levels.

Tapeka Point

Early (1971) activated sludge plant -irregular results. Since had small scale marshland with two surface flow ponds and a root zone system.

Ruakaka

Oxidation pond, marsh tertiary treatment. Effluent from common marsh system disposed of in sand filtration area. The number of birds and species increased manyfold in area surrounding the marsh. Marsh system fosters the removal of algae by several mechanisms -allows effluent to soak into sand dunes without significant ponding. Nutrients in effluent will promote growth of grasses etc. and stabilises dunes.

Waipu

Effluent discharged into sandhill subsurface irrigation field -low bacteria levels 10 m from disposal area.

WETLANDS

Treatment by using wetlands involves passing effluent (usually treated sewage) through a wetland in order to remove nutrients. The section is divided into subsections according to the type of treatment. They are: using constructed wetlands, where an artificial wetland is created in order to treat the sewage, and natural wetlands, where the effluent is treated by passing it through an existing wetland.

Constructed wetlands may also be divided in to surface and subsurface flow types. In surface flow wetlands effluent flows over the substrate with aquatic plants either floating or partly immersed in the effluent (such plants may include duckweed or bulrushes). Subsurface flow wetlands involve passing effluent through the substrate with aquatic plants such as bulrushes growing hydroponically in it and oxygen being brought into the system by the plants through their roots. In all cases of wetland treatment, treated effluent is discharged into a wetland as a means of removing nutrients before final discharge into a receiving water (this is referred to as polishing).

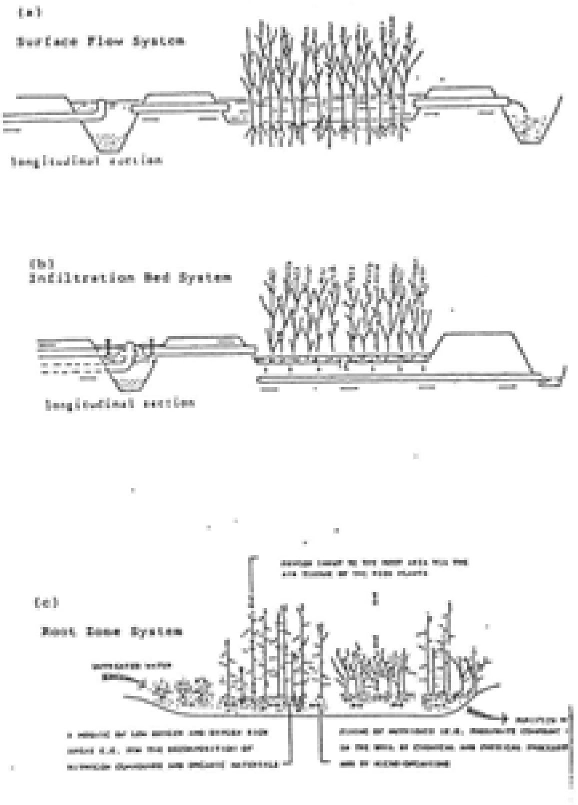
Venus (1987) gives a general review of all types of constructed wetlands.

Kloosterman and Griggs (1988) gives a more detailed overview of constructed wetlands and also goes into many of the design considerations. It also has a very extensive list of relevant references.

Venus, Garry C., 1987. *Wetland wastewater treatment: A review.* G. C. Venus, Whangarei.

The following entry is a summary of Venus' report on various wetlands wastewater treatment systems, which are a relatively new method of treating wastewater. It deals with the subject from a New Zealand perspective.

The illustration below from Venus (1987) shows three basic artificial wetland systems.



from Lawson (1983)

Types of Wetland Systems

Root Zone System

- Dense growth of reeds. Treatment takes place in the root system.
- Diverse species of bacteria giving desired level of treatment. Emphasis on soil organisms and enhanced ion exchange between the water and soil.
- Deeper rhizome of *Phragmites* (reeds) encouraged leading to porous soils.
- Aerobic composting of sludge and decomposing leaf matter.
- Passage of oxygen though reed stems into root zones creates aerobic spaces in low oxygen areas giving increased decomposition.
- No harvesting of plants. Bed engineered to wastewater characteristics

Only general information is given -nothing specific about the life expectancy, odour production of relative costs of this type of system. Cost-wise Venus simply says that it is relatively cheaper that a conventional sewage treatment system.

Artificial Surface Flow Wetlands

An effective but new technique. Floating aquatic plants are used for removal of heavy metals.

Natural wetlands

These have few water quality problems compared with conventional systems, but there is not enough available (NZ) data at present. Nothing is mentioned about possible ecological impacts.

Effectiveness of Wetland Treatment Systems

- BOD reduction can be significant
- Suspended solids - little net reduction but wastewater is transformed in character from effluent derived to wetlands derived (such as plant detritus).
- Surface flows not effective at nitrification but are effective at denitrification (Subsurface flows are the opposite). Operational data is inconsistent.
- Phosphorous removal is intermittent. Removal is by precipitation and absorbtion onto sediment particles (main mechanism) and sedimentation (lesser mechanism). Ultimate phosphorous removal can be achieved by: Harvesting of plants, dredging of sediments and reabsorbing of phosphorous stored in sediments and release to receiving waters when it would have the least environmental impact.
- Bacterial and viral pathogen reduction is much greater than conventional systems.
- Metals - removed by plant uptake, chemical precipitation, ion exchange with and absorbtion to clay and inorganic compounds. Removal by plant uptake and harvesting is small.

Maori Values

Apparent general support of Maori communities because this type of treatment avoids direct discharge of effluent into receiving waters. Some objections were made by local communities because these systems ultimately involve water being discharged into receiving waters. Proponents of such schemes should consult with Maori communities at the earliest possible time to cultural impacts.

Conclusions

Suitable New Zealand applications wetlands treatment systems (no specific system is mentioned here) are: Small scale (ie: a few households), Intermediate scale (ie: up to a small town) and polishing of effluent before discharge into sensitive receiving waters. Lack of reliable long term data in New Zealand. Research (ie: on site in situ pilot trial) needed, including data on New Zealand plant species.

Hammer, D. A. (ed.), 1990 (2nd ed.) ***Constructed Wetlands for Treatment. Municipal, Industrial and Agricultural.*** **Lewis Publishers, Michigan 48118, USA.**

This book is divided into 4 sections:

Section 1 - General principles
Section 2 - Case Histories
Section 3 - Design, construction and operation
Section 4 - Recent results from the field and laboratory.

General Principles

The first paper on a general perspective of constructed wetlands lists the components advantages and disadvantages of constructed wetlands:

Components

- Substrate -with a hydraulic conductivity
- Plants adapted to water saturated anaerobic substrates
- A water column (in or above the surface of the substrate).
- Invertebrates and vertebrates
- Aerobic and anaerobic microbial populations

Advantages of Wetlands

- Relatively inexpensive to construct and operate
- Easy to maintain
- Effective and reliable treatment
- Tolerant of fluctuating hydraulic and contaminant loadings
- Indirect benefits - new wildlife habitats

Disadvantages of Constructed Wetlands

- Large land requirements
- Current imprecise design and operating data
- Biological and hydrological complexity and a lack of understanding of important process dynamics.
- Problems with pests

Section 2 - Case Histories

Various case studies, mostly from North America, are discussed in this section.

Section 3 - Design, Construction and Operation

A paper by G. A. Brodie contains a flowchart (pp. 315) which gives a generalised view of the methodology in setting up and running an operation. This chart has been reproduced below.

Siting considerations include: land use, hydrology, geology, environmental and regulatory considerations.

Section 4 - Recent Results

This is the largest section in the book and has a large number of papers on various topics on constructed wetlands.

Because of the size of the book it is not possible to review it all.

Kloosterman, V. and Griggs, J. 1988 ***Manual for Alternative Wastewater Treatment Systems. Volume I - Wastewater Wetlands.*** **Works Consultancy Services, Whangarei.**

Aim of the report

The report presents information on various aspects of constructed wetlands to allow the evaluation of various proposals utilising constructed wetlands for wastewater treatment. It describes a range of design and operating parameters. Sections 1 to 3 are reviewed and the section on operation and maintenance are examined in more detail than the design parameters.

The co author - Jeff Griggs - is from DOC's Northland Conservancy

Types of constructed wetlands:

Surface Flow Wetlands

Systems with emergent plants such as bulrushes are applicable to the New Zealand situation. Systems with floating plants use plants that are considered as noxious pests in New Zealand so are not appropriate.

Subsurface flow (Root zone systems)

Emergent plants rooted in substrate and grow hydroponically as effluent is passed through the substrate and root zone.

Pollution Removal Mechanisms:

BOD removal

That associated with settleable solids in the wastewater removed by metabolic activity from microorganisms.

Solids

Long hydraulic residence times within these systems means that solids settle out. Solids are also removed by bacterial growth and adsorption onto sediment.

Nitrogen removal

- Bacterial nitrification/denitrification(greatest)
- Volitisation of ammonia
- Uptake by and subsequent harvesting of plants

Phosphorous removal
Variable and transitory.
Primary mechanism: biological and chemical storage *in situ.*

Bacteria/viruses

Die-off by exposure to physical and chemical processes, biological inactivation and predation by micro-organisms.

Heavy metals

- Chemical precipitation
- Ion exchange with and adsorption to settled clay and organic compounds.
- Plant uptake.

Refractory organics

Plant uptake, adsorption to intra system surfaces and changes to the chemical nature of compounds.

Wetland Applications

Domestic sewage

individual households, small and large community (municipal) scales.

Seasonal recreational communities

Examples include coastal communities where there is seasonal loading (may also enhance wildlife habitat).

Farm waste

Seasonal fluctuations of farm waste can still degrade stream quality even if they comply with existing guidelines.

Design Parameters

- Establish treatment objectives - standards of receiving waters, influent wastewater type, hydraulic loadings
- Establish design objectives -maximum flexibility and versatility, simple operation, minimum maintenance
- Evaluate site conditions -topography, soil type natural drainage, climate
- Determine pollutant mass loadings eg: BOD, Suspended solids, Nitrogen, Phosphorous
- Select wetland type
- Select suitable plants
- Select substrate
- System design parameters -lay-out etc.

