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Review of Approaches for Purifying Runoff from Effluent Irrigated Land

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDIX

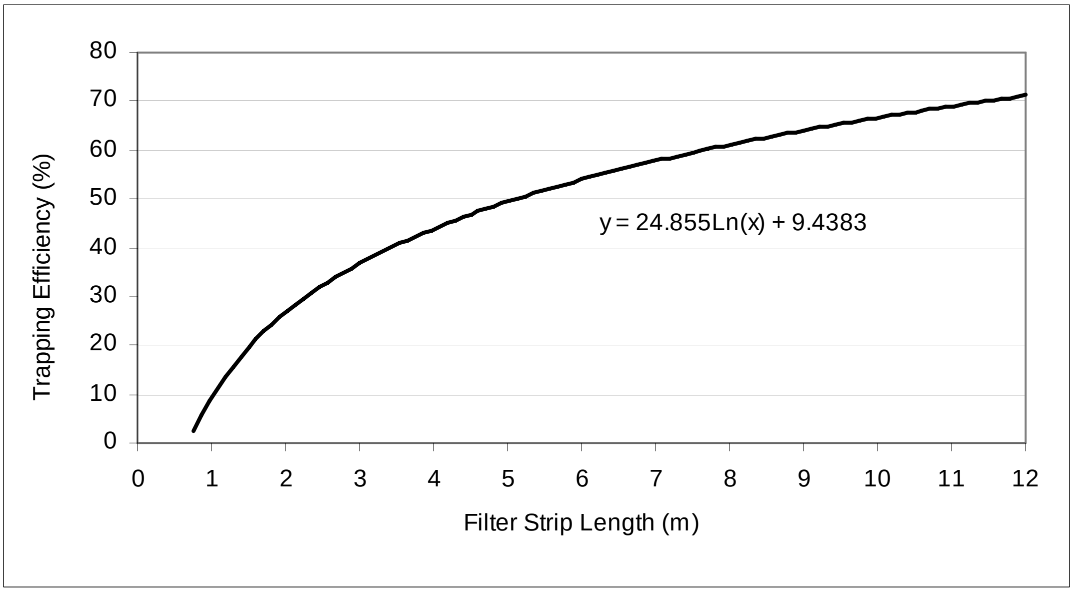
EXECUTIVE SUMMARY

This literature review provides an assessment of the performance of grass vegetative filter strips, buffer strips and other low cost treatment technologies for reducing pollutant concentrations in runoff from effluent irrigated land or discharge of treated abattoir effluent from wet weather storages. The review has been initiated by Meat and Livestock Australia in the light of the increasing levels of environmental protection being required for abattoirs. In particular, the need to ensure that all elements of the effluent treatment and re-use process are accounted for in setting appropriate performance standards for the capacity of wet weather storage for treated effluent and the management of stormwater runoff from effluent irrigated land.

The terms “buffer strip” and “vegetative filter strip” are often considered synonymous although they differ technically. Buffer strips are short but wide vegetated areas that are generally placed between a disturbed area and a watercourse. Unlike a buffer strip, a vegetative filter strip is longer than it is wider and may incorporate a permeable soil substrate to enhance infiltration of runoff. Although both these terms are referred to in this study, the evaluation of their effectiveness has not been differentiated because the technical literature is inconsistent or unclear. For the purposes of this study, both the terms “buffer strip” and “vegetative filter strip” refer to managed areas containing grasses and/or legumes only. Natural systems including forested riparian buffers that include grasses, tress and shrubs are not within the scope of this review.

The use of vegetative filter strips is widely recognised in Australia as a suitable method of treatment for urban stormwater. Much of the information available on the performance of vegetative filter strips for stormwater management has been established overseas, although some research has been conducted in Australia. Because of the applicability of vegetative filter strips to urban stormwater treatment, most research has been focussed on the ability of vegetative filter strips to reduce sediment and associated particulate bound plant nutrients, such as total phosphorous. The various studies examined by this report indicate that vegetative filter strips are capable of removing greater than 75% of sediment and associated total phosphorous from stormwater, principally through sedimentation, infiltration and interception of particles by the vegetation. Figure S-1 shows typical sediment removal efficiency with increasing length of vegetative filter strip and indicates that about 70% of sediment can be trapped with flow lengths of 12 m.

A limited number of studies on stormwater treatment have examined the effect of vegetative filter strips in reducing the concentrations of soluble nutrients. It is these soluble nutrients that are the primary concern for abattoir irrigated effluent. Because sediment and other debris is removed during the effluent treatment process, secondary treated abattoir effluent almost exclusively consists of soluble forms of nitrogen and phosphorous. The dominant form of nitrogen in secondary treated effluent is ammonia-N and organic nitrogen (TKN) with nitrate-N usually comprising less than 1% of the total nitrogen concentration. Phosphorous is present principally as ortho-phosphate (PO_4). Unlike secondary treated effluent, runoff from effluent irrigated areas is likely to be considerably diluted. Such runoff would be more similar to stormwater runoff where much of the plant nutrients, particularly phosphorus, are bound to soil particles with only a small proportion being soluble.



Adapted from: Wong and McCuen (1982)

Figure S-1
Sediment Removal Efficiency with Increasing Length of Vegetative Filter Strips

The effectiveness of vegetative filter strips in removing soluble nutrients has largely been the domain of overseas research where they have been used successfully for overland flow treatment of effluent and for the treatment of runoff from intensive livestock industries such as feedlots. Not only have they been used successfully but are regarded as a “best management practice” for managing secondary treated effluent from the livestock industry when designed correctly. Much of the research on the use of vegetative filter strips for the overland flow treatment effluent has been undertaken since the 1970's with their application to stormwater management becoming popular in the late 1980's. This indicates that the increasing use of grass vegetative filter strips for stormwater management in Australia is an extension from the successful use of vegetative filter strips for effluent treatment and stormwater management overseas.

Soluble nutrient removal processes in vegetative filter strips tend to be through infiltration of the water, direct uptake by plants, adhesion to colloids, denitrification and microbial breakdown. Variability in removal efficiency of soluble nutrients is principally due to the influence of site topography, soil characteristics and vegetative filter strips design. However, factors such as uniform flow, vegetative filter strips length and soil infiltration rates appear to influence the extent to which soluble nutrients are removed from a vegetative filter strips.

The research reviewed in this report shows that a significant proportion of soluble nutrients can be removed using grass vegetative filter strips. Typical average removal efficiency of soluble nutrient concentrations for vegetative filter strips 9 m and greater in length was over 50% for ortho-phosphate and 70% for TKN. Figures S-2 and S-3 show the effect of filter strip length on reduction in nitrogen and phosphorous concentration. The data used to produce these figures represent all the research reviewed for this study and indicate that, with filter strip lengths of 30 m, concentration reduction of approximately 74% for ortho-phosphate and 80% for TKN can be achieved.

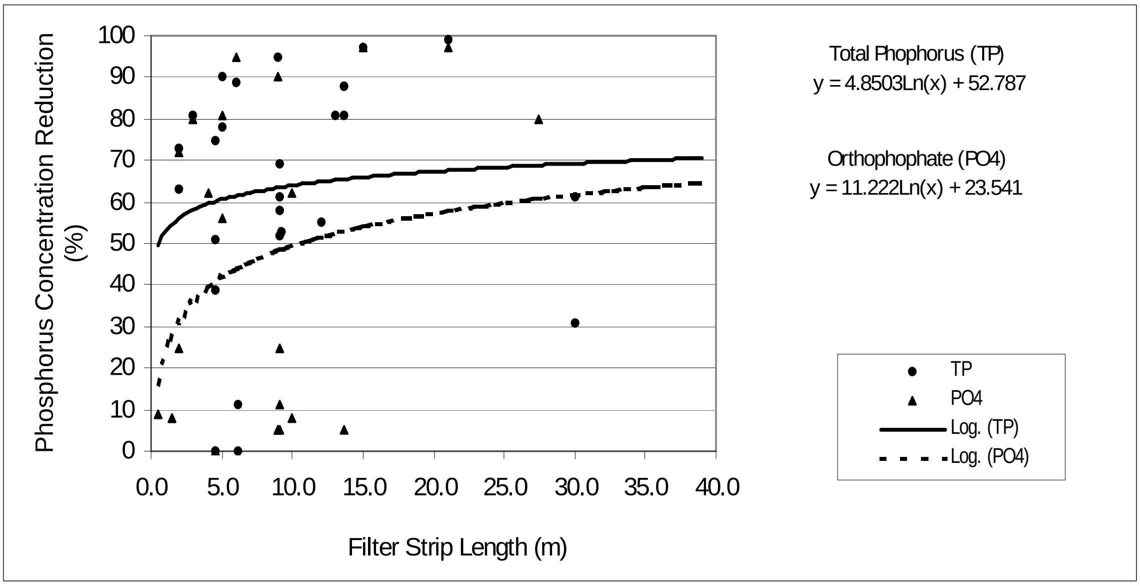


Figure S-2
Effect of Filter Strip Length on Reduction in Phosphorous Concentration

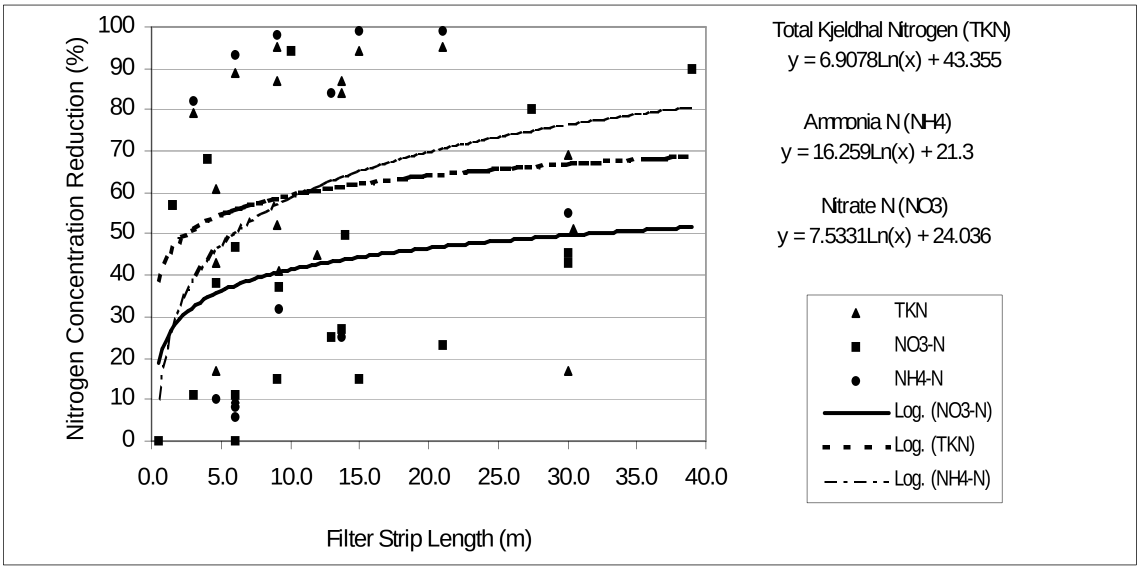


Figure S-3
Effect of Filter Strip Length on Reduction in Nitrogen Concentration

Unlike the large body of research available on nutrient removal by vegetative filter strips, research into the removal of BOD by vegetative filter strips is limited. However, the available research indicates that BOD reductions of between 40% to 85% are achievable for vegetative filter strips. The efficiency of vegetative filter strips in reducing pesticides is also not well researched although metabolisation of the chemical by micro-organisms in the buffer strip is believed to be the main process by which pesticides are neutralised.

The research reviewed in this report indicates that vegetative filter strips could reduce bacteria concentrations by 70% or possibly as much as 100%. The process of pathogen removal appears to be a combination of exposure to ultraviolet light, capture of particulate attached pathogens in the buffer strip and infiltration of pathogens into the soil profile. However, there is no research available as to the fate of pathogens that have infiltrated into the soil profile.

The high removal rate of soluble nutrients by vegetative filter strips and particularly their suitability in removing particulate attached nutrients indicates that vegetative filter strips are an appropriate method of treating runoff from effluent irrigated land. Also, the high efficiency of vegetative filter strips in removing nitrogen, phosphorous and BOD concentrations from secondary treated effluent indicates the potential for this method of treatment to significantly reduce pollutant concentrations between the point of discharge from an effluent storage and the boundary of the property. This pollutant reduction capability of vegetative filter strips should be taken into account in determining the EPA's requirements for the design capacity of wet weather storages.

This review has identified that factors such as slope, buffer length, soil type, vegetation type and hydraulic loading rate all affect the ability of a buffer strip to remove nutrients. A review of the available research indicates that the design of vegetative filter strips should ideally conform to the following:

- slopes less than 10%, and preferably between 1% and 5%;
- loam soil, and
- non-clumping grasses such as kikuyu.

If a buffer strip is being designed to receive effluent as part of an overland flow treatment system, the depth of flow will be an important contributing factor to overall efficiency of removal of soluble nutrient. Generally, the lower the hydraulic loading rate (ie low flow depths or slopes) the greater the reduction in nutrient concentration and load. The research reviewed indicates that flow depth should be no greater than 50 mm, with depths of flow of 10 mm being preferred as this encourages higher soluble nutrient removal rates. Figure S-4 shows the achievable flow rate for varying site slopes for flow depths of 50 mm, 25 mm and 10 mm.

