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MANAGEMENT OF DAIRY WASTE: A LOW COST TREATMENT SYSTEM USING PHOSPHORUS-ADSORBING MATERIALS

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ABSTRACT

Dairy wastes are a source of nutrient pollution of surface and ground waters in high rainfall areas of south west Western Australia. Many of the state's 546 dairies are sited over soils that are either sandy, leading to pollution of ground waters, or clayey, causing reductions in surface water quality. Awareness of the environmental implications of their activities is motivating dairy farmers to join Land Conservation District Committees, where water quality improvement is a primary goal. A low cost treatment system has been designed to reduce the water pollution potential of dairy waste. It incorporates three stages: a sump in which anaerobic digestion occurs; an aerobic vegetated filter with a base of permeable phosphorus-absorbing material; and an irrigated plantation or crop using water that has passed through the system. This paper describes the theoretical background to the design.

KEYWORDS

Dairy waste; waste treatment; water pollution; vegetated filter; anaerobic digestion; animal waste pollution.

INTRODUCTION

The south west corner of Western Australia contains most of the state's 546 dairy farms. With a mediterranean climate and annual rainfall averaging from 800 to 1100 millimetres, dairy herds of from 20 to 600 animals supply the bulk of the state's fresh and manufacturing milk supplies.

Most dairy farms were established many years ago, at a time when environmental protection was considered to be less important than access to transport and selection of better quality soils. As a result, pollution of surface and ground waters by inappropriate dairy waste disposal has occurred.

For example, on the Swan Coastal Plain, a flat-lying area underlain by sediments, many dairies are located on elevated sand dunes and ridges. While the sandy soils provide good drainage, they are largely incapable of modifying the pollutant load of dairy wastes before they enter the ground water. In turn, this nutrient enriched water often returns to the surface, causing elevated nutrient levels in streams and estuaries.

LAND CONSERVATION DISTRICT COMMITTEES

The community's concern about the environment has had a major impact on agricultural practices in many farming areas. Under the Soil Conservation Act, land owners are able to form themselves into groups to act co-operatively to improve farming practices and broaden community knowledge.

Of the 150 Land Conservation District Committees (LCDC) now established, most aim to achieve on-farm improvements to soil, water and vegetation qualities. However, in late 1989, the Vasse-Wonnerup LCDC was formed with an additional aim of improving the environmental quality of the Vasse and Wonnerup estuaries, two coastal wetlands of local and international significance. This determination arose after studies (McAlpine et al., 1989) had shown high levels of phosphorus (P) entering the estuaries from water courses draining from agricultural land.

The Vasse-Wonnerup LCDC represents some 120 farmers in an area 230 kilometres south of Perth. It has initiated three projects to assist in overcoming the eutrophication problems of the estuaries:

* a survey of the nutrient status of agricultural soils, so that excess fertilizer applications can be curtailed,
* monitoring of the nutrient contents of the four major watercourses entering the estuaries, and
* design and installation (on a voluntary basis) of waste treatment systems on dairy farms within the land conservation district.

This paper describes the theoretical background to and design parameters of the waste treatment system suggested by the author to the LCDC.

DAIRY AND FARM CHARACTERISTICS

The system described in this paper has been designed for dairies which are located on sandy soils with the winter water table lying below the ground surface. Its size and treatment capacity is based upon the waste generated from a twice-daily milking of 100 cows. Although the state average dairy herd numbers some 200 head, the treatment system can be increased in volume and area, as appropriate, in direct proportion to the size of the dairy herd.

An important precondition that must be fulfilled as part of the treatment system construction is the need to divert rain water away from the facility. Especially in winter, rainfall added to normal dairy effluent can overload the P-removing ability of the treatment system.

It is therefore essential that all dairies have appropriate plumbing installed so that roof runoff is not added to the flow of liquid from the dairy that is entering the waste treatment system. As well, after each milking when washdown has been completed, water derived from rain falling on the dairy floor should be diverted away from the treatment system.

BASIC DESIGN PRINCIPLES

A typical 100 cow dairying operation generates some 2500 litres of milking shed waste twice each day (Hal Scott, pers. comm., 1990). This liquid may contain up to 5600 mg/L of BOD, 350 mg/L of contained nitrogen and 180mg/L of contained P (Anon., 1990a).

Implicit within the design evaluation was the requirement that as little P as possible be allowed to enter surface or ground waters. While other constituents of the waste were environmentally impacting, action to reduce P was assumed to assist in reducing the levels of other nutrients and contaminants. As well, P is generally accepted as being the limiting nutrient in most cases of waterbody eutrophication (Anon., 1984; Ryding and Rast, 1989; Anon., 1990b).