Operation and Maintenance

Larger systems should be divided into a number of separate cells so that specific areas can be isolated for maintenance without affecting the whole system.

- Surface flow -drain cells and remove unwanted plants
- Subsurface flow -adjust water level -drown out unwanted species

Pest problems - mosquitoes controlled by keeping the water level below the top of the substrate - this will also minimise odour.

Harvesting

- Remove accumulated plant biomass reduces BOD, suspended solids, phosphorous loadings released by decaying vegetation
- Reduces water surface congestion -improves circulation. Cutting and mulching in place gives a source of carbon that improves nitrogen removal.
- Commercial harvesting
- Removes nutrients and toxic trace elements previously assimilated by plants.

CONSTRUCTED WETLANDS
SURFACE FLOW

The following papers which have been summarised deal with surface flow constructed wetlands.

Wolverton (1987) is a good introductory paper on the subject of surface flow wetlands. It appeared as the first paper in the hook Aquatic Plants for Water Treatment and Resource Recovery. This book was obtained by myself though library interloan from the MAF Regional Library at Invermay, Mosgiel. This is the only entry under this heading.

B. C., 1987. Aquatic Plants for Wastewater Treatment. in *Aquatic Plants for Water Treatment and Resource Recovery.* by Reddy, K.R. and Smith, W. H. (eds.) Magnolia Publishing Inc. pp. 3 - 16

- Steady increase in such methods over the last 20 years.
- NASA one of the main leaders in developing such technology because of its importance in the space programme.
- Wetlands treatment involves the cooperative growth of both plants and organisms associated with the plants - especially around the root systems (a symbiotic relationship).
- Organic chemicals are degraded and plants adsorb as food along with N, P and other minerals -also removes suspended solids and brings oxygen from leaves to root-zones.
- Water Hyacinth *(Eichhornia crassipes)* -the most studied plant -detrimental and beneficial effects on the environment -has been used in a number of projects. Reeds *(Phragrnites)* have also been used.
- Duckweed (*Lemna, Spirodela,* and *Wolffia* sp.) - wide geographical location – can vegetate at temperatures down to 1° to 3° C but can cause anaerobic conditions of a total mat forms.
- Biomass removal is required for sustained functioning -may be converted into energy, feed or fertiliser.

CONSTRUCTED WETLANDS SUBSURFACE FLOW

The following articles that have been summarised are on suhsurface flow constructed wetlands.

Steiner *et al.* (1991) gives a very good introduction to subsurface flow wetlands. It is aimed at getting some of the technical facts across to a layman who may be considering building such a system. It was published by the Tennessee Valley Authority.

Worrall (1992) is an introductory level article on subsurface flow constructed wetlands which appear in a popular science magazine in the United Kingdom.

Cooper *et. al.* (1989) is a paper form the United Kingdom which has been written at a technical level on subsurface flow wetlands. An interesting technique used these people was a mobile 'test tank' wetland.

Brix (1987) is a technical paper on subsurface flow wetlands on Northern Europe where the cold weather can be an additional factor. Subsurface flow wetlands will still work in cold climates so this paper is of relevance to some South Island locations.

Gersberg *et. al.* (1987) is a technical paper written on a trial system at Santee, California.

Gersberg *et. al.* (1987) compared a number of plant species with a control bed. It found that in the conditions and location they had, bulrushes generally were the best plant to use in subsurface flow wetlands.

Gersberg *et. al.* (1984) looks at the ability of a subsurface flow constructed wetland to remove viral and bacterial pollutants.

Steiner, G. G., Watson, J. T. and Choate, K. D., 1991 General Design, Construction and Operational Guidelines. Constructed Wetlands and Wastewater Treatment Systems for Small Users Including Individual Residences. Tennessee Valley Authority, March 1991

The following report that has been summarised briefly deals with the design parameters in a subsurface flow constructed wetland. It is a technical document which also has a lot of general information on this type of treatment.

Constructed Wetlands (CW) are very site specific -all designs should be prepared and reviewed on a site by site basis.

Pre-treatment

Low flow fixtures help to minimises wastewater. Septic tanks should precede constructed wetlands to remove coarse and heavy solids.

Hydraulic and organic loading

Can be determined on a number of household bedrooms basis. Organic loading of 0.5 kg BOD_5 per day/person.

Basis of CW design and construction

Type

subsurface or surface flow (surface flow not covered in report).
Small - single cell. Larger -2 cell in series. Multiple cell system in parallel and or series.

Dimensions

1.3 square feet/gallon/day (the report is written in imperial units). Aerobic microorganisms that degrade waste organics obtain oxygen from plant roots.

Various Design Features

Liner

Control of water level, prevents seepage either out of the cell or infiltration into the cell - compacted clay , heavy duty PVC or a sealed concrete block.

Substrate

the most common type is sized, washed (no fines) gravel -rounded (river) surfaces. Other options: sand or a gravel/sand mixture. Limestone compacts easily and may react with silicon to from a gel that clogs the gravel so should not be used. 5 cm to 10 cm stones at the ends of the cells, pea gravel (1 cm) in the middle zone. 8 cm layer of surface mulch on top of the substrate controls odours, prevents sun scalding of vegetation, visual attractiveness.

Pumping and piping

Ideally gravity flow or pumped at a low rate (1/3 the design rate) perforated PVC drainpipes.

Water level control

Water level control is critical - plants must not dry out or be drowned out measured in a standpipe.

Berms

Prevents surface runoff entering the system, retains the wastewater, compacted clay prevents seepage.

Vegetation

Use plants that grow naturally in the area. This American report recommends the following plants: Cattails, sedges, grasses, bulrush, giant reed (*Phragmites australis*). Decorative species have an aesthetic attractiveness and may he used on the cell perimeters the report recommends the following plants: lilies, elephant ear, water iris.

Planting

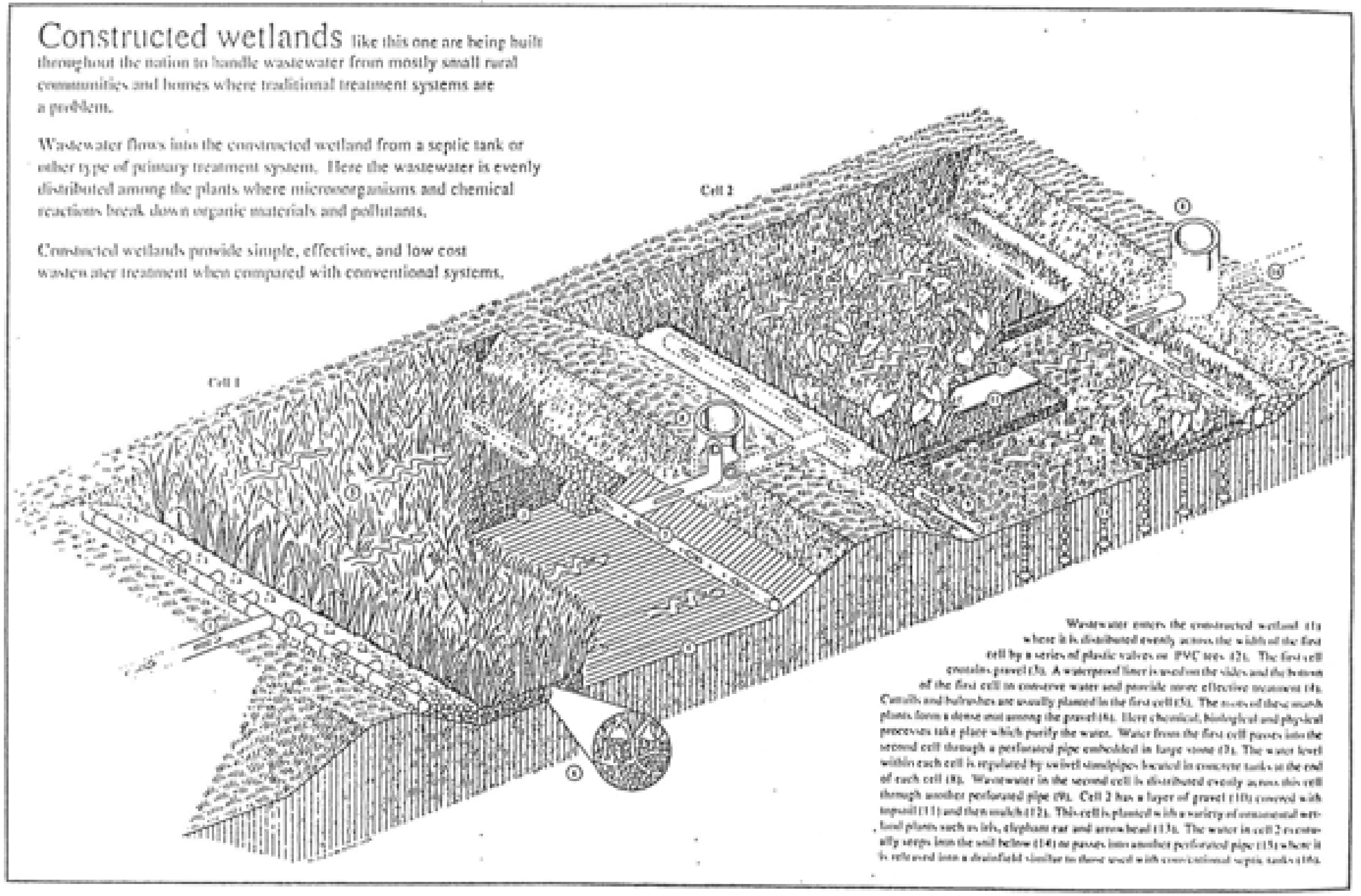
Planting over summer reduces winter mortality -grid pattern gives an even distribution.

Start up

One growing season before continuous discharge of wastewater. Water + fertiliser to start with.

Water level

Should be 3 cm below the top of the substrate needs to be maintained and checked.



Constructed wetlands like this one are being built throughout the nation to handle wastewater from mostly small rural communities and homes where traditional treatment systems are a problem.

Wastewater flows into the constructed wetland from a septic tank or other type of primary treatment system. Here the wastewater is evenly distributed among the plants where microorganisms and chemical reactions break down organic materials and pollutants.

Constructed wetlands provide simple, effective, and low cost wastewater treatment when compared with conventional systems.