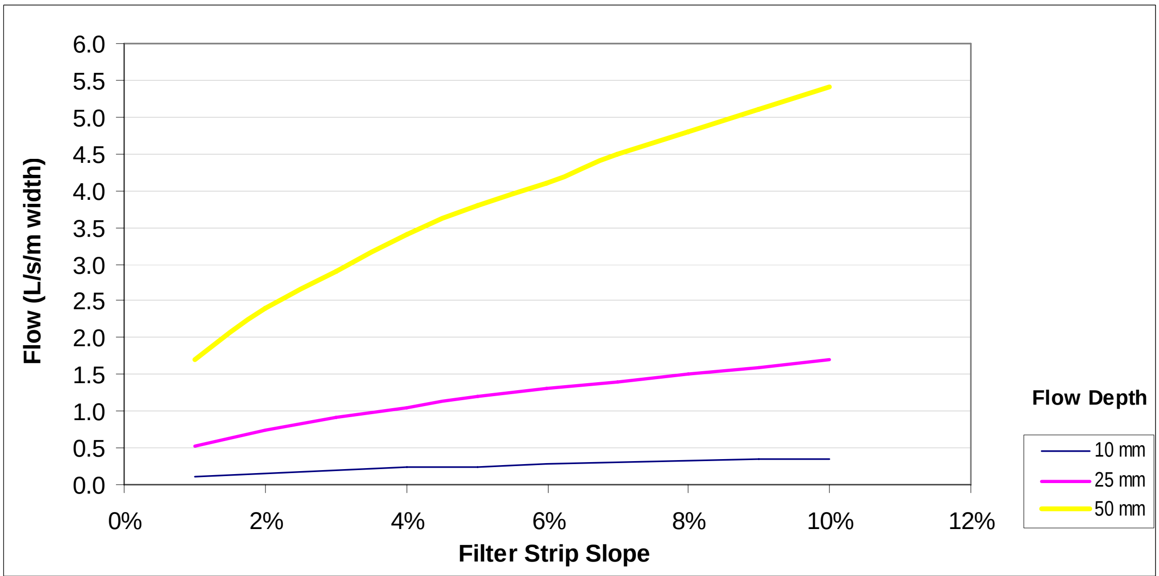


Figure S-4
Applied Flow Rate to Achieve 10 - 50 mm Flow Depths for Varying Slopes

Other low cost techniques for treatment of discharges from effluent irrigation wet weather storages and runoff from effluent irrigated land include constructed wetlands, floating macrophyte (duckweed systems) and the CSIRO FILTER treatment. The relative merits of these systems compared to vegetative filter strips are summarised in Table S-1. Of these three options, a wetland utilising the floating macrophyte “duckweed” is considered most suitable as an alternative to vegetative filter strips because it requires less land area and maintenance compared to a constructed wetland and consistently exhibits greater nutrient uptake rates than vegetative filter strips. Duckweed systems have been successfully used to remove 70% to 99% of all soluble nutrients in livestock effluent treatment applications and to reduce BOD concentrations. They have also been shown to be capable of removing salts to some extent. When used in a dam, duckweed systems are also beneficial because they may provide additional wet weather storage for secondary treated effluent, and reduce nutrient loading rates to the irrigation area.

Table S-1
Comparison of Treatment Options

Parameter	Vegetative Filter Strips	Constructed Wetlands	Duckweed Systems	CSIRO “FILTER”
TKN Removal	✓✓	✓✓	✓✓	✓
TP Removal	✓✓	✓✓	✓✓	✓✓✓
Dissolved N Removal	✓✓	✓✓	✓✓✓	✓✓
Dissolved P Removal	✓	✓	✓✓	✓✓✓
Sediment Removal	✓✓✓	Pre-treatment reqd	Pre-treatment reqd	✓✓✓
BOD Removal	✓✓	✓	✓	✓✓✓
Capital Costs	✓✓✓	✓	✓✓✓	✓
Maintenance Costs	✓✓✓	✓	✓✓	✓✓

Key: ✓ Low efficiency / high cost ✓✓ Moderate efficiency & cost ✓✓✓High efficiency / low cost

1 INTRODUCTION

1.1 Scope

This literature review has been prepared for Meat and Livestock Australia to provide an assessment of the performance of grass vegetative filter strips, buffer strips and other low cost treatment technologies for reducing pollutant concentrations in runoff from effluent irrigated land or discharge of treated abattoir effluent from wet weather storages. Although this review is principally concerned with the performance of vegetative filter strips, the performance of constructed wetlands and other low cost technologies has also been reviewed briefly.

It is envisaged that the meat processing industry will benefit from this study in a number of ways including:

- Possible reduction in capital investment in dams for storage of effluent during wet weather;
- Enhanced environmental protection resulting from appropriate treatment of runoff from effluent irritation areas;
- Improved treatment of stormwater runoff from some operational areas of abattoir sites;
- Technical details that can be used as a basis for providing low cost solutions for reducing contaminant release from land irrigation areas.

1.2 Background

Abattoir effluent has been classified by the NSW Environment Protection Authority (1995) draft guideline *"Use of Effluent by Irrigation"* as moderate to high strength waste. This classification is based on the concentration of pollutants such as nutrients (TP and TN), biological oxygen demand (BOD) and total dissolved salts (TDS). Table 1 shows the classification criteria for effluent strength based on the NSW EPA (1995) draft guidelines and associated requirement for provision of wet weather storage.

Table 1
Classification of Effluent Strength Used by NSW EPA

Effluent Strength Classification	Total N	Total P	BOD	TDS	Storage Required
	mg/L	mg/L	mg/L	mg/L	for Wettest Year in X
Low	<50	<10	<40	<500	2
Intermediate	50-100	10-20	40-1500	500-1000	4
High	>100	>20	>1500	>1000	10
Typical Abattoir Effluent	*130-300*	*30-50*	*50*	*see Sec 2.2*	*1 in 10 (High)*

From discussions between the meat processing industry and the NSW EPA, industry understands that the concentrations listed in Table 1 relate to any discharge from the boundary of the property, not to the concentrations of pollutants in the effluent storage dam. The reasoning for adopting the concentration at the property boundary is that the classification is aimed at protecting the local aquatic environment, which is external to the wet weather storage. It is possible that future guidelines may also include oil and grease, pesticides and metals in the classification of effluent strength. An important implication is that if the concentration of any one water quality parameter exceeds the criteria used to classify the effluent as low, intermediate or high strength then the most stringent effluent classification criteria applies.

2 WATER QUALITY CHARACTERISTICS OF SECONDARY TREATED ABATTOIR EFFLUENT

2.1 Nitrogen and Phosphorous

The main pollutants that are present in secondary treated abattoir effluent are nitrogen and phosphorous with dissolved forms being dominant. Both nitrogen and phosphorous can cause significant environmental degradation if present in moderate concentrations in aquatic ecosystems. Their impact is most often associated with the eutrophication of freshwater creeks and rivers producing algal blooms and promoting weed invasion of riparian areas. The eutrophication effect may also extend into estuaries where phytoplankton blooms may occur. Both of these forms of blooms can produce algal and phytoplankton species that are toxic to aquatic biota.

Nitrogen is produced in abattoir effluent through contact of various organic materials with water used in the meat processing. In raw wastewater, the nitrogen form is that of organic nitrogen and ammonia (NH_3-N), with the two forms collectively referred to as Total Kjeldahl Nitrogen (TKN). Organic nitrogen is sourced from natural materials such as proteins, peptides, nucleic acid and urea. Unlike ammonia and nitrate (NO_3-N), organic nitrogen may exist as both the dissolved and suspended forms in the effluent. Most organic nitrogen in effluent is converted to ammonia-N in anaerobic lagoons. Generally, 80% of the nitrogen present in secondary treated wastewater is ammonia with nitrate normally comprising less than 1% of the total nitrogen content (Talyor Consulting & Rust PPK Pty Ltd, 1995). This is important, as nitrate irrigated to land is not readily absorbed by soil and any nitrate which is not absorbed by vegetation can percolate to groundwater causing contamination. Concentrations of Total Kjeldahl Nitrogen in anaerobic/aerobic lagoon treated abattoir effluent typically vary from 200 mg/L to 300 mg/L (Talyor Consulting & Rust PPK Pty Ltd, 1995).

Phosphorous in effluent from anaerobic/aerobic lagoons is present principally in the dissolved form of phosphates (PO_4), including ortho-phosphates and poly-phosphates. Concentrations in secondary treated abattoir effluent in irrigation wet weather storages vary from approximately 35 mg/L to 50 mg/L (Talyor Consulting & Rust PPK Pty Ltd, 1995). Unlike nitrogen, which can be readily removed from the effluent through denitrification that occurs in the treatment lagoons, phosphorous is more difficult to remove in a wastewater treatment system.

2.2 Biological Oxygen Demand & Salinity

Other chemical characteristics of effluent that may potentially be degrading to the environment are the biological oxygen demand (BOD) and salinity. Biological oxygen demand is a measure of the oxygen consumed during a specified time period (usually over 5 days) for the degradation of organic material. The BOD of secondary treated abattoir effluent is typically 50 mg/L (Lyall & Macoun Consulting Engineers, 1995; Environment Protection Authority, 1995).

The salinity of water is most often measured as either total dissolved salts (TDS, mg/L) or as electrical conductivity (EC, mS/cm). For secondary treated abattoir effluent the salinity is difficult to define, as the TDS comprises of both sodium and chloride and other types of salts, which are not as damaging to soils and aquatic environments. Typically, the TDS concentration of secondary treated abattoir effluent ranges from 960 mg/L to 1,600 mg/L. However, typical sodium and chloride concentrations are only of the order of 100 - 200 mg/L for each element (pers com, Dr Mike Johns, 2002). Also, the variability in the TDS concentration between abattoirs is a result of the varying concentration of salts in the freshwater imported into the abattoir.

3 VEGETATIVE FILTER STRIPS AND THE PROCESSES OF POLLUTANT REMOVAL

3.1 Definition of a Vegetative Filter Strip

The terms “buffer strip” and “vegetative filter strip” refer to vegetated areas which are used to remove pollutants from stormwater runoff and wastewater. These areas may be engineered to gain the greatest pollutant removal performance potential possible, and in such cases are generally referred to as vegetative filter strips.

This review has found that the terminology is not consistent between countries. For the purposes of this study, the following terminology, illustrated in Figure 1, has been adopted:

> *The term “buffer strip” is defined as a grassed area, that is generally wider (across the direction of flow) than it is longer (in the direction of flow). Not all buffer strips are grassed; some use legumes as the vegetative cover or consist of natural forested buffers. Buffer strips are generally placed between a disturbed area and a waterway, and may not be engineered to achieve uniformly distributed flow.*
>
> *Unlike a buffer strip, a “vegetative filter strip”, is specifically designed to ensure the uniform distribution of flow. They are typically longer than wider. The majority of the research reviewed by this report deals with the performance of vegetative filter strips.*

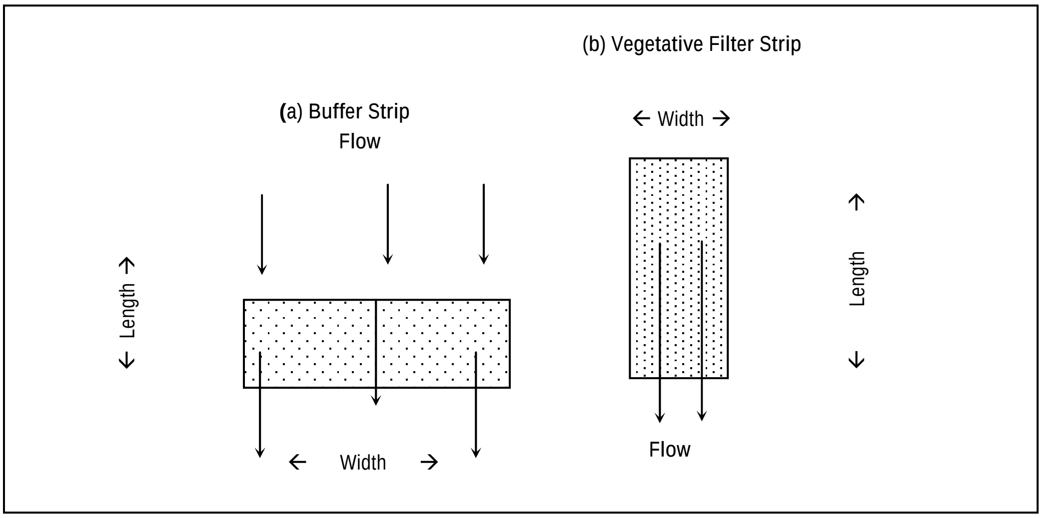


Figure 1
Definition of Flow Direction in Buffer Strips and Vegetative Filter Strips

3.2 Pollutant Removal Processes in Vegetative Filter Strips

As previously mentioned, the pollutants associated with secondary treated abattoir effluent are primarily the dissolved forms of nitrogen and phosphorous, along with TDS and BOD. Although not specifically categorised as a pollutant, pathogens may also be present in secondary treated effluent. The functions of a vegetative filter strip that aid in removing these pollutants and pathogens are described in the following sections.

3.2.1 Nitrogen and Phosphorous Removal Processes

Sediment bound phosphorous and particulate nitrogen removal is associated with sediment retention within a filter strip. The removal of dissolved forms of nutrients from overland flow can occur through the following processes:

- interaction of overland flow with microbial communities on the surfaces of soil, leaf litter and above ground plant organs;
- nutrient uptake by fine roots of plants which are concentrated on or near the surface both during the flow event and between flow events;
- nitrogen losses to the atmosphere, and
- infiltration of dissolved nutrients into the soil profile, and associated retention on clay colloids or subsequent uptake by plants.

Denitrification is the primary mechanism whereby nitrate (NO_3) is converted to gaseous N_2O and N_2. However, denitrification will only occur in a grass buffer if the following soil conditions are present:

- healthy populations of denitrifying bacteria present;
- sufficient quantities of organic carbon available; and
- alternating anaerobic and aerobic conditions (achieved by alternating saturation and drying phases).

Because vegetative filter strips do not generally satisfy most of these criteria, nitrate tends to pass through the vegetative filter strips as overland flow or infiltrate to groundwater rather than be denitrified.

In addition to phosphorous removal through absorption in plant biomass, the presence of Iron and Aluminium sesquioxides in the soil are important for the retention of phosphorous in the soil profile. Although clay soils have poor hydraulic properties, an abundance of sesquioxides and strong sorption properties make clay soils ideal for retaining phosphorous compared to sandy soils (Department of Primary Industry QLD, 2001).

3.2.2 Sediment Removal Processes

Typically, sediment removal is not an issue for abattoir effluent as it is removed in the treatment process. However, sediment removal is important for stormwater from the abattoir holding yards and pens as well as runoff from effluent irrigated land.