It was determined that the first stage of treatment must involve a liquid storage facility in which biological digestion could take place. Since liquid flowing from this stage would still be high in nutrients, the second stage could have involved direct use of this liquid on crops or other planted vegetation. However, further treatment was preferred for three reasons: dairy farmers would generally prefer not to have their time taken up attending to additional pumps, pipes, crops, special fencing, etc; use of this water over sandy soils would still allow some ground water nutrient enrichment to occur; and the author had previously been involved in the use of artificial vegetated wetlands in water treatment (Masters, 1988, 1989) and the application of industrial wastes in pollution control (Masters, 1990).

REJECTION OF OVERLAND FLOW VEGETATIVE-SOIL TREATMENT

A literature search showed that the use of overland flow vegetative-soil treatment methods and its variations has been a popular research topic in the USA (Paterson et al., 1980; Westerman and Overcash, 1980; Young et al., 1980; Edwards et al., 1983; Schwer and Clausen, 1989).

However, similar methods were rejected for use in the Vasse-Wonnerup area due to the sandy, absorptive nature of the soils of many dairy farms. Vegetative-soil treatment is most effective when soils are moderately impermeable, such that there is a less absorptive loss into the soil and instead greater interaction between all components of the water/soil/vegetation system.

GENERAL DESIGN OF WASTE TREATMENT SYSTEM

Figure 1 shows the three components of the suggested dairy waste treatment system:

A SUMP - to hold at least 20 day's supply of waste so that anaerobic digestion of the nutrients can occur

A BIOLOGICAL FILTER - a combination of P-absorbing material as base, with wetland or other water-loving plants growing within the slowly flowing water, and

An IRRIGATED CROP of trees or other useful plants to make final use of any treated water that may exit the filter.

The Sump

A suitably sized sump accomplishes two functions. First, it holds most of the solid matter that is washed twice daily from the dairy. Every few years, these solids can be removed by a backhoe or similar machine and spread onto paddocks, sold as a potting mix additive to nurseries, or otherwise disposed of in an environmentally acceptable manner. Since it is high in P and organic matter, it is a cheap and effective fertilizer and a useful soil conditioner.

Second, a sump that can hold liquid for at least 20 days allows anaerobic (oxygen-free) bacterial digestion of some of the contained