Wastewater enters the constructed wetland (1) where it is distributed evenly across the width of the first cell by a series of plastic valves or PVC tees (2). The first cell contains gravel (3). A waterproof liner is used on the sides and the bottom of the first cell to conserve water and provide more effective treatment (4). Cattails and bulrushes are usually planted in the first cell (5). The roots of these marsh plants form a dense mat among the gravel (6). Here chemical, biological and physical processes take place which purify the water. Water from the first cell passes into the second cell through a perforated pipe embedded in large stone (7). The water level within each cell is regulated by swivel standpipes located in concrete tanks at the end of each cell (8). Wastewater in the second cell is distributed evenly across this cell through another perforated pipe (9). Cell 2 has a layer of gravel (10) covered with topsoil (11) and then mulch (12). This cell is planted with a variety of ornamental wetland plants such as iris, elephant ear and arrowhead (13). The water in cell 2 eventually seeps into the soil below (14) or passes into another perforated pipe (15) where it is released into a drainfield similar to those used with conventional septic tanks (16).

Figure 1. Cut-A-Way Perspective of a Constructed Wetlands System

Worrall, Peter, 1992 The Reed Bed Solution. ***Landscape Design,*** **March 1992 No. 208: pp: 16 – 18.**

This is a short article that has been written at an introductory level for a general audience. The article appeared in a popular British journal.

In early days sewage was treated by irrigating to land - called a sewage farm. The political and social climate and the tightness of environmental legislation has created an interest in new methods in dealing with waste water.

There is possibly a 20 year cycle before beds need to be excavated. Maximum oxygen transfer means that sediment will be oxidised and form a reduced volume as a soil -like substrate.

Metals and chemicals can be precipitated out of solution and fixed into the substrate and altered into less toxic substances - reeds can take up some of the substances.

Reasons for failures of treatment beds:

- Invalid assumptions made about what a reed bed system can and cannot do
- Many reed beds are designed using principles that are untrue rather than drawing from experience
- There is a need for constant management

Constructed wetlands can enhance the landscape quality.

Cooper. P. E., Hobson, M. A. and Jones, S., 1989 Sewage Treatment by Reed Bed Systems. ***Journal of the Institution of Water and Environmental Management 3,*** **February: pp: 258 - 265**

Systems in Europe generally use the common reed (*Phragmites australis*). Rhizomes of reeds (the root-mat) grow horizontally and vertically opening up the soil to a hydraulic pathway along which wastewater can be treated. Plants carry the oxygen to the treatment zone. Suspended solids are composted.

Soil/growth medium (can be soil or fine gravel) -this is the part of the system with the greatest uncertainty at the moment. Low hydraulic conductivity causes overland flow problems. Silica gravel is poor at removing phosphate.

A feed distribution zone is usually present – 0.5m wide and with 60 – 100mm stones (this is a zone at the end of the wetland where sewage is feed into the bed - it usually consists of coarser gravel so that the sewage is evenly distributed across the entire cross section of the reed bed).

Small scale mobile test tanks were also constructed -tests indicated that units will with steady improvements in BOD values from 200mg/l to 20 mg/l over almost a year as bacterial populations developed. The system can not be considered being in a steady state even after one year.

Gravel systems appear to well from the start -most of the treatment is initially due to physical filtration. Some soil systems had overland flow problems and excessive weeds.

Brix, H., 1987 Treatment of Wastewater in the Rhizosphere of Wetland Plants - The Root Zone Method. *Water Science Technology* Vol. 19, pp. 107 -119.

The paper is concerned with subsurface flow treatment to remove nutrients such as phosphorous and nitrogen. Mechanically treated wastewater was fed into one end.

The common reed (*Phragmites australis*) was used - deep roots and rhizomes (over 1 metre deep) - negligible direct uptake of nutrients.

Function of the reed bed

(a) Supply oxygen to heterotrophic micro organisms in the rhizosphere

(b) increase/stabilise the hydraulic conductivity of the soil.

Degradation of organic matter and denitrification of nitrogen is largely done by microorganisms. Organic content is decomposed to carbon dioxide and water where the root zone is oxidised. Fig. 3 from Brix, 1987 has been reproduced here to help show the functions performed by the roots.

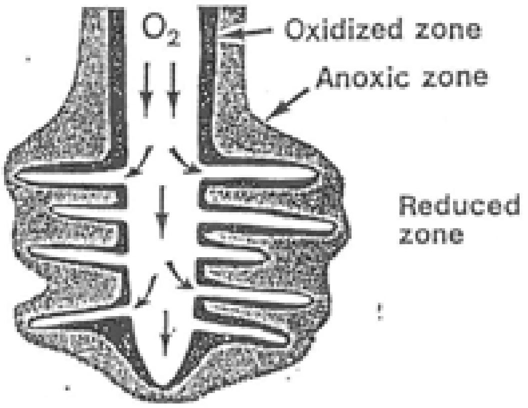


Fig. 3. Simplified representation of the redox-conditions around roots of wetland plants. Oxygen is transported from the atmosphere to the roots via the aerenchyma. A part of the oxygen diffuses into the substrate creating an oxidized zone (+oxygen) and an anoxic zone (-oxygen, +nitrate) around the roots in the otherwise reduced substrate (-oxygen, -nitrate).

Soils

Soils are effective at removing suspended solids and pathogenic viruses and bacteria. A significant mechanism is precipitation -coprecipitation of phosphate with iron, aluminum and calcium can remove significant quantities of phosphorus. Heavy metals may be precipitated with sulphide in zones where sulphide reduction occurs.

The cleaning efficiency is lower in winter -a relatively high temperature is maintained by: plant and litter cover giving an insulation effect, production of heat from microbial activity and the influx of wastewater at a relatively high temperature.

Removal Efficiencies

BOD

51 - 95% -highest where the surface loading was least.

Nitrogen

Generally less than 30%. Low concentrations of nitrate and nitrite - low nitrification rate.

Phosphorus

11 -94% - a variation due to a different degree of surface runoff and soil composition.

Seasonal variations

A slight reduction in the removal of BOD. No seasonal trends in either N or P.

Conclusions

The paper showed that root-zone treatment systems can very nearly attain secondary treatment quality for the removal of BOD. Gersberg *et. al.* (1984), showed that for artificial wetlands on gravel, the removal efficiency for total nitrogen was less than 25%, but when the system received primary effluent with a 1:2 (primary to secondary) blend of effluent this improved to 80%.

Gersburg, R. M., Elkins, B. V. and Goldman, C. R., 1984. Wastewater Treatment by Artificial Wetlands. *Water Science Technology* 17: 443 - 450

The report describes studies of artificial wetlands at Santee, California which demonstrated the capacity of these systems for secondary and advanced treatment.

Artificial wetland systems have several advantages over natural systems: flexibility is selection of size and site, greater operational control for scientific testing and environmentally sound alternative to discharging into a natural wetlands, preserving aesthetic values and providing an enhancement for wildlife.

The site consisted of plastic lined excavations with emergent vegetation growing in gravel.

80% mean removal efficiencies for nitrogen and total inorganic nitrogen. Maximum N in the water supply is 10 mg/l - mostly below this limit. Mean removal efficiency for BOD about 93% (3.2 mg/l), 88% for suspended solids (1.9 mg/l). Removal of total N was low when primary effluent was applied due to significant amounts of ammonia.

The system was found to require relatively little attention -no chemicals, attractive in cost and energy consumption - attractive for small communities attempting to meet treatment needs while being environmentally sound.

Gersberg, R. M., Elkins, B. V., Lyon, S. R. and Goldman, C. R., 1987 Role of Aquatic Plants in Wastewater Treatment by Artificial Wetlands. *Water Research* 20 (3): 363 – 369.

The paper examines quantitatively the role of a variety of higher plants in a water treatment situation (Bulrush, Common reed, Cattail and an unvegetated bed). The main points are as follows.

- Most of the nitrogen entering the system is in the form of ammonia - loss is greatest in bulrushes (94%), is also high with reeds (78%) poor with cattails (28%) and unvegetated (11%).
- BOD - Bulrush (96% removal efficiency) gave superior treatment than reeds (81%), cattails (74%) and unvegetated (69%). BOD removal is enhanced under anaerobic conditions. Bulrush gave superior treatment due to translocation of oxygen into an otherwise anaerobic zone.
- Suspended solids were found to have the same removal rates in all beds -physical processes such as sedimentation or filtering.
- The cost of the operation is reduced because the aeration is done by the plants.

Figures 2 and 3 in Gersberg *et. al.* (1987) are reproduced on the next page. They show the performance of each type of aquatic plant and the unvegetated control bed.

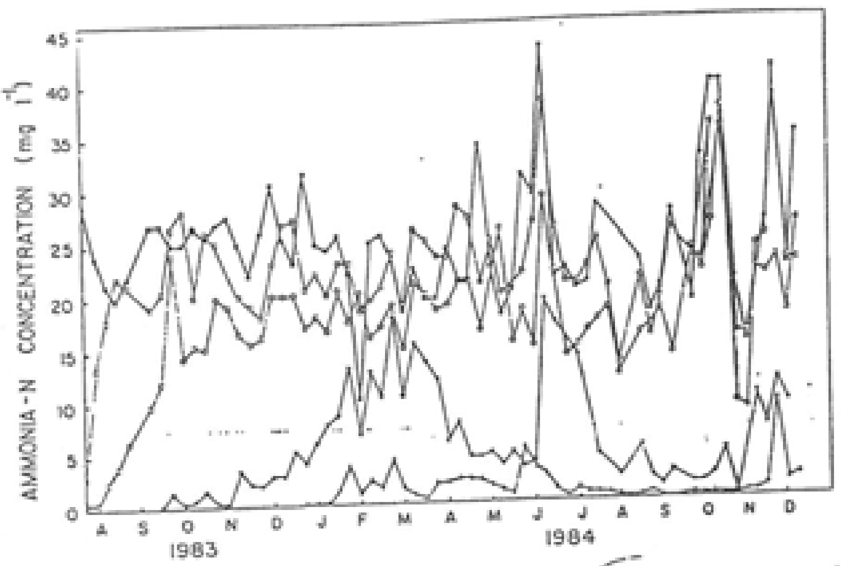


Fig. 2. Level of ammonia-N in the inflow (●——●) and effluent of the vegetated and unvegetated beds, at a primary wastewater application rate of 4.7 cm day^{-1}. ● Inflow; □ unvegetated; ○ cattails; ▽ reeds; ◇ bulrushes.