The reduction in sediment concentrations attributable to a vegetative filter strips is primarily the result of the reduction in flow velocity across the strip due to increased retardance by the vegetation (Corell, 1997). Therefore, the more dense the vegetation, the greater the friction loss throughout the buffer strip and the greater the sediment removal. Backwater effects on long vegetative filter strips also create conditions that facilitate sediment deposition.

Although sedimentation is the principle process by which sediment may be removed from a vegetative filter strips, the adhesion and interception of fine particulates by the vegetation may also play a role in sediment removal, along with the infiltration of water into the soil, which acts like a filter removing sediment.

3.2.3 Pathogen Removal Processes

There is little information available as to the processes of pathogen removal in grass vegetative filter strips. However, the retention of sediment bound pathogens is likely to be the major process for pathogen reduction. It is also possible that some pathogens in the water column are removed by infiltration (Lammers-Helps & Robinson, 1991).

In addition to these processes, reductions in pathogens is likely to be attributable to exposure to ultraviolet light (UV) although the linkage between pathogen removal in a vegetative filter strips and natural UV disinfection has not been adequately established.

3.2.4 Pesticides and Herbicide Removal Processes

Runoff from crops treated with herbicides or pesticides and irrigated with abattoir effluent may contain traces of those pesticides/herbicides. However, there is no evidence to suggest that pesticides and herbicides are present in secondary treated abattoir effluent.

Vegetative filter strips have the ability to remove and detoxify pesticides, principally through the breakdown of organic chemicals by microorganisms present in the soil. These microorganisms adapt to the presence of a pesticide/herbicide and metabolise the compound as an energy source, breaking it down into various compounds and ultimately carbon dioxide (Klapproth, 2000). Other removal processes occur through adhesion to clay particles and organic matter which, due to their large surface area, have a high affinity for pesticides/herbicides.

4 EFFECTIVENESS OF VEGETATIVE FILTER STRIPS IN REMOVING POLLUTANTS

Overseas research into the effectiveness of vegetative filter strips in removing pollutants from wastewater is considerably advanced when compared to the current state of Australian research on vegetative filter strip performance. In the United States of America, treatment of effluent discharged from wastewater treatment ponds using vegetative filter strips as an overland flow treatment system is generally considered “best practice management”. In such cases the vegetative filter strip acts as one part of a treatment train approach to effluent treatment. In such a situation the vegetative filter strip may be used as a final polishing phase, removing nutrients. Therefore, a significant amount of research has been conducted in the use of vegetative filter strips for overland flow treatment of effluent. In Australia most research on vegetative filter strips has focussed on their use for stormwater and agricultural runoff treatment, which is further discussed in Section 4.2.

The majority of the research into the use of vegetative filter strips for overland flow treatment of wastewater referred to in this report has been undertaken by members of the American Society of Agricultural Engineers. This research is principally concerned with studies undertaken to assess the effectiveness of vegetative filter strips in treating effluent and agricultural drainage, and is highly relevant to this study. As a result much of the information summarised in this study is sourced from the Journal of the American Society of Agricultural Engineers. Appendix A contains a summary of the technical literature related to pollutant removal potential of vegetative filter strips.

4.1 Reduction of Phosphorous and Nitrogen Concentrations

Research into the ability of vegetative filter strips to remove nutrients and sediment from treated effluent derived from livestock industries has been conducted since the 1970's, although most recently there has been an increase in the prevalence of such research.

Research by Chaubey et al. (1994) applied liquid swine manure to 3 m plots at the up-slope end of a 21 m long grass vegetative filter strips at 203 kg/ha TN and 141 kg/ha TP. Simulated rainfall with an intensity of 50 mm/h was directed over the plots, with resulting runoff being directed over a 1.3 m wide by 24 m long grass vegetative filter strip, while ensuring uniform distribution of flow. Concentrations of pollutants in the runoff entering the vegetative filter strips were approximately 20 mg/L of TKN and 11 mg/L of TP. The vegetative filter strips achieved a dissolved phosphorous concentration reduction of 97%, TKN reduction of 95% and a 99% reduction in ammonia-N concentrations. Even with buffer strip lengths of 3 m, ortho-phosphate concentration reductions of 80% were achieved.

Toombes (date unknown) used 70 m to 100 m long vegetative filter strips on clayey loam soils to treat runoff from dairy farms. Sampling of the dairy farm runoff indicated that mean ammonia-N concentrations were 221 mg/L and TP concentrations 69 mg/L. Average reductions in TP concentrations were 31% for all plots, although a TP concentration reduction of 99% was recorded on one plot. Average nitrate-N concentration reductions of 45% were also recorded for all plots.

Hawkins et al. (1995) applied swine lagoon effluent with an average nitrogen concentration of 160 mg/L (primarily ammonia) and a TP concentration of 2.7 mg/L directly to the up-slope end of a vegetative filter strip by using a gutter as a level spreader. The soil type in the grass buffer was a sandy loam, and effluent was supplied to the gutter 3 days per week for 2 hours a day over a 6 month period. The depth of overland flow varied from 10 mm on an 11% slope (application rate of 792 L/h) to 17.5 mm on a 5% slope (application rate of 2376 L/h). This equated to a TKN loading of 18,000 kg/ha on the 11% slope plot and 54,000 kg/ha on the 5% slope plot. The reductions in nutrient concentration attributable to the vegetative filter strip were 47% for nitrate-N, 10% for TKN and 11% for TP. The higher nutrient removal rates were recorded at the 5% slope plot, which was attributable to the greater hydraulic loading that created a more dense microbial mat which increased nutrient removal.

Overman et al. (1988) referred to a study undertaken in Florida by Overman & Schanze, (1984), in which the effect of hydraulic loading rate on treatment performance of a 12 m wide by 30 m long vegetative filter strips was examined. The study indicated that TKN concentration reductions of 51% could be expected at a hydraulic loading rate of 0.12 m^3/h/m. At greater hydraulic loading rates (up to 0.26 m^3/h/m) TKN concentration reductions decreased to 30%. Overman et al. (1988) also referred to another study undertaken in South Carolina by Wolf (1985) that found that TKN concentrations could be reduced by 75% at a effluent application rate of 0.21 m^3/h/m. The wastewater used in the South Carolina study exhibited a nitrogen concentration of 5 mg/L and a BOD of 35 mg/L.

Hubbard et al. (1998) used a 30m wide grass buffer to receive swine lagoon effluent which exhibited an average TKN concentration of 160 mg/L, with most of the nitrogen consisting of ammonia-N. Nitrate concentrations in the effluent ranged from less than 1 mg/L to 20 mg/L. Two different wastewater application rates were used for the study where each buffer strip plot had wastewater applied at once per week and twice per week over a period of 3 years. Each wastewater application consisted of 1285 L/d per plot, which corresponded to a 10 mm depth of wastewater flow per plot. The results indicated that the grass buffer was capable of reducing the ammonia-N concentration by 55% and nitrate-N concentration by 43%.

Ortho-phosphate reductions by a 9 m vegetative filter strip receiving runoff from a feedlot was variable, ranging from 11% to 53% (Dillaha et al. 1986). It was suggested that the lower recorded reductions in ortho-phosphate were attributable to sediment bound phosphorous being converted to soluble forms, which were leached from the filter during subsequent rainfall events. Doyle et al. (1977) found that a 4 m long vegetative filter strip was capable of removing 62% of the ortho-phosphate and 68% of soluble nitrogen from runoff originating from dairy manure. However, vegetative filter strips of 0.5 m length removed no nitrogen and ammonium concentrations actually increased with increasing filter strip length. This was presumably due to mineralisation of organic nitrogen compounds previously trapped in the filter strip.

Barfield et al. (1998) found that when a vegetative filter strip of 13 m length was used to receive rainfall runoff from plots subjected to erosion, TP concentrations were reduced by 84% on average and ammonia-N concentrations by 84% on average. A large proportion of this nutrient removal was attributable to the high infiltration rate of well structured silt loam Karst soils, where 94% of all runoff up-slope of the grass buffer was infiltrated.

It apparent that much of the research reviewed has not specifically examined the effectiveness of vegetative filter strips in reducing pollutants present in abattoir effluent. However, in many instances the concentration of pollutants in the applied effluent was similar to that expected for secondary treated abattoir effluent and still resulted in significant nutrient reductions (Department of Primary Industries QLD, 2001; Hawkins et al. 1995; Toombes, date unknown).

To illustrate the trend of nutrient removal between the studies reviewed a comparison was made between the length of a vegetative filter strip and the associated pollutant concentration reduction. Figures 2 and 3 show the relationship between the length of vegetative filter strip to the percentage reduction in nutrient concentration. The data points on each figure indicate the pollutant removal efficiency recorded for all studies reviewed by this study, with logarithmic lines of best fit (eg. Log-TP) showing the trend of nutrient removal with increasing vegetative filter strip length. Figure 2 shows that the removal of ortho-phosphate and TP is significantly dependent on vegetative filter strip length. Figure 3 shows that this trend is less pronounced for the removal of nitrogen with increasing vegetative filter strip length, indicating substantial (80%) ammonia-N removal can be achieved using relatively short grass vegetative filter strips.

Table 2 shows the mean pollutant concentration reduction and standard deviation for all the research reviewed by this study. The statistics for vegetative filter strips with a length of 9 m or greater indicate that TKN concentration reductions would be generally greater than 50% when accounting for the 22% deviation from the mean (65%). Mean ammonia-N concentration reductions of 73% could be expected for vegetative filter strips 9 m or greater in length, with concentration reductions being generally greater than 40%. The reduction in TP concentrations would be 70% on average, and generally greater than 50% when accounting for the standard deviation from the mean. Ortho-phosphate mean concentration reductions are estimated at 52%, although there is a large degree of variability. However, it should be noted that ortho-phosphate concentration reductions of up to 97% were recorded using a well designed buffer strip.

Table 2
Summary of Effect of Filter Strip Length on Reduction in Pollutant Concentration

Statistic	Pollutant Reduction %				
	TKN	Nitrate-N	Ammonia - N	Total P	Orthophosphate
All Filter Strip Lengths					
Average	59%	40%	58%	63%	43%
Std Dev	30%	28%	39%	28%	37%
Number	19	21	12	26	24
Filter Strips 9 m and Greater					
Av (> 9m)	68%	45%	70%	70%	48%
Std Dev	26%	28%	33%	20%	39%
Number	12	12	7	14	11

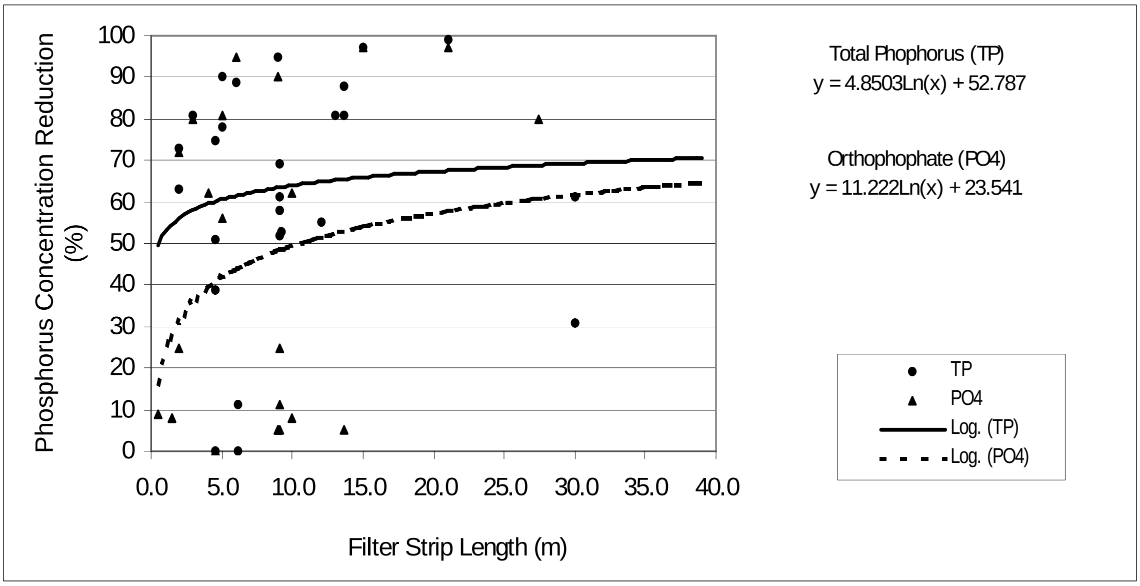


Figure 2
Effect of Filter Strip Length on Reduction in Phosphorous Concentration

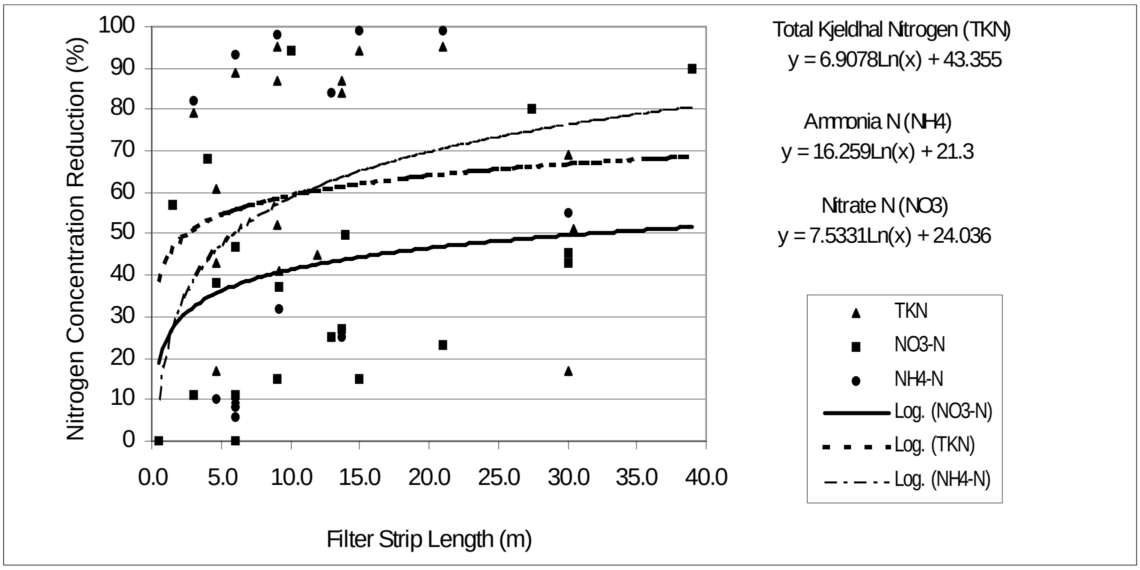


Figure 3
Effect of Filter Strip Length on Reduction in Nitrogen Concentration

4.2 Reduction of Phosphorous and Nitrogen Loads

Although this review of the performance of vegetative filter strips is principally focussed on their effectiveness in reducing pollutant concentrations, vegetative filter strips have been shown to significantly decrease the load (mass) of nutrients. The processes by which the load reduction occurs, are through reduction in concentration (as discussed above) and reduction in volume attributable to the infiltration of runoff into the soil.

A study by Hawkins et al (1995) on the treatment of swine lagoon effluent by a vegetative filter strip indicated that the reduction in TN loads varied between 69% and 77%. The TP load reduction varied between 72% and 79%. Similarly, research in Virginia indicated that vegetative filter strips are efficient in removing sediment and nutrient loads from feedlot effluent (Dillaha et al, 1988). Nitrogen loads were reduced by up to 52% and total phosphorous loads by an equivalent amount. Other researchers have also found that grass vegetative filter strips were useful in reducing the mass of TKN, TP and ortho-phosphate content in manure polluted runoff by up to 75% (Thompson, 1977; Lim et al. 1998).

Dillaha et al. (1989) determined that for cropland runoff, vegetative filter strips of 9 m in length reduced the TP loads by up to 87% when 93% of the TP was sediment bound. However, higher soluble nutrient removal rates were recorded by Fogle et al. (1994), where up to 97% of the phosphate and ammonia load was removed by the buffer strip. Barfield et al. (1998) found that when a vegetative filter strips of 13 m was used to receive rainfall runoff from erosion plots, TP load reductions of 96% and ammonia-N load reductions of 97% were recorded. This was one of the few studies which examined the effect of infiltration versus absorption in removing nutrients. The results indicated that the fraction of pollutant load absorbed generally increases with plot length, and that for areas where infiltration is minimal up to 50% of the mass reduction in TP could be attributable to absorption. Consequently, even buffer lengths as short as 4.5 m achieved mass ammonia-N reductions of 92% on average.

Parsons et al. (1991) found that a 5 m buffer strip treating cropland runoff was less effective in reducing nutrients with only 26% of total phosphorous and 50% of total nitrogen load removed. Paterson et al. (1980) also recorded load reductions of nutrients that were lower than recorded for most other studies, with 38% of ammonia and 7% of ortho-phosphate load being removed from dairy effluent applied to a buffer strip. The low mass removal efficiency of the buffer strip in this study is attributable to the short buffer lengths that were used. It would be expected that a longer vegetative filter strips would have achieved greater mass nutrient removal rates.

Figures 4 and 5 illustrate the trend of nutrient load removal with increasing buffer strip length while Table 3 provides summary statistics. For both nitrogen and phosphorous, the percentage reduction in loads are greater than that recorded for reductions in nutrient concentrations.

Table 3
Summary of Effect of Filter Strip Length on Reduction in Pollutant Load

Statistic	**Pollutant Reduction %**			
	TKN	Ammonia -N	Total P	Orthophosphate
All Filter Strip Lengths				
Average	64%	78%	68%	67%
Std Dev	23%	24%	25%	26%
Number	20	15	27	22
Filter Strips 9 m and Greater				
Av (> 9m)	73%	88%	81%	77%
Std Dev	20%	14%	16%	20%
Number	13	9	13	10

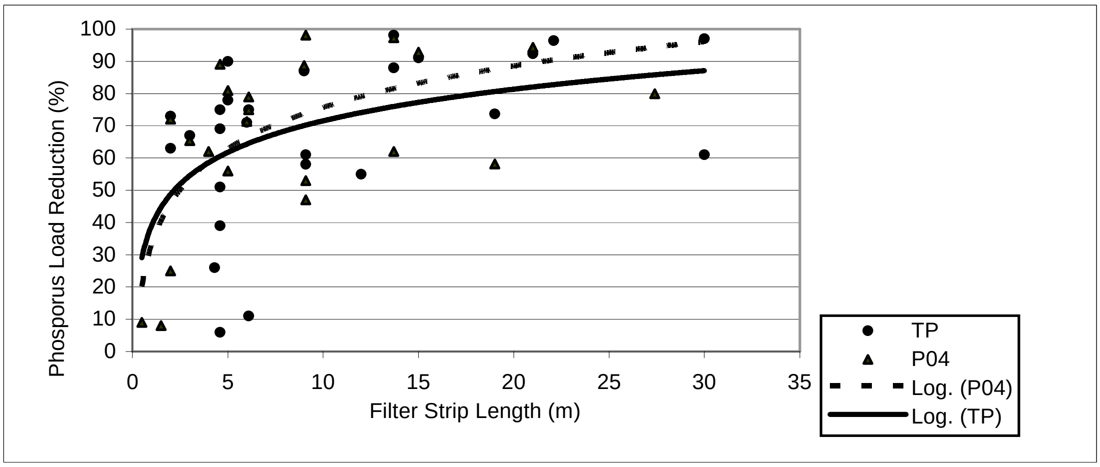


Figure 4
Effect of Filter Strip Length on Phosphorous Load Reduction

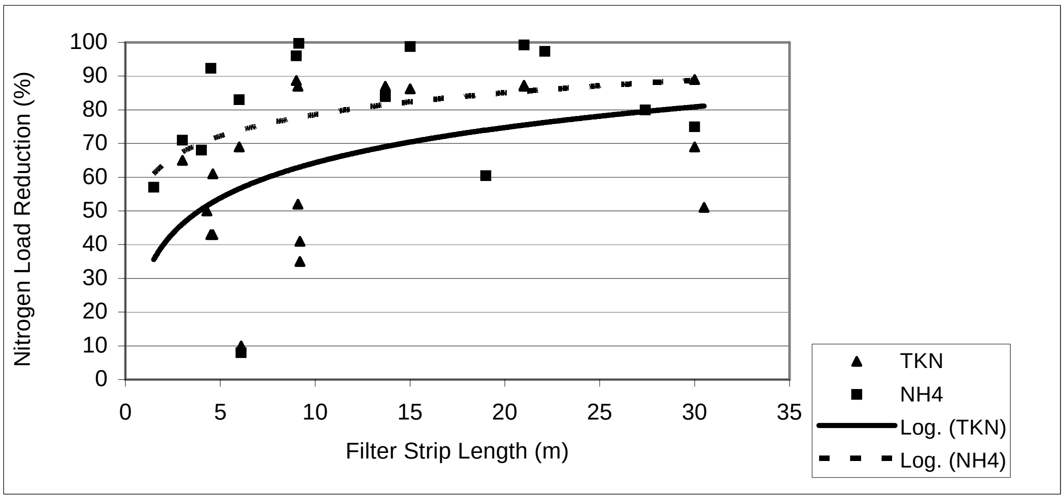
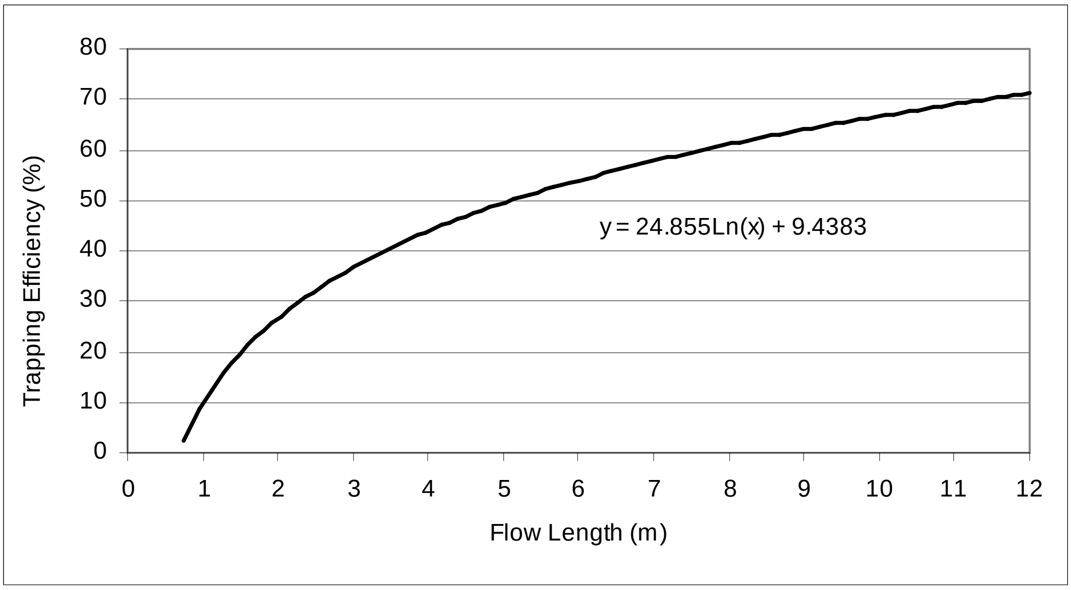


Figure 5
Effect of Filter Strip Length on Nitrogen Load Reduction

4.3 Sediment Removal

Sediment removal is one of the most widely researched aspects of the performance of vegetative filter strips. The interest in this topic is generally attributable to the importance of sediment removal for stormwater treatment and the management of agricultural drainage. Unlike the variability exhibited in nutrient removal studies, the consensus is that vegetative filter strips are a reliable means of removing sediment, with removal efficiencies of greater than 80% being recorded (Ghaffarzadeh et al. 1992; Lynch et al. 1985; Peterjohn & Correl, 1984; Hawkins et al. 1995; Barfield et al. 1998; Lammers-Helps & Robinson, 1991; Hayes et al. 1991; Overman et al. 1998; Fogle et al. 1994). Where lower sediment removal rates were found, this was generally the result of concentrated flows occurring within the vegetative filter strips, steep slopes being present, short vegetative filter strips lengths or natural buffer strips being used.

Figure 6 shows the relationship between vegetative filter strips length and sediment trapping efficiency as derived by Wong and McCuen (1982). This figure shows that trapping efficiencies of approximately 65% can be obtained by vegetative filter strips of moderate length (10 m).



Adapted from: Wong and McCuen (1982)

Figure 6
Effect of Vegetative Filter Strip Length on Sediment Trapping Efficiency

4.4 BOD Reduction

The documentation on BOD removal by vegetative filter strips is sparse, with most focus being directed towards nutrient and sediment removal. Paterson et al. (1980) found that 42% of BOD was removed from dairy effluent applied to a grass buffer. Overman et al (1988) has referred to two studies that examined BOD removal. The first study was undertaken by Wolfe (1985) and indicated that BOD concentrations were reduced by 86% at a hydraulic loading rate of 0.094

m^3/h/m. The subsequent study by Overman and Schanze (1984) estimated a BOD removal of 24% at hydraulic loading rates of 0.17 m^3/h/m. At lower (0.12 m^3/h/m) and higher (0.23 m^3/h/m) hydraulic loading rates BOD removal dropped to 7.5% and 10% respectively. Toombes (date unknown) estimated that vegetative filter strips were capable of reducing BOD in from wetland treated dairy farm effluent by 85%, and feedlot runoff BOD by 51% on average.

4.5 Pathogen Removal

Removal of pathogens by vegetative filter strips has received limited attention to date compared to the research on nutrient removal. Chaubey et al. (1994) estimated that swine manure runoff containing a faecal coliform concentration of $1.14E^6$ CFU/100 mL was reduced by 87% by a 21 m long grass buffer strip. Young et al. (1980) found that vegetative filter strips removed 69% of faecal coliforms and 70% of faecal streptococci bacteria from feedlot runoff. Similar results were obtained by other research where faecal coliform populations were reduced by between 64% and 87% (Bauder et al. date unknowm; Williamson et al. 1999; Keaton et al. 1998). Cooprider (1998) found that faecal coliform reduction by a vegetative filter strip (estimated at between 33% and 75%) was not dependant on the extent of vegetative cover, indicating that the removal of faecal coliforms is attributable to the length of the vegetative filter strip and soil conditions.

McLaughlin (2001) showed that *cryptosporidium* applied in laboratory conditions to a vegetated plot of 1 m soil depth (silty loam) resulted in the removal of all organisms from the leachate collected. Similarly, Lim et al. (1998) found that a vegetative filter strip of 6.1 m was sufficient to reduce faecal coliform concentrations in manure runoff (estimated at $2E^7$ FC/100 ml) to zero. However, there is no definitive information available as to the fate of pathogenic organisms in the soil profile.

4.6 Pesticides, Herbicides and Metal Removal

While there is no evidence to show that abattoir effluent contains chemicals such as herbicides and pesticides, the ability of vegetative filter strips to reduce concentrations of these pollutants is covered for the sake of completeness of this review.

Generally, there is little information on the ability of grass vegetative filter strips to reduce concentrations of metals, herbicides and pesticides. Edwards et al. (1997) examined the effect of a 3 m grass buffer strip with a mean runoff depth of 1.9 cm on reducing the mass transport of Cu, Fe, K, Na and Zn from areas treated with poultry manure. This study found that all metals decreased with increasing buffer length in a first order fashion, principally as a result of sedimentation of clay particles to which heavy metals were attached.

Hoffman and Gerik (1995) showed that grass buffer strips were effective in reducing total herbicide applications from cropland runoff. Obviously, high concentrations of herbicides would reduce the buffer strip effectiveness by killing the vegetative cover.

4.7 Australian Research on Vegetative Filter Strips

In Australia, research into the effectiveness of vegetative filter strips for pollutant removal is limited compared to the research that has been conducted overseas. The research conducted in Australia has been predominantly focussed on the use of vegetative filter strips for urban stormwater management and treatment of agricultural drainage, with no apparent research on their use for specifically treating effluent from abattoirs or intensive livestock sites (eg feedlots, piggeries), or for treatment of runoff from effluent irrigated land.