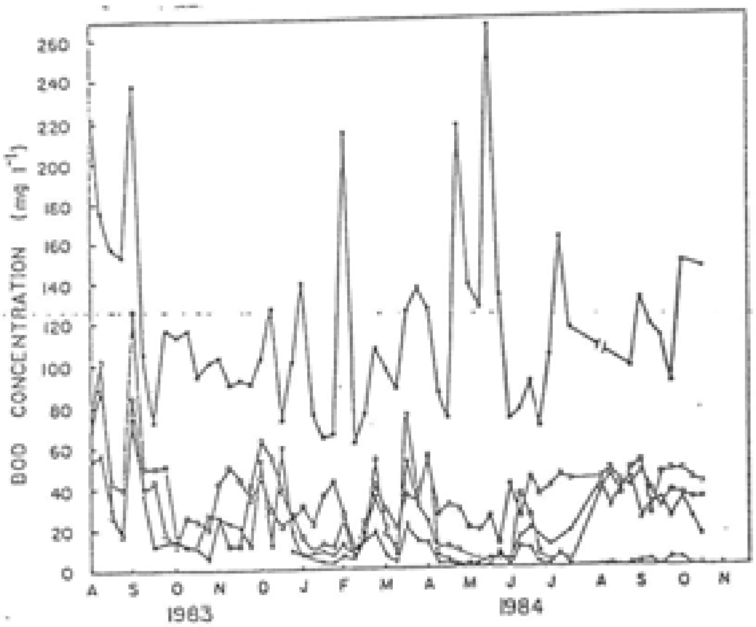


Fig. 3. Level of BOD$_5$ (biochemical oxygen demand) in the inflow (●——●) and effluent of the vegetated and unvegetated beds, at a primary wastewater application rate of 4.7 cm day^{-1}. ● Inflow; □ unvegetated; ○ cattails; ▽ reeds; ◇ bulrushes.

Gersberg, R. M., Brenner, R, Lyon, S.R. and Elkins, B. V. Survival of Bacteria and Viruses in Municipal Wastewaters Applied to Artificial Wetlands in Aquatic Plants for Water Treatment and Recovery by Reddy, K. R. and Smith, W. H. (eds.), 1987.

A study of removal of bacterial and viral pollution indicators in wetland ecosystems located at Santee, California. The main points are as follows:

- Hydraulic application rate of 5 cm/day. The mean influent total level was reduced by 99.1% in the effluent of a bulrush bed compared to 95.7% for an unvegetated bed - the study showed that higher aquatic plants have an important role in the removal of bacterial and viral pollution.
- Removal of pathogens is by both physical and chemical processes (eg. filtration, absorbtion), and biological inactivation and predation.
- Root excretions from certain aquatic plants can kill bacteria.
- Plants may aerate otherwise anaerobic substrate which can enhance die-offs.
- The paper concludes by advocating this form of treatment as a lower technology approach for reducing disease causing bacteria and viruses as well as other harmful constituents.

NATURAL WETLANDS WASTEWATER DISCHARGES

The following section deals with discharging wastewater into a naturally occurring wetland as a means of giving it a final polish before being discharged into receiving waters.

Cooke (1991) was concerned with the environmental effects that a wastewater discharge would have on a natural wetland. He also gave guidelines for conservation officers in assessing these impacts.

Howard Williams (1985) covered nutrient cycling in wetlands. Wastewater discharges are dealt with towards the end of the paper.

KRTA (1986) is a case study of a proposed sewage treatment scheme where treated sewage would have been discharged into the Gollands Valley Wetland. The report covers a wide range of possible environmental impacts.

Dr Cooke, J. G. 1991 Conservation Guidelines for Assessing the Potential Impacts of Wastewater Discharges to Wetlands. ***New Zealand Department of Conservation Science and Research Series #31***

This report was written for use by conservation officers responsible for the assessment of the potential impacts of wastewater discharges into wetlands. Two relevant chapters are:

Chapter 2 -	Reviews the ecological impacts of wastewater discharge into wetlands.
Chapter 3 -	Presents some practical guidelines for undertaking an assessment of a wastewater discharge proposal. It includes flow diagrams for auditing of potential proposals.

- The table on Primary Functions and Values of Wetlands is also of interest and has been reproduced here at the end of this entry

Wetlands can be extremely cost-effective at recovering a variety of pollutants from wastewaters.

Natural wetlands provide a valuable habitat for many plant and animal species as well as performing important hydraulic and pollutant buffering functions.

Maori perspective

Maoris tend to oppose direct discharge of sewage into natural waters because it is an affront to its wairua and therefore affects the mana of those who use it. Land application the traditional Maori method of disposal and wetland wastewater treatment is more acceptable than conventional treatment systems.

Constructed wetlands

A cost-effective alternative to conventional treatment systems - especially for rural or beach settlements where the cost of conventional treatment systems is too high. These systems are less diverse, and there is more control over the treatment process and therefore greater removal efficiencies. It does not threaten the ecology of natural wetlands and may even provide an additional wildlife habitat.

Reasons why wetlands may be considered for wastewater management.

- May be the only aquatic system available - soils and/or ground water levels may be unsuitable for land disposal
- Choice between advanced conventional treatment with surface water or secondary treatment with wetland disposal
- For partially drained or altered wetlands, wastewater discharges may restore flows and thereby achieving wetlands restoration/preservation as well as wastewater treatment objectives

Wetlands are complex and poorly understood. They are hydraulically slow moving systems. DOC's involvement would be as an advocate for wetlands protection.

The changes to wetlands from wastewater discharges which may lead to unacceptable conditions or serve as indicators are listed below:

- Changes in species composition
- Nuisance growth of algae
- Heavy metal accumulation in food chain
- Net export of nutrients and suspended solids
- Ground water contamination
- Indication of pathogene problem
- Damage to adjacent ecosystems
- Downstream eutrophication

Excessive hydraulic loading can convert a wetland to another wetland type, or damage it so that plant and animal assemblages are threatened. Higher water velocity cause changes in sediment deposition, undermining vegetation and cause erosion. Less stagnant water may cause an increase in species diversity. Residence time of the water might be changed. The seasonal rise and fall of the water-table may be influenced. An increased frequency of depth of flooding may cause nutrient removal.

Nutrients

Nutrients from wastewaters results in wetlands assimilating increased levels of nutrients. Hydrological export and denitrification is significant and the only method of N removal is reverting it to atmospheric nitrogen. Anaerobic conditions exist in wetlands but significant oxygenisation occurs. Wetland plants are thought to provide the means of transporting oxygen into the sediment. Phosphorous removal is by precipitation or sorption and depends on extractable iron and aluminium (can decline with time). Wetlands are not final sinks for nutrients discharged to them, but transform, remove, store and release various forms of nutrients.

Heavy Metals

Heavy metals are removed by: animal uptake, movement to ground water and on to sediment. Aquatic plants will assimilate some heavy metals but not others. Changes in pH influence the solubility of metals - wetlands act as a limited sink for heavy metal. The report recommended that discharges of high concentrations of heavy metals into wetlands should be avoided.

Ecology

The flora may be changed. Plants are adapted to nutrient poor environment. Some species may be out-competed by other species adapted to the high nutrients from wastewater which can lead to a reduction in diversity (eg: salt marshes, peat bogs). Physiological changes can be induced, eg: weakens stems. Fauna changes vegetation which results in changes in fauna. Changes in flow-rate have a direct effect on environment, fish populations and plant species compositions.

Principal Issues

- Wastewater characteristics and management objectives
- Type and value of wetland
- Environmental condition of the wetland and its perceived sensitivity to the discharge
- Perceived alteration of wetland function and values

The following table has been reproduced from Cooke's (1991) report.

WETLANDS - PRIMARY FUNCTIONS AND VALUES

1 -GEOMORPHOLOGY * Erosion control -dampen peak flows downstream

2 -HYDROLOGY
* Flood control -dampen floods
* Saltwater intrusion control -creates ground water pressure
* Ground water supply

3 -WATER QUALITY ENHANCEMENT * Waste management systems

4 -ECOLOGY
* Wildlife habitat
* Habitat for threatened & endangered species
* Waterfowl breeding habitat
* Freshwater fisheries
* Aquatic production
* Nutrient material cycling

5 – CULTURAL RESOURCES
* Maori values -food, flax, herbs, artifacts, moas
* Harvest of natural products
* Recreational -Ducks
* Landscape values

Howard-Williams, C., 1985 Cycling Retention of Nitrogen and Phosphorus in Wetlands: A Theoretical and Applied Perspective. *Freshwater Biology*. 15: 391 - 431

This paper gives a detailed analysis of nitrogen and phosphorus cycling in wetlands - two sections near the end of the article deals with wastewater management. It pre-dates some of the most recent developments.

If a wetland is acting as a nutrient sink it is not in a steady state (other than denitrify-ication).

Applying wastewater to wetlands has the following effects:

- Nutrient enrichment causes increased production (plant growth)
- Species changes -fast growing plants such as algae proliferate with deleterious effects on redox conditions
- The carrier of the nutrients (ie. the sewage) can create problems (eg. heavy metals). Substantial areas of wetlands are required for large scale nutrient removal

Two types of artificial wetland

Constructed wetlands

Constructed wetlands are planted with wetland species. They are not effective in the removal of dissolved nutrients (most studies described have not attempted to determine how to gain the maximum efficiency of the systems or loading rates, but the author felt that if done it could greatly improve performance).

Create wetlands alone natural waterways

This would remove diffuse sources of nutrients such as agricultural run-off -develop protected riparian strips along stream margins - can remove significant quantities of nitrogen and phosphorus at low loading rates. Artificial wetlands are effective at removing nutrients only if their removal mechanisms are properly understood and managed.