4.7.1 Estimated Pollutant Removal Efficiency - Effluent Treatment

The Department of Primary Industries, Queensland (2001) has undertaken research into the use of vegetative filter strips to reduce phosphorous concentrations in runoff from piggery effluent irrigation areas. For this study kikuyu grass vegetative filter strips with lengths of 2 m and 5 m were used. Each vegetative filter strip incorporated a 40 m up-slope length to the irrigation plot where the swine effluent was applied. The concentration of TP in the wastewater ranged between 16 mg/L and 44 mg/L, with TKN ranging from 159 mg/L to 713 mg/L. Approximately 80% of the TKN consisted of ammonia-N, and 86% of the phosphorous was present as ortho-phosphate in the irrigated effluent. These nutrient concentrations are comparable to those typical of secondary treated abattoir effluent, with TKN concentrations generally being greater than that expected for the meat processing industry.

This research indicated that vegetative filter strips could reduce the concentration of total phosphorous in the runoff by between 78% and 90%. TP concentrations associated with particle sizes less than 0.45 microns were reduced by between 75% and 82%, and ortho-phosphate by between 56% and 81%. As this study was focussed on phosphorous reductions, there was no mention of the nitrogen reductions attributable to the vegetative filter strip. However, runoff volumes from the vegetative filter strip were reduced by 80% through infiltration, and it was suggested that total mass reductions of over 90% could be expected for phosphorous.

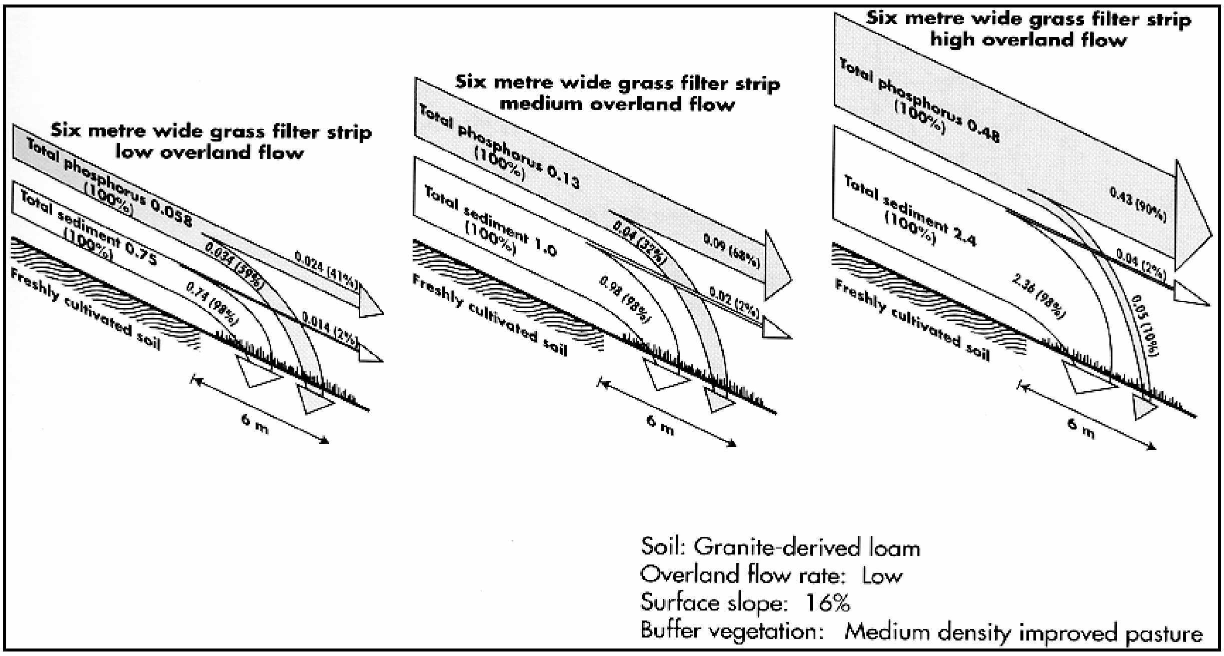
4.7.2 Estimated Pollutant Removal Efficiency – Stormwater/ Agricultural Drainage

Research into the sediment trapping efficiency of vegetative filter strips has resulted in variable results, although in all cases the sediment trapping efficiency for “well designed” vegetative filter strips have been greater than 60% (Hairsine, 1996; Karssies & Prosser, 1999; Wong et al. 2000). Table 2 also shows the range of pollutant reductions attributable to vegetative filter strips recorded by this research.

The NSW Environment Protection Authority has recognised the appropriateness of using vegetative filter strips for the removal of sediment and nutrients in urban stormwater management with quoted total phosphorous removal estimated at 29% (EPA, 1997). However, the estimated pollutant removal efficiency has been based on limited overseas research by Horner et al. (1994) and was limited to an average residence time of nine minutes. As nitrogen removal was minimal, it would be expected that the total phosphorous was sediment bound.

Although not specifically targeted at vegetative filter strips, a study by Roberts et al. (1998) on using irrigation drains for nutrient scavenging indicated that some agricultural drains were capable of reducing concentrations of ammonia-N by 95% and nitrate-N by 92%, based on data from the Whitton Drain. However, the effect of the drains in reducing pollutant concentrations for other sites was limited. This was attributable to the design of the irrigation drains, which are designed for conveyance rather than water quality treatment, and contained poor vegetative cover in places.

Bren et al. (1997) in Wong et al. (2000) determined that a 6 m wide buffer strip receiving runoff from freshly cultivated soil was sufficient to reduce total phosphorous concentrations by 59% with low overland flows. Figure 7 shows the efficiency of phosphorous removal declined to 10% for high flows.



Source: Bren et al. (1997) in Wong et al. (2000)

Figure 7
Sediment Removal Efficiency with Increased Flow

5 DESIGN GUIDELINES FOR VEGETATIVE FILTER STRIPS

The following sections outline some general design rules for vegetative filter strips. These guidelines have been formulated based on the findings of the review set out in this report. It is envisaged, however, that these guidelines would be reviewed in the light of ongoing research conducted by MLA and others.

5.1 Slope

A review of the available research indicates that slope of the vegetative filter strip is more important for sediment removal than for removal of soluble nutrients and other dissolved chemicals. Significant reductions in nutrient concentration have been documented on both low and moderate slopes, which indicates that other factors such as soil infiltration capacity and depth of flow may be more important design criteria. However, to ensure that all aspects of design are considered, a vegetative filter strip should be located on slopes <10%, and preferably on slopes between 1% and 5% to aid drainage.

5.2 Length and Flow Distribution

Based on Figures 2 and 3, the length of a vegetative filter strip should be at least 30 m to promote good phosphorous and nitrogen removal. For the treatment of effluent by overland flow, the vegetative filter strip width should be determined according to the desired effluent application rate, although a length of 30 m is desirable (see Section 6.5). Where the vegetative filter strip is to act as a buffer between a irrigation area and a waterway, the flow path length should be at least 12 m to ensure good sediment removal.

Most poorly designed vegetative filter strips fail because concentrated flow causes erosion. Ensuring that flow is evenly distributed across the entire width of the vegetative filter strip will avoid erosion and maximise contact time with vegetation and the soil, thereby ensuring efficient pollutant removal. The importance of creating uniform sheet flow conditions was characterised by Dillaha et al. (1986) where they found that vegetative filter strips subjected to concentrated flows were inefficient in removing phosphorous compared to vegetative filter strips with uniformly distributed flow. Good flow distribution can be accomplished by using a level spreader bank at the start of the vegetative filter strip.

5.3 Soil Type

Its is apparent from the research that soils with good infiltration rates will remove a greater proportion of soluble nutrients. In addition, the soil needs to be sufficiently fertile to ensure good vegetative growth and phosphorous removal. Because the presence of sesquioxides in clays is important in retaining phosphorous in the soil, a loamy soil with some clay is likely to achieve the greatest nutrient reductions.

5.4 Vegetation

A vegetative filter strip does not necessarily need to consist of grasses and may consist of other pasture species. However, the type of vegetation chosen needs to be a perennial, exhibit high nutrient uptake, have a low maintenance requirement and form a dense vegetative cover, all of which are satisfied by stoloniferous rhizome developing grasses such as kikuyu, couch or signal grass (Karssies & Prosser, 1999). Clump developing grasses should not be used as they may concentrate flow and do not facilitate uniform vegetative cover of the vegetative filter strip.

Ideally, grasses in a vegetative filter strips should be kept at an even height by periodic mowing and should be at least as high as the required depth of flow above the soil surface. A guideline to grass height is between 75 mm and 150 mm, depending on the depth of flow (see Section 6.5). Periodic mowing and removal of clippings would aid in removing nutrients from the site. Because of the compaction of the soil by stock, vegetative filter strips should be excluded from livestock grazing.

5.5 Hydraulic Loading and Depth of Flow

Depth of flow over the vegetative filter strip should preferably be kept to a maximum of two thirds the height of the grass, although ideally less than 50 mm flow depth. Table 4 shows the relationship between slope and applied flow rate to achieve a flow depth of 50 mm for grass vegetative filter strips with varying slopes.

Table 4
Treatable Flow for Various Filter Strip Slopes

Slope (%)	Flow (L/s/m width)	Manning's "n"	Flow Depth (mm)	Velocity (m/s)	VR*
1%	1.7	0.4	50	0.03	0.002
2%	2.4	0.4	50	0.05	0.002
3%	2.9	0.4	50	0.06	0.003
4%	3.4	0.4	50	0.07	0.003
5%	3.8	0.4	50	0.08	0.004
6%	4.1	0.4	50	0.08	0.004
7%	4.5	0.4	50	0.09	0.005
8%	4.8	0.4	50	0.10	0.005
9%	5.1	0.4	50	0.10	0.005
10%	5.4	0.4	50	0.11	0.005

Note: * VR is product of velocity and hydraulic radius

This relationship has been established using Manning's equation based on values of Manning's "n" for grasses with length of 150-250 mm and a vegetal retardance "class C" (Queensland Irrigation and Water Supply Commission, 1976). It can be seen that flow all slopes to 9%, a flow depth of 50 mm can be achieved while ensuring velocity is kept less than 0.1 m/s. This velocity is sufficiently low to promote sedimentation and ensure a detention time of at least 5 minutes for a 30 m vegetative filter strips.

Figure 8 shows the flow that can be applied to a vegetative filter strip to obtain flow depths of 50 mm, 25 mm and 10 mm for varying slopes. For flow depths of 10 mm, flow velocity will generally be less than 0.03 m/s for a 9% slope which equates to a retention time of approximately 16 minutes in a 30 m filter strip. It should be noted that the design flow depth for each situation will most likely have to be determined experimentally in order to asses treatment performance with increasing hydraulic loading rates.

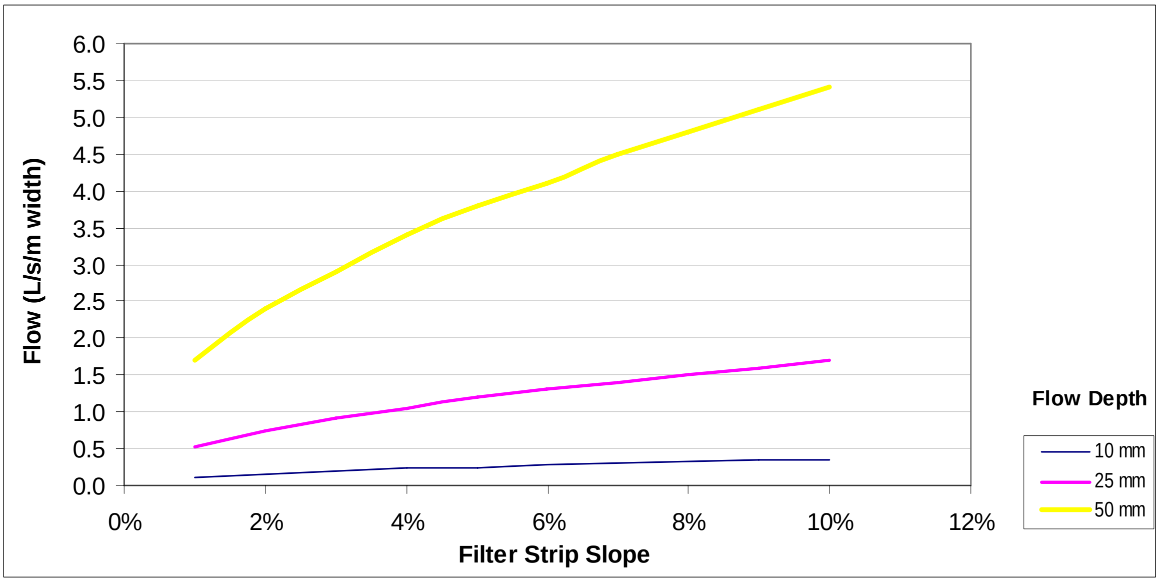


Figure 8
Applied Flow for Varying Flow Depths and Filter Strips Slopes

5.6 Treatment of Wet Weather Storage Overflow

The research literature indicates that a vegetative filter strip is an appropriate method for water quality treatment of overflows from a wet weather effluent storage. For such treatment the design guidelines discussed previously would also apply. To ensure efficient flow distribution through the vegetative filter strip, the flow rate of the overflow would need to be controlled.

A system incorporating a automated pump set to start at some critical storage level in the wet weather storage would be the most desirable method by which flow could be regulated into the vegetative filter strip.

6 OTHER LOW COST OPTIONS FOR TREATING EFFLUENT DISCHARGES AND RUNOFF FROM IRRIGATION AREAS

The following sections discuss other low cost options for managing effluent discharges from wet weather storage or managing runoff from irrigated areas. These options include constructed wetlands, floating macrophyte systems and the CSIRO “FILTER” system.

6.1 Emergent Macrophyte Constructed Wetlands

Grass vegetative filter strips are one of the most cost-effective forms of water treatment requiring little maintenance. However, there are other technologies that can offer similar performance such as constructed wetlands. Unlike a grass buffer, wetlands also increase bio-diversity by providing aquatic habitat in the form of macrophytes.