KRTA, 1986 The Gollans valley Wetlands: An Environmental Appraisal in Relation to a Proposal for Effluent Treatment. ***Report prepared for the Hutt Valley Drainage Board.***

This report was prepared for the Hutt Valley Drainage Board by K.R.T.A. about the possible effects that a proposed sewage treatment system using the existing Valley Wetland (near Eastbourne, Wellington -Wellington Conservancy) would have.

The valley is unique to Wellington region and uncommon in New Zealand - a topogonous mire with a wide variety of plant community types which intermerge, and several rare and important plant species. The wetland has a greater variety of plant communities than any other freshwater swamp in the Wellington region. The lakes are a good waterbird habitat. Two threatened species in the wetland are the Bittern and Giant Kokopu (large native fish).

Two important features of the wetland are:

- Private ownership = artificial inaccessibility
- Wetland vegetation is relatively unmodified -type locality for several plant species

Potential Effects of the Proposal

Proposed system

Hutt Valley miliscreened sewage with a biological secondary treatment process would be settled and then discharged into natural wetland of Valley. Toxic substances would be contained or treated prior to discharge, eg: heavy metals would be reduced 60 -80% after biological treatment.

Hydrology

The discharge into the wetland would have caused increased flow volume and velocity. With nutrient rich water containing large populations of bacteria etc., much of the incoming suspended solids would be conglomerated and flocculated on the pond floor.

Heavy metals are particularly likely to precipitate and thus accumulate initially in the sediment phase, which is the site of the greatest biological activity. This gives the heavy metals an enhanced likelihood of entering the food chain.

Increased sediment deposition enhances biota activity -the most competitive species form large populations of a few species (ie. the wetland ecosystem becomes a type of monoculture).

Suspended or dissolved solids cause increased water turbidity -certain rare birds may be disadvantaged by a reduced ability to see their prey.

Sewage would be high in phosphorus (summer) and there would be an increased nutrient content in the wetland system from the effluent.

Wetlands are highly effective at removing heavy metals, biocides, mineral oils etc. Heavy metals are magnified in the food chain. Fluorine -can be taken up by plants and enter the food chain.

Conclusions

The report recommended artificial wetland treatment on pastoral land in Gollands Valley with the existing natural wetland not being utilised.

LAND APPLICATION

This involves the disposal of wastewater onto plots of land. The nutrients are removed by a combination of soil filtration and plant uptake with harvesting ultimately removing the nutrients. A large forest land application system near Rotorua is described which processes sewage from the city of Rotorua.

Bell and Schipper (1989) is a good introduction to land application treatment.

DSIR series 114 (1976) is an old technical report on land application techniques.

Quin (1979) is concerned with the use of municipal sewage for irrigating pasture, with the grass giving the added bonus of removing nutrients from the sewage as a form of fertiliser.

Clark and Hodges (1987) gives a brief outline of the site investigations that were undertaken for Rotorua Forest Treatment Scheme (Bay of Plenty Conservancy).

Barton et. al. (1990) covers the ability of forests to remove nitrogen from treated sewage with respect to the Rotorua Forest Treatment Scheme.

Schipper et. al. (1990) also covers the ability of forests to remove nitrogen from treated sewage, but deals with a case study from the Coromandel Peninsula.

Barton (1990) gives what he call an introduction to soil physics in relation to land application treatment. It is very technical in nature.

McQueen (1990) looks at the damage that stock and vehicle traffic can do to soil which would result in a reduced ability for a block of land to strip nutrients out of the soil.

Speir (1990) deals with the monitoring of a land application system with respect to the Freezing Works (Canterbury Conservancy) and the Rotorua Forest Sewage Treatment System

Bell, A. R. and Schipper, L. A., 1989 An Introduction to Land Treatment of Wastewater. Forest Land Treatment Collective Technical Review #1. November, 1989 pp. 3 - 16

Types of Land Treatment of Wastewater

Slow Rate (SR)

- High removal of most wastewater constituents
- Requires large land area, costly - cost may be offset by revenue earning crop

Rapid Infiltration (RI)

- Effectiveness varies with soil type and thickness -deep, fine soils best
- BOD (Biochemical Oxygen Demand) reduced
- Suspended solids, phosphorous and trace constituents removed
- Nitrogen removal low
- Can be cheaper than SR, requires small land area, high application rate

Overland Flow (OF)

- First stage of municipal wastewater treatment
- Large BOD reduction and high rate of removal of suspended solids and nitrogen is possible
- High application rate, required area low, low cost

Wetlands Treatment

- Polishing stage for wastewater treatment (eg: denitrification or for treatment of wastewaters which will not cause a build up of any potentially harmful components within the wetland)

Table 1 and Figure 1 from Bell and Schipper (1989) has been reproduced on the next page. They both give a very good summary of these methods at an introductory level.

After Bell and Schipper, (1989)

Table 1: Site characteristics and design features of land treatment systems (from US EPA 1981).

	Slow Rate	Rapid Infiltration	Overland Flow
Soil:			
Permeability	>1.5 mm/h	>40 mm/h	<5 mm/h
Texture	clay loams to sands	sands and sandy loams	clays and clay loams
Vegetation:	agricultural (agric) or forest	not required	agricultural
Slope Suitability:	Agric. / Forest		
0 - 7°	high / high	high	high
8 - 20°	low - mod / high	low	unsuitable
21 - 35°	very low / mod	unsuitable	unsuitable
> 35°	unsuitable / very low	unsuitable	unsuitable
Area required:	3 - >1000 ha	1 - 20 ha	1 - 20 ha
Minimum depth to ground water:	1 m in all cases 3 m for high loads	1 m during loading 3 m during drying	not critical
Application (mode): Method	spray or surface	usually surface	spray or surface
	cyclic: 4 - 12 h/app 1 app/7-20 d	cyclic: 8 h/app 1 app/5-15 d	8-12 h/app 2-7 app/wk
Loading rate	15-100 mm/wk 0.5-6 m/y	100-2400 mm/wk 6-125 m/y	60-400 mm/wk 3-20 m/y

Table 2: Average composition of sewage and expected quality of sewage after land treatment at well managed sites (units of g/m³ unless otherwise stated; from US EPA, 1981).

	Sewage	Slow Rate	Rapid Infiltration	Overland flow
BOD	220	<2	5	10
Suspended solids	220	<1	2	10
Total nitrogen	40	3	10	5
Ammonia nitrogen	25	<0.5	0.5	<4
Organic nitrogen	15	0	0	0
Total phosphorus	8	<0.1	1	4
Faecal coliforms (no. /100 ml)	$10^7 - 10^8$	0	10	200

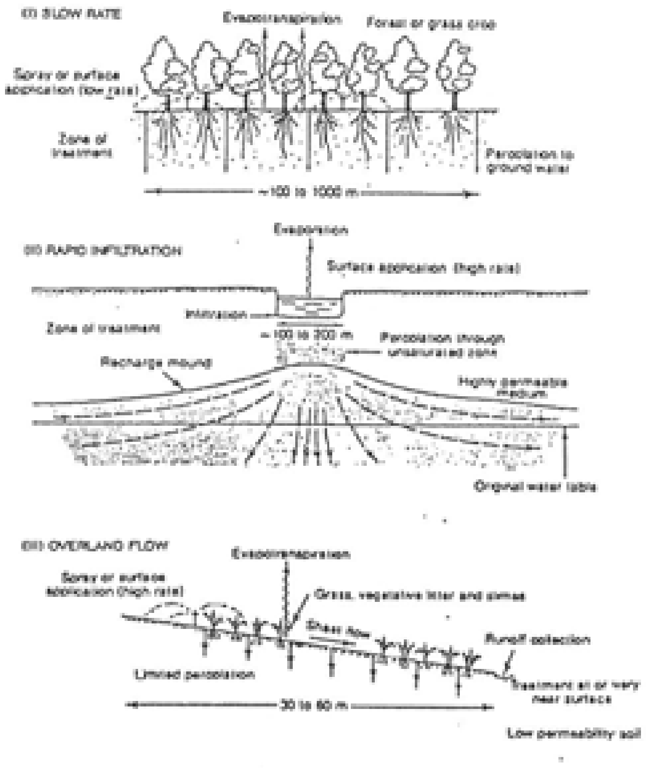


Figure 1: Methods of land treatment of wastewater (adapted from Todd 1980): i) slow rate; ii) rapid infiltration; and iii) overland flow.

D.S.I.R., 1976 Interim Guide for Land Application of Treated Sewage Effluent. ***Department of Scientific and Industrial Research Information Series 114,*** **1976**

The following is the main points from this early report on land application. The points have been laid out largely in note form for this entry.

For successful operation there must be an adequate supply of land, suitable soils, drainage, slope, hydrological characteristics, climate and vegetation cover.

Objectives of Land Application Treatment of Wastewater

- Means of treating for improving effluent quality
- Means of disposal
- A form of irrigation
- To recharge ground water

Irrigation treatment method

- Purification predominantly in root zone -flow is slow.

Overland Flow Method

- Purification in microbiological slimes, on grass stems and soil surface
- Rapid flooding, little infiltration
- Organic and suspended solids are removed. Nutrients remain

Rapid Infiltration

- Little purification in highly permeable medium
- Usable only where receiving water quality is not critical

The report recommended that effluent generally be excluded from land used for recreational purposes, grazing (other than sheep), crops for human consumption, where ground water contamination might occur for health reasons.

Site Requirements

Permeable soils with sufficient infiltration capacity and minimum run off. Aerobic conditions but with interaction of wastes with soil minerals, plants and organisms. Sufficient exchange capacity to hold nutrients for use by plants and soil organisms - minimum migration to ground water. Sufficient thickness of soil to allow renovation of effluent.

Drainage

Sufficient to avoid waterlogging.

Slope

- Possibility of surface run-off increases with greater slope
- Slope < 1° - boarded dykes or low pressure sprinklers
- 1° – 11° - Rolling Land - Low pressure sprinklers
- Steeper slopes - Permeable soils only

Climate

Not too cold (ie: not sub-alpine). Plant organism growth needed. Freezing of pipes? In sub-tropics the soils tend to be high in clay content causing low infiltration rates.

Vegetation

Forest, pasture, crops, bare -different rates of nutrient removal.

Hydrology

Water may leave site by overland flow, interflow, percolation to ground water, evaporation, evapotranspiration.

Site

For controlled flooding land should be flat enough to prevent run-off, no fissures or cracks to allow effluent to reach ground water without treatment. Levelling of undulations prevents ponding. Ditches required for overland flow systems. No drains required for infiltration systems.

Vegetation Cover

Pasture

Rotational grazing with sheep only. Nitrate poisoning of grazing animals may occur.

Lucerne

Light, free draining soils only -grazing requires special management.

Cereals

Wide range of climates -nitrate poisoning possible if used for grain feed.

Maize

Can use large nitrogen and potassium quantities - responds well to irrigation.

Forests

Can dispose of large quantities of water - *P. radiata*, eucalypts rapid growth rate, long growing seasons, deep canopy, higher evapotranspiration. Aerosol spray drift minimised, litter promotes infiltration.

Nutrient Behaviour in Soils

Phosphorous (P)

Most soils strongly retain P and it will tend to concentrate in the surface layer. P concentrations: 0.05 - 0.2 in percolated water g/cc in percolated water not significant, 1 gm/cubic metre is high. Most P loss is due to erosion of topsoil layer.

Nitrogen (N)

N containing organic matter is continual mineralised and nitrified by microorganisms. Ammonia to nitrate via nitrite requires aerobic soils that are open textured and well drained. Nitrate is freely mobile and leaches. Plant uptake of N is maximum with crops that have a high N requirement. Anaerobic organisms turn nitrate/rite into nitrogen gas which is lost from the soil.

Constituents of Interest

Bacteria, Major ionic species, pH, Carbon Dioxide, Total Organic Carbon (TOC), Nitrate, Nitrite, Ammonia (NH_3), Iron, Magnesium, Detergents, Toxic trace elements, dissolved oxygen, Sulphide, Phosphorous, Chloride, Organic compounds.

After D.S.I.R., 1976 Tables 3 and 4

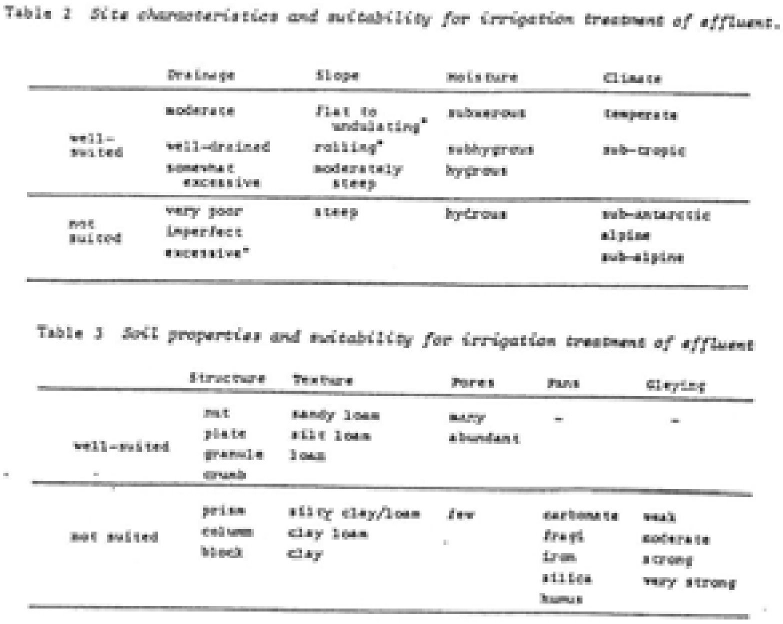


Table 2 *Site characteristics and suitability for irrigation treatment of effluent.*

	Drainage	Slope	Moisture	Climate
well-suited	moderate well-drained somewhat excessive	flat to undulating* rolling* moderately steep	subxerous subhygrous hygrous	temperate sub-tropic
not suited	very poor imperfect excessive*	steep	hydrous	sub-antarctic alpine sub-alpine

Table 3 *Soil properties and suitability for irrigation treatment of effluent*

	Structure	Texture	Pores	Pans	Gleying
well-suited	nut plate granule crumb	sandy loam silt loam loam	many abundant	-	-
not suited	prism column block	silty clay/loam clay loam clay	few	carbonate fragi iron silica humus	weak moderate strong very strong

Quinn, B. F., 1979 A Comparison of Nutrient Removal by Harvested Reed Canarygrass (*Phalaris arundinacea*) with Ryegrass-Clover in Plots Irrigated With Treated Sewage. ***New Zealand Journal of Agricultural Research,*** **22: 291 – 302.**

The aim of the project discussed in this paper is to use municipal sewage effluent as irrigation water and plant nutrients where suitable topography and soils are available.

Plots of reed-canarygrass were surface irrigated at weekly intervals over 12 months. Treated sewage effluent produced similar dry matter yields, removed similar quantities of nutrients as plots of ryegrass-clover. Canarygrass maintained low levels (<3 mg/l) of NO_3-N drainage water throughout the year, under ryegrass-clover was as high as 18 mg/l. High nitrogen levels were thought to be caused by continuous mineralisation of soil N, and nitrification of the effluent NH_4-N at temperatures too low for herbage growth (<5 degrees C). In winter time Canarygrass provides a continuous uptake of nitrogen.

Nutrients were utilised by cropping much more than grazing (90% of the nutrients ingested by animals are excreted) but causes difficulties (ie: Health risks, higher level of required management, greater time during which the land is out of use between harvesting and growth of subsequent crops. Harvested pastures can be made into silage and fed out directly onto areas of low soil fertility.

Clark, S and Hodges, J., 1987 Rotorua Sewage Efluent Disposal. ***New Zealand Water Supply and Disposal Association Annual Conference Proceedings, Rotorua, New Zealand, 2 -4*** **September 1987.**

A brief paper that backgrounds the investigations into the land application scheme that currently treats Rotorua's sewage.

Lake Rotorua is currently eutrophic - the lake catchment is not much larger than the lake itself -the lake waters have a long detention time - slow flushing.

Detailed investigations were carried out on the Whakarewarewa State Forest -soil, riparian zones, hydrology, background water quality, public aspirations etc.

A combination of in-plant treatment and land purification was determined to be the most cost-effective.

Barton, P. G., Dyck, G. R. and Oliver, G. R., 1990 Renovation of Sewage and Nitrogen by Application to Forests. ***An Introduction to Land Treatment.*** **Forest Land Treatment Collective Technical Review No. 1 November 1989. pp. 29 – 44.**

This is a case study of a wastewater treatment project near Rotorua where wastewater is applied directly to forested land.

Nitrogen Renovation

- Crop uptake and subsequent harvest
- Denitrification in soils and wetlands

Crop uptake is a function of tree species, tree growth rate, rate of nitrogen accumulation in various tree components, length of growing cycle and intensity of harvest.

- Nitrogen uptake is greatest for fast, young growing stands eg. eucalyptus
- Denitrification is site specific and depends on physical and chemical soil properties

Case Study - Whakarewarewa Forest (Near Rotorua, Bay of Plenty Conservancy)

Whakarewarewa Forest -4.5 km from Rotorua City -700 ha surrounding Waipa Sawmill. It is well suited for sewage spray irrigation. Soils are Volcanic, porous, high (55%) water storage capacity and, high hydraulic loading rate and chemical properties giving high phosphorus removal. Application rates: 3 - 5 mm/hour, 100 mm/week.

Harvesting crops increases nitrogen removal -a block of flat land is desirable but not available in case study area.

Nitrogen fixing Acacia can accumulate high amounts of nitrogen applied in sewage. Denitrification most important pathway for nitrogen removal -on-site denitrification may be increased by alternate wetting and drying.

Advantages of using forests

- Out of food chain
- Less expensive than agricultural land
- Less machine access that degrades the soil
- Organic forest floor allows higher hydraulic loading rates and aids the removal of pathogens
- Forest soil permit the use of steep slopes
- Forest canopy reduces the transport of pathogens by aerosols
- Smaller standby areas (areas in fallow)

Means of removing nitrogen from the soil

- Soil storage – negligible
- Crop uptake and harvest
- Gaseous loss – NH_3 volitisation (small), denitrification Nutrient removal increases with shorter rotation periods (3 time for 10 year length rather than 35 year length)

Schipper, L. A., Dyck, W. J., Barton, P. G. and Hodgkiss, P. D. 1989. Nitrogen Renovation by Denitrification in Forest Sewage Irrigation Systems. ***Biological Wastes*** **29: 181 - 187**

The following notes are from a paper which was written on an on site survey that was carried out in the Coromandel Peninsular near Whangamata.

A sub-catchment of Whangamata Sewage Irrigation Scheme in Tairua Forest, Coromandel Peninsular was studied for 60 weeks - Spray irrigation of sewage onto *Pinus radiata* forests that drained onto a wetland over a 20 m distance down a fairly steep (about 1 in 2) slope.

Nitrogen renovation in a forest spray-irrigation system was monitored by soil and ground-water nitrate concentrations for 14 months -98% of the nitrogen applied to the site was removed.

The major objective of treating sewage is to remove nitrogen and avoid pollution and eutrophication of receiving waters.

300 kg/ha/year of nitrogen is taken up by trees and understorey (radiata pine forest in NZ), is unaccounted for - denitrification is considered to be the major mechanism responsible for nitrate removal.

Barton, P. ***G.,*** **1990 An Introduction to Soil Physics and Hydrology.** ***Land Treatment Collective Technical Review no. 2, June, 1990***

This paper is a review of some of the physics of soil aeration. Its importance is in understanding the soil character which assists in wastewater management and allows the operator to obtain the most effective treatment possible. The paper is fairly technical.

Soil Aeration

Air movement is from the atmosphere into the soil and plants. Most exchange is though the soil. In saturated soil the exchange is through the plants - gas moves in dissolved through water and is too slow to be effective for plants. Aerobic respiration in plant roots involves the continuous absorption of oxygen and the evolution of carbon dioxide.

Soil Respiration

Oxygen depletion and carbon dioxide production in soils -rate is controlled by temperature, water supply, type and amount of repairing tissue, and the amount of available substrate for microbial degradation. Forest floor decomposition increases rapidly following application of wastewater and sludge -there is a lot of available carbon and nutrients. As temperature increases the rate that microorganisms respire increase. Rate of gas diffusion through soil increases with the proportion of soil volume occupied by gas-filled pores.