Phosphorous removal by wetlands is primarily related to sedimentation of phosphorous bound to particulates, and interception of these particulates by biofilms growing on the surface of macrophytes. Ortho-phosphate is removed by absorption by biofilms and macrophytes. Nitrogen removal in wetlands may occur through ammonia volatilisation, denitrification and storage in living biomass, detritus and sediments. However, the pH of most wastewater is unlikely to promote volatilisation as a significant mechanism for ammonia removal (Oostrom & Russell, 1992).

Wetlands containing emergent macrophytes have been used successfully for the treatment of treated livestock effluent and irrigation return water, with typical TKN removal efficiencies of between 50% and 90% being recorded (Chescheir et al 1992; Breen & Craigie, 1997; Costello, 1990). However, wetlands are not appropriate for treating effluent that has not already been subjected to some form of secondary treatment (Finlayson et al, 1986).

Wetlands are also considered a suitable treatment technique for urban stormwater runoff, exhibiting nutrient removal rates of up to 80% depending on factors such as the hydraulic residence time and hydraulic loading rate (Environment Protection Authority 1997; Lawrence & Breen 1998). Hydraulic loading rate, which is more dependant on surface area than wetland volume, appears to be the determining factor in the removal of soluble nutrients from stormwater (Environment Protection Authority 1997).

The advantages of constructed wetlands are that they are capable of storing a large volume of water and treating it over several days, thereby maximising hydraulic retention time. Because of the long exposure to UV light, concentrations of bacteria can be reduced by 3 to 5 orders of magnitude (Bavor & Andel, unknown date). The disadvantages of wetlands are that they require a greater capital investment than vegetative filter strips, have large land requirements and are more maintenance intensive than grass vegetative filter strips. Land requirements are large due to the fact that a large surface area is required to remove soluble nutrients. Wetlands are also dynamic biological systems which are known to periodically release nutrients stored in decaying vegetative material and the soil, and their effectiveness is greatly dependant on the density and health of the macrophytes.

Overall, constructed emergent macrophyte wetlands could provide a degree of water quality treatment similar to grass vegetative filter strips. However, the large land requirements, variable performance and high maintenance requirements discourage their use in treating abattoir effluent when compared to grass vegetative filter strips. Overall, wetlands would be most appropriate as a irrigation area runoff collection point, incorporating a “tailings dam” with a fringing macrophyte zone of at least 33% of the total surface area. This fringing macrophyte zone may be up to 1 m in depth.

6.2 Floating Macrophyte Constructed Wetlands

Floating macrophyte wetlands are vastly different to constructed wetlands containing emergent macrophytes in that they using floating aquatic plants that may be located in ponds, flow through systems or plastic/concrete tanks. Much research has been conducted into the use of floating macrophytes such as “duckweed” systems for treating wastewater, with duckweed systems becoming popular in the United States of America and in third world countries. Often inappropriately associated as being a weed, duckweed is actually a native floating macrophyte that belongs to the Lemnacae family. The most common species found throughout Australia is the Lemna sp, which is about 2-5 mm in size and are found in arid, tropical and temperate areas of Australia.

Duckweed systems have been successfully used to remove dissolved nutrients from livestock industry and municipal effluent. Typical nitrogen removal rates are 75%-85 for TKN and up to 99% for ammonia (Langston, 1996; Harvey & Fox 1973; Reedy and Debusk 1987; Skillicorn et al. 1993; Tripathi et al. 1991). Duckweed has a preference to absorb ammonia over nitrate which accounts for the high ammonia removal rates (Oran, 1990).

Removal of ortho-phosophate by duckweed from wastewater typically ranges from 75% to 97% for detention times of up to one month (Sutton and Ornes 1975; Skillicorn et al. 1993; Langston, 1996). The US Environmental Protection Authority (1988) *"Design Manual for Constructed Wetlands and Aquatic Plant Systems"* has indicated that duckweed systems are capable of reducing BOD by at least 50%. The nutrient uptake rates of Duckweed compared to other emergent macrophytes are shown in Table 5.

Table 5
Comparison of Nutrient Removal Between Macrophyte Species

Plant Type	Species	N- Uptake kg/ha/yr	P- Uptake kg/ha/y
Floating	*Lemna sp* (duckweed)	350 - 1200	116 - 400
Emergent	*Typha sp*	600 - 2630	75 - 403
Emergent	*Juncus*	800	110
Emergent	*Scirpus*	125	18
Emergent	*Phragmites*	225	35

Source: Reddy & DeBusk (1987)

More specifically Zirschky and Reed (1988) have examined the uptake capability for a range of elements from duckweed based systems. Their results are shown in Table 6, and uptake rates are expressed as grams of removal per meter squared of duckweed per year.

Table 6
Chemical Removal by *Lemna sp.*

Element	Uptake Rate ($g/m^2/y$)
N	6110
P	800
Al	2600
Ca	6000
Mg	800
Mn	90
K	2520
Na	390
Cl	1000

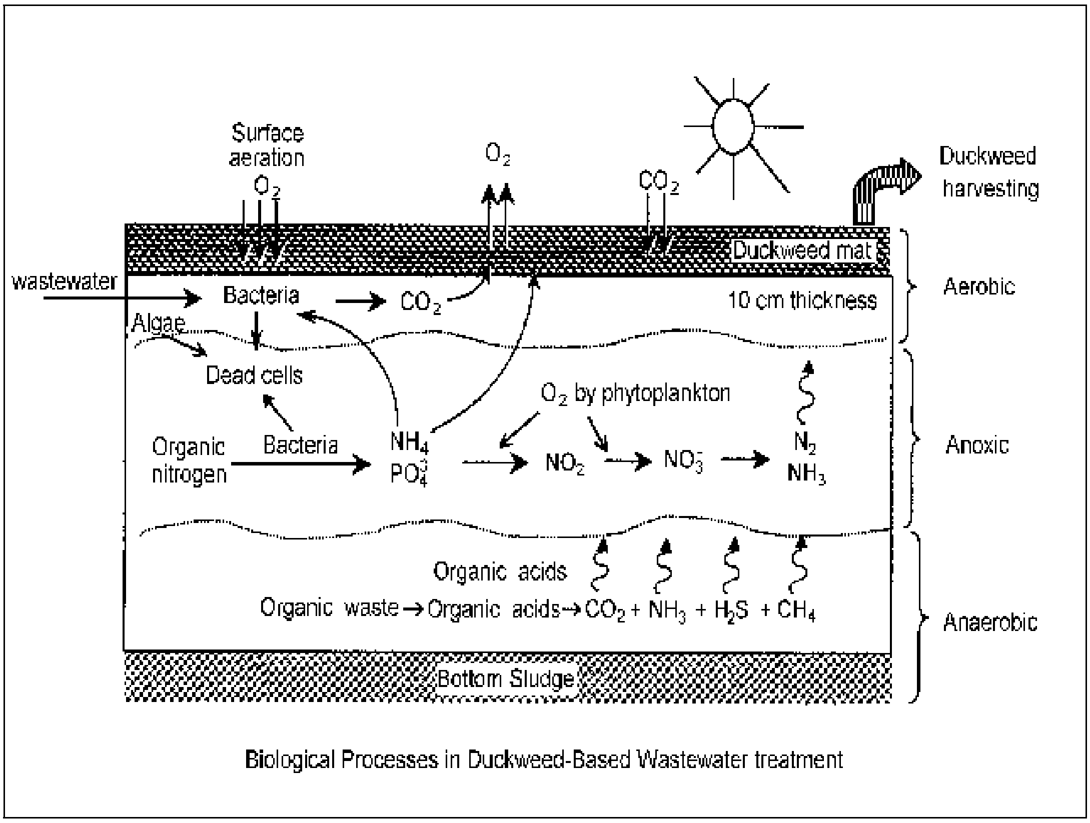
Source: Zirschky & Reed (1988)

Unlike emergent macrophytes, floating macrophytes such as "duckweed" have many advantages, including:

- nitrogen and phosphorous uptake rates approximately 2-3 times greater than those of many emergent macrophytes;
- they require less land area, as they can be housed in concrete/plastic tanks;
- have a more predictable performance than emergent macrophyte systems, as there is no sediment source in the wetland which can resuspend nutrients;
- growth rates are independent of soil substrate conditions, as growth is reliant on nutrients in the water and sunlight (hence their high affinity for removal of nutrients from wastewater);
- may provide a source of livestock feed, as they have more protein per square meter than soy beans (although pathogens in the wastewater may limit this use);
- are low maintenance requiring only biomass removal by simple methods;
- by obstructing sunlight by forming a thick vegetation mat, they reduce algae production and promote anaerobic conditions which facilitate denitrification;
- are tolerable to climatic extremes, and
- have much greater reproductive rates than emergent macrophytes as they reproduce asexually by budding as well as sexually (this aids the plants in establishing quickly and also allows the plants to repopulate quickly after harvesting or die-off from stress).

Floating macrophyte systems typically consist of a baffled pond system where the macrophytes are allowed to completely cover the water surface. Rates of plant reproduction in duckweed systems are very high, allowing substantial plant cover to form quickly. The process by which a duckweed system removes pollutants is shown in Figure 9.

These macrophytes remove soluble nutrients by plant uptake and, as they completely cover the water surface creating anaerobic conditions, they also promote denitrification. To remove nutrients from the system, approximately 30% to 50% of the plant biomass is removed fortnightly or monthly (although the optimum harvesting regime needs to be determined by trial and error). One of the main advantages of duckweed is that when the plant has removed nearly all the nitrogen from the wastewater, the duckweed will begin to "polish" the water as the plant tries to obtain sufficient nutrients for growth. This water "polishing" is often attributable to the ability of duckweed to remove metals and even many salts.



Source: Smith & Moelyowati (2001).

Figure 9
Biological Processes in Duckweed Based Wastewater Treatment System

The following issues need to be addressed in the design of a duckweed treatment system:

- The duckweed needs to be sheltered from wind if used on a open dam, as winds will clump the duckweed preventing it from fully covering the water surface. Wind protection is most often accomplished through using floating baffles or cells that reduce wind velocity over the pond surface.
- For flow-through systems the duckweed will need to be contained in cells to ensure it does not clump at one end of the treatment system and ensure good contact time with the water.
- Netting of open ponds may be required, as some species of duckweed are a preferred food source for ducks and other waterfowl. However, some species are less desirable to waterfowl.
- Depending on altitude some species of duckweed may become dormant through the winter (approximately 3 months) where nutrient uptake decreases significantly. To reduce this, it is advisable to use locally endemic species to the region that are adapted to the local climate.
- Disposal of the harvested duckweed will need to be considered. As duckweed consists predominantly of water it is usually composted.

Overall, the applicability of a duckweed biological water polishing system to abattoirs is considered viable compared with emergent macrophyte wetlands. Although, the use of vegetative filter strips is likely to be more cost effective, a duckweed system is typically more efficient at removing dissolved nutrients when compared to vegetative filter strips. In addition, duckweed systems could be retro-fitted into existing wet weather storage facilities and used to help reduce the nutrient loading to an irrigation area by further reducing the nutrient concentration of the treated effluent.

6.3 CSIRO "FILTER" Treatment

Another form of overland flow treatment which acts similar to a vegetative filter strip is the "FILTER" system developed by the CSIRO in Australia. This system works by applying effluent through flood irrigation to a cropped or grassed area overlying a permeable soil. Effluent then percolates through the soil to a drainage system below that collects the excess water and pumps it to a discharge/reuse location. Trials with municipal sewage effluent have indicated that the system is capable of reducing Organic N loads by 50%, ammonia-N by 99%, TP by 96% and BOD by 95% (CSIRO, 2000; Coughlan et al, 2003). However, the concentration of soluble nutrients in the effluent was much lower than abattoir effluent. In addition, due to the leaching process used by this system the concentration of salts in the discharge water is often greater than that of the applied effluent.

Overall, the large capital costs (estimated at $50k/ha) and land area requirements of such a system are likely to result in this system being inappropriate for the meat processing industry.

6.4 Comparison of Treatment Options

Table 7 provides a summary of the performance of the treatment options listed above, compared to vegetative filter strips.

Table 7
Comparison of Treatment Options

Parameter	Vegetative Filter Strips	Constructed Wetlands	Duckweed Systems	CSIRO "FILTER"
TKN Removal	✓✓	✓✓	✓✓	✓
TP Removal	✓✓	✓✓	✓✓	✓✓✓
Dissolved N Removal	✓✓	✓✓	✓✓✓	✓✓
Dissolved P Removal	✓	✓	✓✓	✓✓✓
Sediment Removal	✓✓✓	Pre-treatment reqd	Pre-treatment reqd	✓✓✓
BOD Removal	✓✓	✓	✓	✓✓✓
Capital Costs	✓✓✓	✓	✓✓✓	✓
Maintenance Costs	✓✓✓	✓	✓✓	✓✓

Key: ✓ Low efficiency / high cost ✓✓ Moderate efficiency & cost ✓✓✓High efficiency / low cost

7 SUMMARY OF VEGETATIVE FILTER STRIP PERFORMANCE

7.1 Pollutant Removal Potential

It is apparent from the research reviewed that vegetative filter strips are an effective means by which sediment, particulate bound nutrients and soluble nutrients can be removed. Reductions in the concentration of particulate attached nutrients of up to 90% could be expected for treatment of effluent discharged from an irrigation wet weather storage. In addition, similar nutrient and sediment removal could be expected for runoff from effluent irrigated land.

Although the performance of vegetative filter strips in removing soluble nutrients is variable, this review of existing research has shown that from vegetative filter strips 9 m or greater in length the expected mean removal efficiency for ortho-phosphate is 52%, and for TKN is 73%. Even when considering variance in the data reviewed, a minimum 50% reduction in TKN would be achievable with an adequately designed filter strip. Using the percentage reduction as shown on the trend lines on Figures 2 and 3, it is probable that the strength of effluent discharged from the wet weather storage could be reduced to an “intermediate” classification under the EPA (1995) irrigation guidelines using a well designed 30 m long vegetative filter strip, as shown in Table 8.