SOIL AIR QUALITY = % O_2, CO_2, N_2 and INERT GAS (volume basis).

Reduced soil aeration can result in substances toxic to plants being produced.

Nutrient Uptake

Affected in soils directly or indirectly or as a result of change in metabolic status of plants caused by less aeration.

Under anaerobic conditions:

- Nitrogen lost from soils by denitrification
- Iron and Magnesium may become more available
- Iron can become toxic to roots
- Less uptake of nitrogen, phosphorus and other nutrients

Changes in aeration may alter susceptibility of plants to disease, virility of organisms, or both.

McQueen, D., 1990. Traffic Damage on Disposal Sites. ***Land Treatment Collective Technical Review No. 2 June 1990***

Problems associated with the traffic from harvesting effluent disposal sites under unsuitably wet conditions cause deterioration of soil surface physical conditions, especially soil conductivity so that the soil may not be able to treat the required level of effluent.

Traffic (from vehicles and/or stock) causes soil compaction and smearing on wet soil.

Evidence of Damage

Surface ponding, overland flow, rut and hove marks, reduced plant yields, anaerobic zones in topsoil (grey colours), increased pollution of ground water (less uptake of contaminants - vegetation and soil absorbtion), localised air pollution (NH_3) production).

Forces applied to the soil by traffic reduces soil volume -pores collapse within soil and especially affecting large conducting pores which are responsible for transporting most of the soil water (conductivity is directly proportional to soil pore radii 4th power).

Sheering and smearing creates a surface barrier.

Typical Ground pressures

- Sheep typically 30 kPa,
- Cattle typically 400 kPa - It is not possible to effects or reduce impact of individual hooves
- Vehicles - Study of crop harvesting under wet conditions causes macroporosity and infiltration rates to decline markedly (infiltration by a factor of 10) -pasture growth decreased 20% - effects were confined to top 20 cm of the soil

Reducing the effect of compaction

Use low pressure tires (30 -40 kPa, not 90 to 100 kPa)
Zero ground pressure systems - confine wheels to specific tracks
Combine both the first and second methods

Soil Water Potential

This is a measure of energy required to remove water from the soil - relates directly to drainage forces. Soil is saturated at 0 kPa, should ideally be less than -100 kPa, tends to be greater than -100 kPa and often -10 to 0 kPa.

Conductivity

The rate of water flow though the soil as influenced by the soil structure. Inadequate conductivity causes waterlogging and increases susceptibility to further compaction.

Control Strategies

- Traffic Systems – low and/or zero ground pressure
- Resilient soils – well-drained, well developed stable structure
- Control flow of animals/vehicles/effluent so critical limits of soil potential and compactive effect are not exceeded

- Computer modelling
- Regular on site measurements of water potential, penetration resistance to determine if critical limits are exceeded

Speir, T. W., Cook, F. K., and Thorn, A. J. 1990 Land Application Treatment of Effluent - Monitoring. ***Land Treatment Collective Proceedings of Technical Business Sessions*** **11 - 12 October, 1990**

Monitoring ensures long-term sustainability of the system so that it is not jeopardised by changes in soil properties. An increase in precipitation (from irrigation) of several fold and/or an increase in fertility status is certain to change some soil properties.

Fairton Freezing Works

80 years of irrigation by border-dykes. The effects on the soil were: higher fertility, more available phosphorous and narrower C/N (carbon/nitrogen) ratio. Soil pH increased significantly due to high pH effluent. Carbon and nitrogen levels stayed the same, and biochemical activity declined implying a decline in "soil health". Soil structure may be adversely affected by border-dykes but can be counteracted if liquid irrigation is rich in nutrients.

Rotorua

In Whakarewarewa State Forest a 1.5m by 1.5m plot was isolated to 2.3m depth - infiltration and drainage functions were measured and again 3 years later. The infiltration rate fell 50% from 7200 mm/day to 3550 mm/day. The soil block was drier from 0.1 -1.0 m depth - lower infiltration rates restricted wetting at this depth. The soil to 0.1 m depth was wetter in the second experiment.

- Infiltration rates in pumiceous soils were very high but the results had major consequences for much more marginal soils.

ANIMAL WASTE DISPOSAL

The disposal of animal waste water is of importance to the New Zealand situation because of its reliance on the agricultural sector. This however involves treating wastes that are very rich in nutrients and suspended solids and thus have a high impact on aquatic systems. Wetlands treatment generally failed after a period of time and oxidation ponds performed poorly.

Churchman and Tait (1986) looks at the effects that the land application of slaughter-house effluent have on soil aggregates.

Russell et. al. (1987) gives a general but technical overview of treating animal waste by land application. The paper refers to conditions in the Waikato Conservancy.

Donnison and Cooper (1987) investigates the die off of facial coliform (bacteria from animal faeces) on land that was irrigated with animal waste.

Van Oostrom (1990) is a technical paper on the treatment of freezing works animal waste by surface flow wetlands in the Waikato Conservancy.

Van Oostrom and Cooper (1990) is concerned with the same project as in Van Oostrom (1990).

Hicky *et. al.* (1989) looks at the performance of a number of oxidation ponds from throughout New Zealand.

Churchman, G. J. and Tait, K., 1986. The Effect of Slaughterhouse Effluent and Water Irrigation upon Aggregation in Seasonally Dry New Zealand Pasture. ***Australian Journal of soil research*** **24: 505 – 16.**

Much slaughterhouse effluent is disposed on pastures. The study is on Lismore silt loam, Canterbury Plains (Canterbury Conservancy). The study was on a site that was irrigated with effluent.

The soil characteristics were as follows:

- 47% sand (> 0.02 mm particles)
- 34% silt (0.02 -0.002 mm particles)
- 19% clay (< 0.002 particles)

The top 20 cm (A horizon) was sampled by spade. The study was intended to determine the stability of soil macro-aggregates and hence the stability of the soil structure when irrigated by effluent.

Deaggregation methods: shaking, calcium-resin treatment, ultrasonics, acetylacetone, periodate - borate, Hydrogen peroxide and citrite-dithionite-bicarbonate (CBD) treatment.

In effluent treated soil clay yields were less than control and irrigated soil (except CBD) - enhanced clay aggregation of soil.

For long term (>25 years) treatment on a silt loam under pasture, effluent did not affect the stability of macro aggregates as measured by wet sieving but increased the stability of clay aggregations as measured when subjected to selective desegregation treatments.

Organic matter was higher in effluent treated soils suggesting that effluent treatment increases humification. Fewer earthworms were recorded on effluent sites. Earthworms enhance the stability of macro aggregates but large differences in the worm counts between the two soils are not seen as leading to any difference in the stabilities.

Russell, J. M., Cooper, R. N. and Donnison, A. M., 1987 Irrigation of High Nitrogen Waste to Pasture in *Alternative Waste Treatment Systems* Bhamidimarri, R. (ed.) Elservier Science. London.

The main points in this paper are outlined below.

Effluent from meat-processing operations contain high concentrations of the plant nutrients nitrogen, phosphorus and potassium - ideal for land application/disposal treatment schemes. Irrigation can be undertaken with primary treated or biologically treated effluent on to cropped or grazed land.

Land application transfers the environmental effect of effluent discharge from surface waters to the soil, plants, ground water. Ground water and subsequent crops must be safe for subsequent use.

The paper deals with high nitrogen containing wastes.

In the Waikato region there is intensive dairying which results in ground waters with 26 g/cubic metre (1200 kg N/ha/year) nitrogen loading.

Drinking water must have a nitrogen content of less than 10 g/cubic metre (500 - 600 kg N/ha/year).

Anaerobic effluent has sufficient cation exchange capacity (CEC) to absorb a threefold increase in NH_3 concentration.

Pasture growth and composition

Stimulates growth by supplying water and nutrients. Primary treated effluent increased pasture production at all loadings up to 2000 kg N/ha/year
Anaerobic effect - pasture production delivered with loadings > 1000 kg N/ha/year - herbage contained high nitrogen-nitrate levels
Soil pH decreased with irrigation, greater with anaerobic effluent
Denitrification loss less than 2% of total N applied. Negligible loss of NH_3 due to volitisation.

Faecal coliform

- die-off rates are greatest in spring, lowest in summer. Warm rainy periods = lower die-off rates due to the splash up of bacteria surviving in the soil. Population growth is in the redissolved nutrients
- No faecal coliform survived in silage

Grazing Animals.

- Pugs the soil causing reduced infiltration, which results in channels in the irrigation area

- Cattle destroy earthworks and boarder-dykes
- Recycle 90% N through faeces and urine

CONCLUSIONS

1000 kg N/ha/year is the maximum successful nitrogen loading rate, but this varies with a number of factors:

- Effluent type
- Pasture grazed or not (number and type of animals)
- Ground water characteristics
- Subsequent use

Strict management procedures are needed for pasture to be safe for stock consumption.

Donnison, A. M. and Cooper, R. N. 1989 Faecal Decline on Pasture Irrigated with Primary Treated Meat-Processing Sewage Effluent. ***New Zealand Journal of Agricultural Research 32:*** **105 - 112**

Primary treated meat-processing effluent irrigated onto a number of New Zealand sites for many years with no reports of public or animal health problems. The effluent contains many harmful pathogens (eg: *Salmonella* sp.) in effluent.

Effluent was applied every 14 days at a rate equivalent to 1000 kg N/ha per year. A 99% reduction in faecal counts were recorded over a 14 day period (99.9% in spring and winter). Faecal coiiform die-off and hours of sunshine appear to be related, also rainfall has an affect (warm/wet weather results in lower die-off rates).

Nutrient loadings of 1000 kg of N/ha per year or less was recommended for irrigation schemes where herbage is mechanically harvested and removed for off-site use; loadings of 500 kg of N/ha per year for schemes where grazing of the irrigated area is part of the management plan.

No faecal coliform were recovered from silage so it can be safely fed to livestock.

Van Oostrom, A. J. 1990 Constructed Wetlands for treating Meat Processing Effluent. Research Conference of Meat Industry of New Zealand. Hamilton, 1990: 84 - 91

Primary treated meat processing effluent contain high concentrations of fat (200-1200 gm^{-3}) and Nitrogen (70-200 gm^{-3}) - 5 to 10 times higher than municipal and domestic wastewaters.

Experiments were conducted using pilot-scale gravel bed and surface flow wetlands for treating meat processing effluent (3 beds of each type).

Gravel Bed Wetlands

Deep rectangular trenches filled with pea gravel planted in bulrush and giant sweet grass. Third bed was unplanted as a control bed. The liquid level was kept below the surface of the gravel.

Surface Flow

Trenches planted in giant sweetgrass, bulrush, iris and raupo. Liquid depth was 400 mm. Gravel beds generally produced higher quality effluents than surface flow.

Results

Suspended solids

Both systems produced fluids with less suspended solids than pond systems -attributed to the baffled nature of wetlands - also a filtration effect. Gravel bed effluent is lower in suspended solids and surface flow systems are less sensitive to suspended solids loading. Fats formed a scum up to 100 mm thick raising doubts that wetlands could handle such high suspended solid levels over the long term.

COD/BOD_5 removal

Surface flow system is less effective than subsurface flow systems at removing these. Anaerobic ponds are cheaper, more sustainable and require less land than wetland systems - but wetlands are more effective at the tertiary and polishing stage. Removal is sedimentation and microbial degradation.

System aeration

Many plant species transport oxygen from atmosphere in to the root zone.

Nitrogen removal

All wetlands received effluent high in nitrogen -removal rates were low averaging 20% which is less effective than flocculative ponds. Removal processes: Plant uptake (removal by harvest), storage and conversion by micro-organisms to nitrogen gas.

Phosphorous removal

Phosphorus removal is low - 13% -31%

Means of removal are: Precipitation, absorbtion onto sediments and substrate, incorporation into microbial biomass and plant uptake.

Phosphorous accumulates in the system so long term removal rates are not sustainable.

Van Oostrom, A. J. and Cooper, R. N., 1990. Meat Processing Effluent and Treatment in Surface Flow and gravel Bed Constructed Wastewater Wetlands. *Wetlands in Water Pollution Control* Cooper, P. F. and Findlater, B. C. (eds.) Pergamon Press, Oxford, 1990

The paper reports on the evaluation of pilot scale surface flow and subsurface flow constructed wetlands for the treatment of partially treated meat processing effluent containing high concentrations of ammonia (>80 gm^{-3}) and nitrogen (>80 gm^{-3}). The material in this paper is similar to that reported in their other paper. Nitrogen removal was low (≤22%) and was probably limited by insufficient nitrification.

Lambs, sheep and cattle produce large volumes of wastewater which is high in nitrogen (80 - 200 gm^{-3}) phosphorous (10 - 20 gm^{-3}) and BOD (800 - 1500 gm^{-3}). Both systems were monitored daily.

Gravel Bed Wetlands

- Hydraulic loading was variable – 60 l/m^3 - was reduced to 30 l/m^3 to reduce the rate of solid accumulation
- Evapotranspiration was greater in the planted beds than in the control. Was higher for the *Schoenoplectus* wetland than for *Glyceria* due to taller plants in the former
- Suspended solids showed considerable attenuation -there was clogging at the inlet end which was overcome by reducing the hydraulic loading
- Chemical Oxygen demand was dependent on loading rate
- Nitrogen removal -effluent was generally 15 -30 g/m^3 lower than the influent (93 - 167 l/m^3)
- Phosphorous removal -Effluent was 2 – 4 g/m^3 lower than the influent (11 -20 l/m^3)

Surface Flow Wetlands

- Hydraulic loading was 10 l/minute
- Organic pollutants removal -substantially reduced by wetlands, especially suspended solids
- Nutrient removal -18 -22% of the total nitrogen was removed
- Phosphorous - 13 -27% was removed

It was found that the gravel size was too fine -the first 2 metres of gravel was replaced with coarser gravel which prevented surface flow for another 12 months -the paper queries the long term viability of gravel bed wetlands because clogging causes surface flow. The system sustainability was less of a problem for surface flow systems. Fat accumulation and poor plant growth meant that the long term integrity was in doubt. Nitrogen removal rates were low (≤22%) under high nitrogen loadings. There was superior BOD, COD, and suspended solid removal than with facultative ponds.

General comments on the paper

- Very concentrated (high toxicity and nutrient loadings) was put through a system that was not suited for it
- Poor plant growth was probably caused buy the plants being poisoned. Fats are hard to metabolise and will not break down in this type of system
- The system is suited for sewage and as a polishing stage for treated effluent but not primary animal processing waste water

Hickey, C. W., Quinn, J. M. and Davies-Cholley, R. J. 1989 Effluent Characteristics of Dairy Shed Ponds and their Potential Impacts on Rivers *New Zealand Journal of Marine and Freshwater Research* Vol. 23: 569 - 584

Effluents of 11 ponds from throughout New Zealand were studied. The treatment process involved was two stage anaerobic followed by aerobic effluent treatment. No significant seasonal response was observed for BOD, suspended solids or ammonia concentrations. Higher algal biomass in summer counteracts an increased rate of mineralisation of BOD and suspended solids expected at higher summer temperatures.

Oxidation pond discharges have the potential to significantly impact receiving waters by affecting the natural biota, degrading the aesthetic role and affecting human uses. Significant oxygen depletion in the receiving waters is possible because of the BOD and ammonia that is present.

Suspended solids can degrade the aesthetic quality -also reduces clarity and smothers the river bed.

Excessive proliferation of algae and macrophytes can choke waterways -reduces drainage capacity and amenity value. Dissolved inorganic nitrogen (DIN) may stimulate algae growth. Ammonia concentrations in pond effluents require >250 fold dilution so that it is not toxic to sensitive fish.

Dairy shed ponds generally perform poorly compared with domestic sewage oxidation ponds.

LIST OF RELEVANT PAPERS

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Most of the papers listed here have been reviewed, however it has not been possible to get them all. This list is by no means exhaustive and there are MANY more papers on this topic which have not been listed.

GLOSSARY OF TERMS

Anaerobic Conditions Conditions where there is no free oxygen present

BOD (Biochemical Oxygen Demand) The amount of oxygen that will be used up in effluent as a result of biological activity. It is often quantified as grams/cubic metre.

BOD_5 The biochemical oxygen demand of effluent after 5 days. This would have allowed enough time for aerobic and anaerobic bacteria to be acting on the nutrients in the effluent. It is often used as a standard measurement.

Constructed wetlands Wetlands that are artificial and have been built entirely for the purpose of removing nutrients from wastewater.

Coprecipitation The precipitation of say a metal that occurs while some other metal is also being precipitated.

Denitrification The loss of nitrogen from the soil or wastewater.

Evapotranspiration Water loss from soil due to the combined effects of evaporation and transpiration (water that is removed from the soil and into the atmosphere by plants.

Faecal Coliform Bacteria such as *E. coli* which exist in the gut of animals and end up in their faeces. These bacteria can also be found in animal derived wastewater.

Hydraulic Conductivity In terms of the substrate, its ability to water to flow trough it.

Macrophyte Large aquatic plants.

Monoculture Where there is only one species of plant present

Natural Wetlands The treatment of wastewater by passing it through a naturally occurring wetland. It is usually best suited as a means of polishing *(see Polishing Stage)*

wastewater before its final discharge into receiving waters.

Nitrification The fixing of nitrogen compounds into the soil.

Overland Flow The flow of water (or wastewater) over the surface of the land.

Oxidation The combination of oxygen with a substance, the removal of hydrogen from it, or any chemical reaction in which an atom loses electrons.

Oxidation Ponds A common means of treating domestic sewage and farm animal waste in New Zealand - usually a two stage system that allows the treatment of wastewater by aerobic processes. It is used both for farm wastes and domestic sewage from small communities.

pH A measure of the level of acidity or alkalinity - A pH of 7 is neutral, above that indicates an increasing level of alkalinity and below indicates increasing levels of acidity.

Polishing Stage The final stage of treatment of wastewater before its discharge into receiving waters. At this stage the last of the nutrients are removed so that when the wastewater is discharged it does not degrade the quality of the receiving waters. Many of the wetlands treatment systems are used at this stage.

Primary Treatment The first stage of treatment that wastewater undergoes when it is being treated. Much of the solids are removed as well as any products that could be difficult to deal with later on such as animal fats.

Rapid Infiltration Method A form of land application treatment where wastewater is poured onto land which is very permeable. The wastewater rapidly infiltrates through the soil where it undergoes treatment. May be used in places where there is permeable soil and a scarcity of land.

Receiving Waters The water body that ultimately receives the treated wastewater.

Reduction Any chemical reaction in which an atom gains electrons.

Rhizome A creeping stem that lies horizontally on the ground and can grow leaves, stems and roots.

Secondary Treatment The second stage of treatment in removing nutrients from wastewater. Many of the alternative forms of treatment may come in at this stage.

Septic Tank A form of on site domestic sewage treatment system which usually caters for one or two households.

Sewage In this report the word 'sewage' refers to wastewater from domestic and industrial sources.

Substrate The soil or medium that planted are growing in. In subsurface wetlands water is passed trough the substrate, which often consists of gravel which the plants are rooted into. The substrate may consist of soil, sand, gravel, boulders or a combination of any of these.

Subsurface Flow Wetlands The effluent is treated as it flows though the substrate. Oxygen is supplied to the effluent though the roots of plants such as Bulrush which allows aerobic and anaerobic bacteria to work on the effluent.

Surface Flow Wetlands The effluent is treated as it flows overland (see Overland Flow) and nutrients are stripped by plants that are immersed in it. Plants may either be partly immersed as in the case of bulrushes or cattails, or they may be totally immersed and floating in it as in the case of duckweed or salvinia.

Suspended Solids (SS) Solid particles (usually very small) that are suspended in wastewater. The treatment process usually tries to remove suspended solids from wastewater. Suspended Solids are usually measured in terms of grams per cubic metre.

TIN Total Inorganic Nitrogen

Topogenous Mire A mire or bog in which the factors that control its formation are topographical such as the presence of a depression in the ground that prevents water from draining away so that the ground is always wet.

Wastewater Incudes all forms of water which are carrying pollutants away from a source. This may include domestic sewage, industrial waste, septic tank effluent, animal waste from farming activity or processing, tip leachate, mine tailing leachates etc.