Table 8
Summary of Vegetative Filter Strip Performance

		NSW EPA Effluent Guidelines		30 m Vegetative Filter Strip		10 m Vegetative Filter Strip	
Parameter	Typical Abattoir Effluent Quality (mg/L)	High Strength (mg/L)	Intermediate Strength (mg/L)	Reduction (%)	Resulting Strength	Reduction (%)	Resulting Strength
TKN	300	> 100	50-100	67%	Int	59%	High
TP	50	> 20	10-20	69%	Int	64%	Int
BOD	50	> 1500	40-1500	50%	Low	40%	Low

Typical secondary treated abattoir effluent has a relatively low BOD, which would be classified by the EPA (1995) guidelines for irrigation as low to moderate strength effluent. Although much of the literature reviewed concentrated on the performance of vegetative filter strips in reducing nutrient concentrations, they are also considered appropriate for reducing the BOD of applied effluent by between 40% and 80%.

There is no substantial evidence to suggest that vegetative filter strips would be capable of reducing the concentration of TDS in secondary treated abattoir effluent. Considering that TDS concentration is part of the EPA (1995) classification criteria for effluent strength, it is unlikely that the classification could be reduced to moderate strength when considering all applicable criteria. However, as much of the TDS in abattoir effluent is made up of salts other than Na and Cl, the use of TDS as a classification criteria for the strength of abattoir effluent may not be appropriate. Under such conditions the EPA (1995) effluent strength classification could be reduced to moderate and wet weather storage requirements reduced accordingly.

7.2 Limitations and Constraints

From the review of literature by this study, the ability of a vegetative filter strip to remove greater than 50% of the soluble phosphorous and nitrogen is variable. This variation is generally attributable to differing field conditions between experiments such as climatic, effluent composition/source and soil type. Of particular note are the importance of infiltration, good vegetative cover and the presence of Fe and Al sesquioxides in the soil for removing dissolved nutrients. This suggests that vegetative filter strips may not be appropriate for use on sites that have soils with infiltration properties that are poor (heavy clays) or very good (sandy soils). Most of the literature that obtained high removal rates for soluble nutrients was based on loam soils which would be the preferred soil type for use in a vegetative filter strips.

It is also apparent that much of the research reviewed has not specifically examined the effectiveness of grass vegetative filter strips in reducing pollutants present in abattoir effluent. However, in many instances the concentration of pollutants in the applied effluent was greater than that which would be expected at an abattoir and still resulted in significant nutrient reductions.

7.3 Knowledge Gaps in Research on Vegetative Filter Strips

As evident through this literature review, there has been limited research conducted in Australia into the effectiveness of grass vegetative filter strips for reducing pollutants in pond treated effluent, or runoff from effluent irrigation areas. It is recommended that MLA work cooperatively with Australian Abattoirs to trial the effectiveness of using grass vegetative filter strips on selected abattoir sites in order to establish the following:

1. The role of infiltration in reducing pollutant concentrations. Infiltration appears to be a significant process by which soluble nutrients are removed (Hayes et al 1984). However, there is little information as to how the removal of soluble nutrients varies with different soil types.

2. The performance of grass vegetative filter strips during winter when vegetation growth is minimal. This needs to be understood in order to manage the vegetative filter strips effectively and predict the conditions under which they can be used effectively.

3. The overall influence of microbes on nutrient removal. Many of the highly efficient overland flow treatment systems evaluated are at least partially attributable to the regular application of effluent that builds up a healthy community of soil microbes which remove nutrients, and improves soil moisture storage. However, the overall influence of microbes on nutrient

removal is not well understood compared to other nutrient removal processes in a vegetative filter strips.

8 REFERENCES

Barfield B.J, Blevins R.L, Fogle A.W, Madison C.E, Inamdar S, Carey D.I, Evangelou V.P. 1998. *Water Quality Impacts of Natural Filter Strips in Karst Areas*, Transactions of the American Society of Agricultural Engineers. Vol 35(5) 1375-1381.

Bauder J.W. Cash S.D. Fajardo J.J. ?. *Managing Nitrate and Bacteria in Runoff from Livestock Confinement Areas with Vegetative Filter Strips*. Journal of Soil and Water Conservation. S6(4) p 184:190.

Bavor, H.J. & Andel, E.F. unknown date. *Nutrient Removal and Disinfection Performance in the Byron Bay Constructed Wetland System*. Water Research Laboratory, University of Western Sydney, Richmond.

Breen, P.F. & Craigie N.M. 1997. *The Use of Wetlands for the Treatment of Irrigation Return Water*. Prepared for Goulburn-Murray Water by Sinclair Knight Merz.

Chaubey I., Edwards, D.R., Daniel T.C. Moore P.A., Nichols D.J. 1994. *Effectiveness of Vegetative Filter Strips in Retaining Surface Applied Swine Manure Constituents*. Transactions of the American Society of Agricultural Engineers. Vol 37(3) p 845-850.

Chescheir, G.M. Skaggs, R.W. Gilliam J.W. 1992. *Evaluation of Wetland Buffer Areas for Treatment of Pumped Agricultural Drainage Water*. Transactions of the American Society of Agricultural Engineers. Vol 35(1) p 175-182.

Cooprider, M.A. 1998. *Factors Affecting Fecal Coliform Reduction by a Vegetative Filter Strip*. KWRRI - 1998 Symposium Proceedings.

Correl D.L. 1997. Buffer *Zones: Their Processes and Potential in Water Protection*. Proceedings of the International Conference on Buffer Zones - September 1996. p 7-20.

Costello, C.J. 1990. *Wetlands Treatment of Dairy Animal Wastes in Irish Drumlin Landscape.* In: Constructed Wetlands for Wastewater Treatment: Municipal, Industrial and Agricultural. Lewis Publishers, Michigan USA.

Coughlan K., Gardner, E. and Sands J. 2003. *Is FILTER for You? A Guide for Local Authorities in Queensland,* Center for Integrated Resource Management, University of Queensland.

Croke J., Wallbrink, P. Fogarty P., Hairsine P., Mockler S., McCormack B., Brophy J. 1999. *Managing Sediment Sources and Movement in Forests*: The Forest Industry and Water Quality. Cooperative Research Centre for Catchment Hydrology, Industry Report 99/11.

CSIRO, 2000. *The FILTER System- Turning Effluent into an Asset*. CSIRO Land and Water, 20 May 2000.

Department of Primary Industries, QLD. 2001. *Waste Disposal to Minimise Organic Phosphorous Mobilisation to Water Resources*. Pig Research and Development Project DAQ61/1354. Prepared for the Pig Research and Development Corporation.

Dillaha, T.A. Reneau R.B. Mostaghimi, S. Lee D. 1989. *Water Quality Impacts of Vegetative Filter Strips*. Paper 89-2043. . American Society of Agricultural Engineers.

Dillaha T.A. Sherrard J.H. Lee D. Mostaghimi S. Shanoltz V.O. 1988. *Evaluation of Vegetative Filter Strips as Best Management Practices for Feedlots*. Journal of Water Pollution Control, Vol 60(7): 1231-1238.

Dillaha T.A. Sherrard J.H. Lee D. Mostaghimi S. Shanoltz V.O. Magette, W.L. 1986. *Use of Vegetative Filter Strips to Minimise Sediment and Phosphorous Losses from Feedlots: Phase 1- Experimental Plot Studies*. Virginia Water Resources Research Centre, Virginia Polytechnic Institute and State University, Blacksburg.

Doyle, R.C. Stanton, G.C. Wolf D.C. 1977. *Effectiveness of Forest and Grass Filters in Improving the Water Quality of Manure Polluted Runoff*. Paper number 77-2501. American Society of Agricultural Engineers.

Edwards, D.R. Moore, P.A. Daniel, T.C. Srivastava, P. Nichols, D.J. 1997. *Vegetative Filter Strip Removal of Metals in Runoff from Poultry Litter Amended Fescuegrass Plots*. Transactions of the American Society of Agricultural Engineers. Vol 40(1) p 121-127.

Environment Protection Authority, NSW. 1997. *Managing Urban Stormwater: Treatment Techniques:*

Environment Protection Authority, NSW. 1995. *The Utilisation of Treated Effluent by Irrigation*. Draft Guidelines for Industry.

Environmental Protection Agency, U.S. 1988. *Design Manual: Constructed Wetlands and Aquatic Plant Systems for Municipal Wastewater Treatment*. EPA 625/1-88/022, September 1988.

Finlayson M., Chick A., Oertzen I., Mitchell D. 1986. *Treatment of Piggery Effluent by an Aquatic Plant Filter*. Biological Wastes, Vol (19) p 179-196.

Fogle A.W., Carey D.I., Barfield B.J., Blevins R.L., Evangelou, V.P., Madison C.E. and Inamdar S.P. 1994. *Impact of Riparian Grass Filter Strips on Surface Water Quality.* Kentucky Geological Survey, Information Circular 46- University of Kentucky, Lexington.

Ghaffarzadeh, M. Robinson, C.A. Cruse, R.M. 1992. *Vegetative Filter Strip Effects on Sediment Deposition from Overland Flow*. Agronomy Abstracts, ASA, Madison, WI, 324.

Harsine P. 1996. *Comparing Grass Filter Strips and Near-Natural Riparian Forests for Buffering Intense Hillslope Sediment Sources*. First National Conference on Stream Management in Australia.

Hawkins G.L. Hill, D.T. Rochester, E.W. Wood, C.W. 1995. *Evaluation of Overland Flow Treatment for Swine Lagoon Effluent*. Transactions of the American Society of Agricultural Engineers. Vol 38(2) p 397-402.

Hayes J.C, Barfeild B.J, Barnhisel R.I. 1984. *Performance of Grass Filters Under Laboratory and Field Conditions*. Transactions of the American Society of Agricultural Engineers. Vol 27 (5) p 1321-1329.

Hoffman, D. & Gerik, T. 1995. *Use of Contour Grass and Wheat Filter Strips to Reduce Runoff Losses of Herbicides*. Proceedings of the 1995 Water for Texas Conference, TWRI, Collage Station, Texas.

Hubbard R.K, Newton G.L, Davis J.G, Lowrance R, Vellidis G, Dove C.R. 1998. *Nitrogen Assimilation by Riparian Buffer Systems Receiving Swine Lagoon Wastewater*. Transactions of the American Society of Agricultural Engineers. Vol 41(5) p 1295-1304.

Irrigation and Water Supply Commission, Queensland. 1976. *Design Manual for Farm Water Supplies, Irrigation and Drainage*.

Karssies L, & Prosser I.P. 1999. *Sediment Storage Capacity of Grass Buffer Strips*. Second Australian Stream Management Conference 8-11th February 1999, Adelaide, South Australia.

Keaton P.K. Kalita P.K. Harner J.P. Starrett S.K. 1998. *Evaluation of Vegetative Filter Strips for Nutrient Removal from Feedlot Runoff*. Paper presented at the 1998 ASAE International Annual Meeting, Orlando, Fl. Paper No. 98-2014, American Society of Agricultural Engineers, St Joseph, MI.

Klapproth, J.C. 2000. *Understanding the Science Behind Riparian Forest Buffers: Effects on Water Quality*. Publication No. 420-151. Virginia State University, Collage of Natural Resources.

Lammers-Helps H. and Robinson D.M. 1991. *Literature Review Pertaining to Buffer Strips: An Extensive and Comprehensive Search, Review and Summary of the Current Literature on Buffer Strips*. The National Soil Conservation Program.

Langston, J.R. 1996. *The Use of Duckweed for the Biological Treatment of Feedlot Wastewater, Tullimba Feedlot NSW*. 4th year major project submitted for the degree of Bachelor of Natural Resources, University Of New England Armidale.

Lawrence, I. & Breen, P. 1998. *Design Guidelines: Stormwater Pollution Control Ponds and Wetlands*. The Cooperative Research Centre for Freshwater Ecology.

Lim, T.T Edwards, D.R. Workman, S.R. Larson, B.T. Dunn, L. 1998. *Vegetative Filter Strip Removal of Cattle Manure Constituents in Runoff*. Transactions of the American Society of Agricultural Engineers, Vol 41(5), p 1375-1381.

Lyall Macoun Consulting Engineers, 1995. *Effluent Irrigation Manual for Meat Processing Plants*. Prepared for the Meat Research Corporation.

Lynch, J.A. Corbett, E.S. Mussallem, K. 1985. *Best Management Practices for Controlling Non-point-Source Pollution on Forested Watersheds*. Journal of Soil and Water Conservation 40, 164-167.

Magette W.L. Brinsfeild R.B., Palmer R.E. and Wood J.D. 1989. *Nutrient and Sediment Removal by Vegetated Filter Strips*: Transactions of the American Society of Agricultural Engineers, Vol 32(2) p 663-667.

McLaughlin, S.J. 2001. *Retention of Cryptosporidium in Vegetative Filter Strips*. Thesis submitted at University of Illinois.

Ostrom, A.J. and Russell, J.M. 1992. *Denitrification in Constructed Wastewater Wetlands Receiving High Concentrations of Nitrate*. Proceedings of Wetland Systems for Water Pollution Control, University of New South Wales, Sydney.

Oran, G. 1990. *Economic Considerations in Wastewater Treatment with Duckweed for Effluent and Nitrogen Renovation*. Journal Water Pollution Control Federation, 62(5): 692-696.

Overman, A.R, Angley E.A. Schanze and Wolfe D.W. 1988. *Process Analysis of Overland Flow Treatment of Wastewater*. Transactions of the American Society of Agricultural Engineers. Vol 41(5) p 1295-1304

Parsons, J.E. 1994. *Reduction in Sediment and Chemical Load Agricultural Field Runoff by Vegetative Filter Strips*. The Water Resources Research Institute, North Carolina State University. Report 286, August 1994.

Parsons, J.E. Daniel, R.B. Gilliam, J.W. Dillaha, T.A. 1991. *The Effect of Vegetation Filter Strips on Sediment and Nutrient Removal from Agricultural Runoff*. Proceedings of the Environmentally Sound Agriculture Conference. Orlando, Florida.

Paterson J.J. Jones J.H. Olsen F.J. McCoy G.C. 1980. *Dairy Liquid Waste Distribution in an Overland Flow Vegetative-Soil Filter System*. Transactions of the American Society of Agricultural Engineers. p 973-984.

Reddy, K.R. and DeBusk, T.A. 1987. *State of the Art Utilisation of Aquatic Plants in Water Pollution Control*. Water Science & Technology, 19(10).

Roberts, J., Thomas, M and Merideth, S. (1998) *Role of Irrigation Drains in Nutrient Scavenging*. Technical Report 26/98. CSIRO Land and Water. December 1998.

Sheridan J.M, Lowrance R. Bosch, D.D. 1999. *Management Effects on Runoff and Sediment Transport in Riparian Forest Buffers*. Transactions of the American Society of Agricultural Engineers. Vol 42(1) p 55-64.

Skillicorn, P., Spira, W., Journey, W. 1993. *Duckweed Aquaculture; a New Farming System for Developing Countries*. The World Bank, Washington, DC.

Smith M.D and Moelyowati, I. 2001. *Duckweed Based Wastewater Treatment (DWWT): Design Guidelines for Hot Climates*. Water Science and Technology Vol 43(11) p 291-299.

Sutton, D.L. and Ornes, W.H. 1975. *Phosphorous Removal from Static Effluent Using Duckweed*. Journal of Environmental Quality, 4(3): 367-370.

Talyor Consulting Pty Ltd & Rust PPK Pty Ltd. 1995. *Identification of Nutrient Sources, Reduction Opportunities and Treatment Options for Australian Abattoirs and Rendering Plants*. A report prepared for the Meat Research Corporation. Environmental Issues Project M.445.

Toombes, M.R. date unkown. *Evaluation of Vegetative Filter Strips to Treat Beef Feedlot and Dairy Yard Runoff in Ontario*. Rural Conservation Clubs Program and Ontario Cattleman's Association.

Tripathi, B.D., Srivastava, J. & Misra, K. 1991. *Nitrogen and Phosphorous Removal Capacity of Four Chosen Aquatic Macrophytes in Tropical Freshwater Ponds*. Environmental Conservation, 18:143-147.

Williamson T.S., Kalita, P.K., Harner J.P. Marchin G.L Rice C.W. 1999. *Coliform Reduction by Filter Strips in Kansas Watershed*. Paper presented at the 1999 ASAE Annual International Meeting, Toronto, Canada. ASAE Paper No.99-2070, St. Joseph, MI.

Wong T., Breen, P. and Lloyd S. 2000. *Water Sensitive Road Design: Design Options for Improving Stormwater Quality of Road Runoff*. Cooperative Research Centre for Catchment Hydrology, Technical Report 00/1.

Wong, S.L. and McCuen, R.H. 1982. *The Design of Vegetative Buffer Strips for Runoff and Sediment Control*. Civil Engineering Department, University of Maryland, Collage Park, MD.

Young R.A. Handwrites T. Anderson W. 1980. *Effectiveness of Vegetative Buffer Strips in Controlling Pollution from Feedlot Runoff*. Journal of Environmental Quality, Vol 9 p 483-487.

Zirschky, J. & Reed, S.C. 1988. *The Use of Duckweed for Wastewater Treatment*. Journal of Water Pollution Control Federation. 60:1253.

APPENDIX A

Summary of Technical Literature

Table A1 - Performance of Vegetated Filter Strips in Reducing Pollutant Concentrations

Literature Source	Sub-reference	Application	Buffer Slope %	Buffer Length m	Buffer Width m	Concentration Reduction (%) TKN %	NO$_3$-N %	NH$_4$-N %	TP %	P diss %	SS %	BOD %	Pathogen Reduct'n %	Comments
Barfield et al (1998)		Agricultural drainage	9	13.0	4.6	-	25	84	81	-	99.7	-	-	Mass reductions in TP were 96%, and NH$_4$ 97%.
Barfield et al (1998)	Young et al. (1980)	Feedlot effluent	4	13.7	-	84-87	-	-	81-88	-	-	-	-	
Bauder et al. (?)		Feedlot runoff	4				97-99	-	-	-	-	-	64-87	Fescue grass on silt loam soil
Chaubey et al. (1994)		Swine effluent	3	3.0	1.5	79	11	82	81	80	80	-	94	Applied with liquid swine effluent at 200 kg N/ha
Chaubey et al. (1994)		Swine effluent	3	6.0	1.5	89	11	93	89	90	82	-	82	
Chaubey et al. (1994)		Swine effluent	3	9.0	1.5	95	15	98	95	95	85	-	90	
Chaubey et al. (1994)		Swine effluent	3	15.0	1.5	94	15	99	97	97	85	-	90	
Chaubey et al. (1994)		Swine effluent	3	21.0	1.5	95	23	99	99	97	91	-	87	
Cooprider (1998)		Poultry manure runoff	9	4.5	4.6	-	-	-	-	-	-	-	33-75	
Croke et al. (1999)		Agricultural drainage	-	25.0	10.0	-	-	-	-	-	80-90	-	-	TP reduction varies with slope and flow
Dep of Primary Industry, QLD (2001)		Piggery effluent irrigation runoff	5	2.0	3.0	-	-	-	63-73	25-72	-	-	-	
Dep of Primary Industry, QLD (2001)		Piggery effluent irrigation runoff	5	5.0	3.0	-	-	-	78-90	56-81	-	-	-	Infiltration accounted for 80% reduction in runoff
Dillaha et al. (1988)		Feedlot effluent	5	4.6	-	43	-	-	39	-	-	-	-	
Dillaha et al. (1988)		Feedlot effluent	16	9.1	-	52	-	-	52	-	-	-	-	
Dillaha et al. (1989)		Agricultural drainage	5	4.6	-	61	-	-	75	-	-	-	-	93% of TP was sediment bound
Dillaha et al. (1989)		Agricultural drainage	16	9.1	-	87	-	-	61	-	-	-	-	93% of TP was sediment bound
Doyle et al. (1977)		Dairy manure runoff	10	4.0	-	-	68	-	-	62	-	-	-	Applied at 850 kg N/ha./y
Doyle et al. (1977)		Dairy manure runoff	10	1.5	-	-	57	-	-	8	-	-	-	Applied at 850 kg N/ha./y
Eastern Canada Soil & Water Conservation	Dillaha et al. (1985)		-	9.1	-	-	-	-	-	25	-	-	-	
Environment Protection Authority (1997)		Stormwater	-	-	-	50-75	-	-	50-75	-	75-100	10-50	-	
Fogle et al (1994)		Agricultural drainage	9	4.6	4.6	-	38	10	0	0	52	-	-	
Fogle et al (1994)		Agricultural drainage	9	9.1	4.6	-	37	32	-	5		-	-	
Fogle et al (1994)		Agricultural drainage	9	13.7	4.6	-	27	25	-	5	90	-	-	
Fogle et al (1994)	Thompson et al (1978)	Dairy manure	4	12.0	-	45	-	-	55	-	-	-	-	Applied at 600 kg N/ha/y
Fogle et al (1994)	Thompson et al (1978)	Dairy manure	4	30.0	-	69	-	-	61	-	-	-	-	
Hairsine P. (1996)		Agricultural drainage	0.16	3 to 6	-	-	-	-	-	-	>90%	-	-	Nutrient reduction greatest when sed attached
Hawkins et al (1995)		Swine effluent	5	6.1	-	9	47	6	11	-	29	-	-	Average effluent water depth 1.75 cm
Hawkins et al (1995)		Swine effluent	11	6.1	-	10	0	8	0	-	-	-	-	Average effluent water depth 1.25 cm
Hayes et al. (1984)		Stormwater	2 to 10	37.0	3.0	-	-	-	-	-	66-90	-	-	
Hubbard et al. (1998)		Swine lagoon effluent	2	30.0	4.0	17	43	55	-	-	-	-	-	
Karssies & Prosser (1999)		Sediment trapping	0.06	-	-	-	-	-	-	-	>60%	-	-	
Lammers-Helps & Robinson, (1991)	Neibling and Alberts (1979)		4.9	-	-	-	-	-	-	-	90	-	-	Removed 83% of clay fraction

Table A1 - Performance of Vegetated Filter Strips in Reducing Pollutant Concentrations

Literature Source	Sub-reference	Application	Buffer Slope %	Buffer Length m	Buffer Width m	Concentration Reduction (%) TKN %	NO$_3$-N %	NH$_4$-N %	TP %	P diss %	SS %	BOD %	Pathogen Reduct'n %	Comments
Lammers-Helps & Robinson, (1991)	Doyle et al 1977	Dairy manure runoff	0.1	0.5	-	-	0	-	-	9	-	-	-	
Lammers-Helps & Robinson, (1991)	Doyle et al 1977	Dairy manure runoff	-	1.5	-	-	57	-	-	8	-	-	-	
Lammers-Helps & Robinson, (1991)	Doyle et al 1977	Dairy manure runoff	-	4.0	-	-	68	-	-	62	-	-	-	
Lammers-Helps & Robinson, (1991)	Kovacic et al (1990)	Cropland runoff	-	14-39	-	-	50-90	-	-	-	-	-	-	
Lammers-Helps & Robinson, (1991)	Kovacic et al (1990)	Cropland runoff	-	10.0	-	-	94	-	-	-	-	-	-	Subsurface flow only
Lynch et al. (1985)		Logging runoff	-	30.0	-	-	-	-	-	-	75-80	-	-	
Magette et al. (1989)		Agricultural drainage	-	4.6	-	17	-	-	51	-	52	-	-	
Magette et al. (1989)		Agricultural drainage	-	9.2	-	41	-	-	53	-	75	-	-	
McLaughlin (2001)		Lab Model	-		-		-	-		-		-	100	Cryptosporidium assessed only
Overman et al. (1988)	Wolfe (1985)	Wastewater	2	-	-	75	-	-	-	-	90	86	-	Hydraulic loading rate of 0.094 m^3/h/m
Overman et al. (1988)	Overman & Schanze (1984)	Wastewater	1.7	30.5	12.2	51	-	-	-	-	16	23.8	-	Hydraulic loading rate of 0.12 to 0.17 m^3/h/m
Paterson (1980)		Dairy Effluent	-	-	-	-	-	38	-	7	-	42	-	
Roberts et al. (1998)		Agricultural drainage	-	-	-	-	92	95	-	-	-	-	-	Study on nutrient scavaging by Ag drains
Sheridan et al. (1999)		Agricultural drainage	3.5	8.0	-	-	-	-	-	-	63	-	-	Average effluent water depth 19.3 cm
Toombs (?)		Feedlot runoff	0.5-4	30-90	-	-	45.2	-	31	-		51.3	40.6	TDS removal efficiency of 29% recorded.
Toombs (?)		Feedlot runoff	0.5		-	89		75	97	-	75	85		Constructed wetland effluent from feedlot
Young et al. (1980)		Feedlot runoff	4	27.4	-	-	80	-	-	80	66	-	69% faecal coliforms & 70% fecal streptococci.	

Table A2 - Performance of Vegetated Filter Strips in Reducing Pollutant Loads

Literature Source	Sub-Referrence	Application	Buffer Slope m	Buffer Length m	Buffer Width m	Pollutant Load Reduction TKN %	NO3-N %	NH4-N %	TP %	P diss %	SS %	BOD %	Pathogen Reduction %	Comments
Peterjohn & Correl (1984)			-	19.0	-	-	60	-	74	58	89	-	-	removed 60% of organic carbon
Parsons et al (1991)		Cropland Runoff	-	5.3	-	50	-	-	26	-	-	-	-	
Hubbard et al (1998)	Carlson et al (1974)	Lab Model	-	6.0	1.5	91	95	100	-	-	-	-	-	
Lim et al. (1998)		Manure runoff	-	6.1	2.4	75	-	-	75	75	75	-	100	
Parsons (1994)		Agricultural drainage	-	4.0	-	50	-	-	50	-	80-90	-	-	
Wong et al (2000)	Bren et al. (1997)	Stormwater	-	-	-	-	-	-	10-60	-	25-80	-	-	Dependant on slope
Dillaha et al. (1989)		Cropland Runoff	5	4.6	-	61	-	-	75	-	-	-	-	
Dillaha et al. (1989)		Cropland Runoff	16	9.1	-	87	-	-	61	-	-	-	-	
Barfield et al. (1998)		Cropland Runoff	9	4.6	-	-	95	92	91	-	-	-	-	91% of runoff infiltrated
Barfield et al. (1998)		Cropland Runoff	9	9.1	-	-	98	98	98	-	-	-	-	97% of runoff infiltrated
Barfield et al. (1998)		Cropland Runoff	9	13.7	-	-	97	97	96	-	-	-	-	94% of runoff infiltrated
Dillaha et al. (1986)		Feedot Runoff	4 to 11	9.1	-	-	-	-	58-69	11-53	81-91	-	-	
Hawkins et al. (1995)		Swine lagoon effluent	5	6.1	-	77	77	77	79	-	-	-	-	Application rate of 2379 L/h
Hawkins et al. (1995)		Swine lagoon effluent	11	6.1	-	69	57	68	72	-	-	-	-	Application rate of 792 L/h
Chaubey et al. (1994)		Swine effluent	3	3.0	1.5	65	-	71	67	65	70	-	-	
Chaubey et al. (1994)		Swine effluent	3	6.0	1.5	69	-	83	71	71	54	-	-	
Chaubey et al. (1994)		Swine effluent	3	9.0	1.5	89	-	96	87	89	67	-	-	
Chaubey et al. (1994)		Swine effluent	3	15.0	1.5	86	-	99	91	93	63	-	-	
Chaubey et al. (1994)		Swine effluent	3	21.0	1.5	87	-	99	92	94	78	-	-	
Fogle et al (1994)		Agricultural drainage	9	4.6	4.6	-	94	92	-	89	97	-	-	
Fogle et al (1994)		Agricultural drainage	9	9.1	4.6	-	98	100	-	98	100	-	-	
Fogle et al (1994)		Agricultural drainage	9	13.7	4.6	-	97	97	-	97	100	-	-	