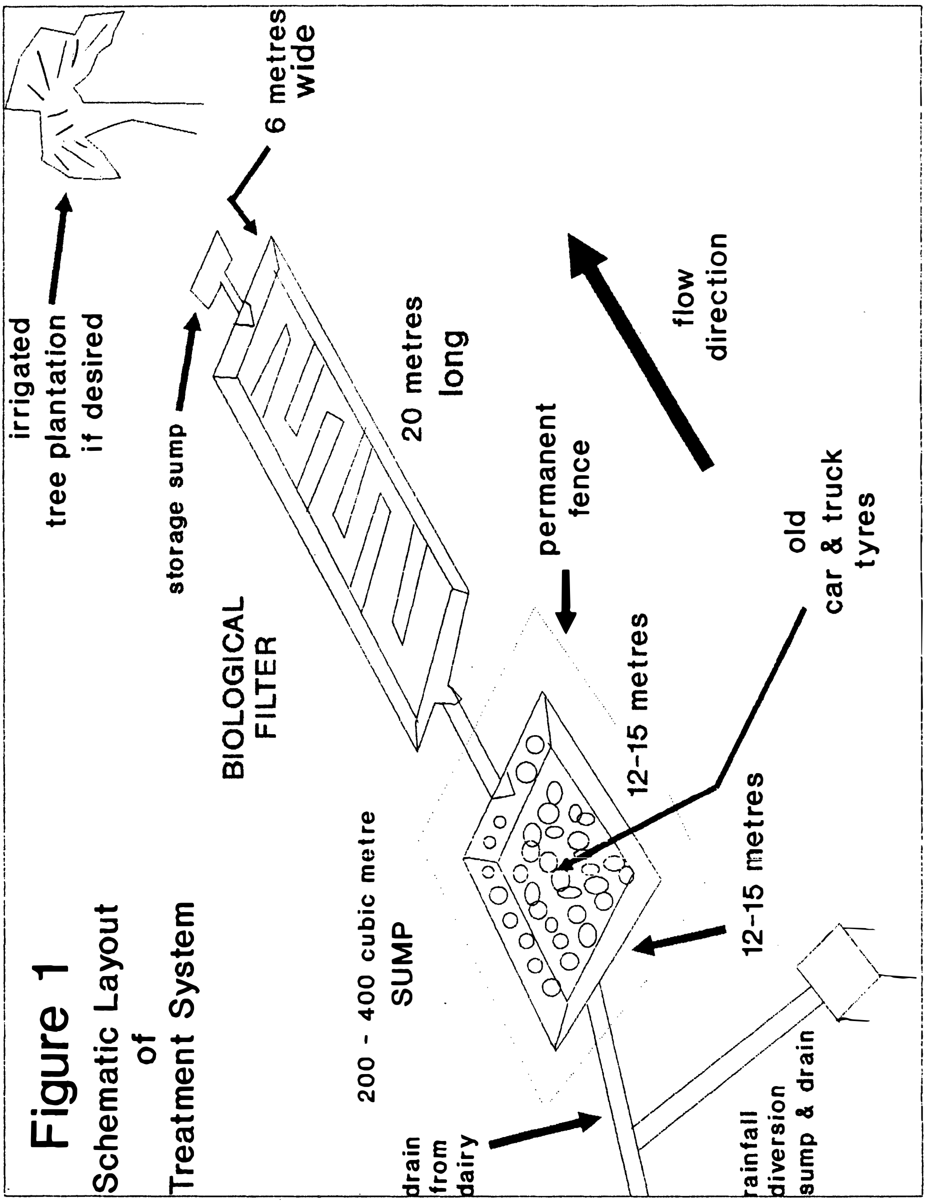

Figure 1
Schematic Layout
of
Treatment System

nutrients and organic matter to occur. A portion of the nitrogen will be returned to the atmosphere while some P will precipitate out of solution, to bind with the solids floating on the surface or to sink to the base of the sump.

The sump size can vary, depending upon site conditions and the amount of land available to a farmer. As a minimum, a sump of about 100 square metres in surface area and 2.5 metres depth is suggested, giving a storage capacity of about 200 cubic metres. However, bigger is generally better, since a larger sump volume will require cleaning out at less frequent intervals.

Discussions with an experienced sewage engineer (Peter Semianiw, Geelong Water Board, pers. comm., 1991) about the preferred depth of the sump showed that 2.5 metres was the usual minimum depth for anaerobic digestion to occur. However, this could be reduced to as little as 1.5 metres if the suspended solids content of liquid in the sump was sufficiently high to prevent entry of light further than a few centimetres in depth.

The encouragement and retention of a surface crust would assist in restricting the entry of light and could further justify a shallow sump in areas where ground conditions prevent greater depths being achieved at reasonable cost.

It is desirable, but not essential, to have the sump lined with clay, an artificial liner or other fine grained material that will reduce liquid outflow. However, Miller et al. (1985) have shown that a sump constructed in coarse sand will effectively seal itself after between 30 and 90 days, depending on the depth of water held in the sump. However, even one month's leakage of water out of a sump could make a significant contribution of nutrient to a nearby waterbody. Hence, if an impervious base is not to be provided, then it is better to have as large a sump as possible so that solids removal, an activity that could cause leakage, occurs at infrequent intervals.

A desirable ideal would be to have the sump lined with a high P-absorbing material, thus ensuring that liquid escaping during the early days of operation of the system would still be subjected to P removal.

As a precaution against breaking the seal that forms at the base of a sump, old car or truck tyres could be laid over the floor and sides of the sump during construction. When the sump is being cleaned out, the excavating machinery would strike the tyres as it is digging and go no further, thus protecting the integrity of the basal seal.

The sump must be fenced to exclude animals and humans. A basal sealing layer can be dug up by the feet of cows or calves, while plastic can be easily torn. As well, the presence of a surface crust may encourage children and animals to consider the sump safe to walk on, with potentially fatal results.

A sump's size and shape should be designed to suit the particular dairy at which it is located. Its design should ensure that the sump is full before liquid flows into the next stage of the treatment system, thus allowing liquid to be retained within the sump for as long a time as possible. As shown in figure 2, the best suggestion to date is for an angled, large diameter pipe to be placed at the discharge end of the sump. This allows the sump to fully fill before discharge begins. As well, liquid leaving the sump would be derived from some depth within the sump, with less likelihood of solids being discharged.

Liquids entering the sump should be allowed to quietly mix with material already present, so that the addition of atmospheric oxygen by agitation

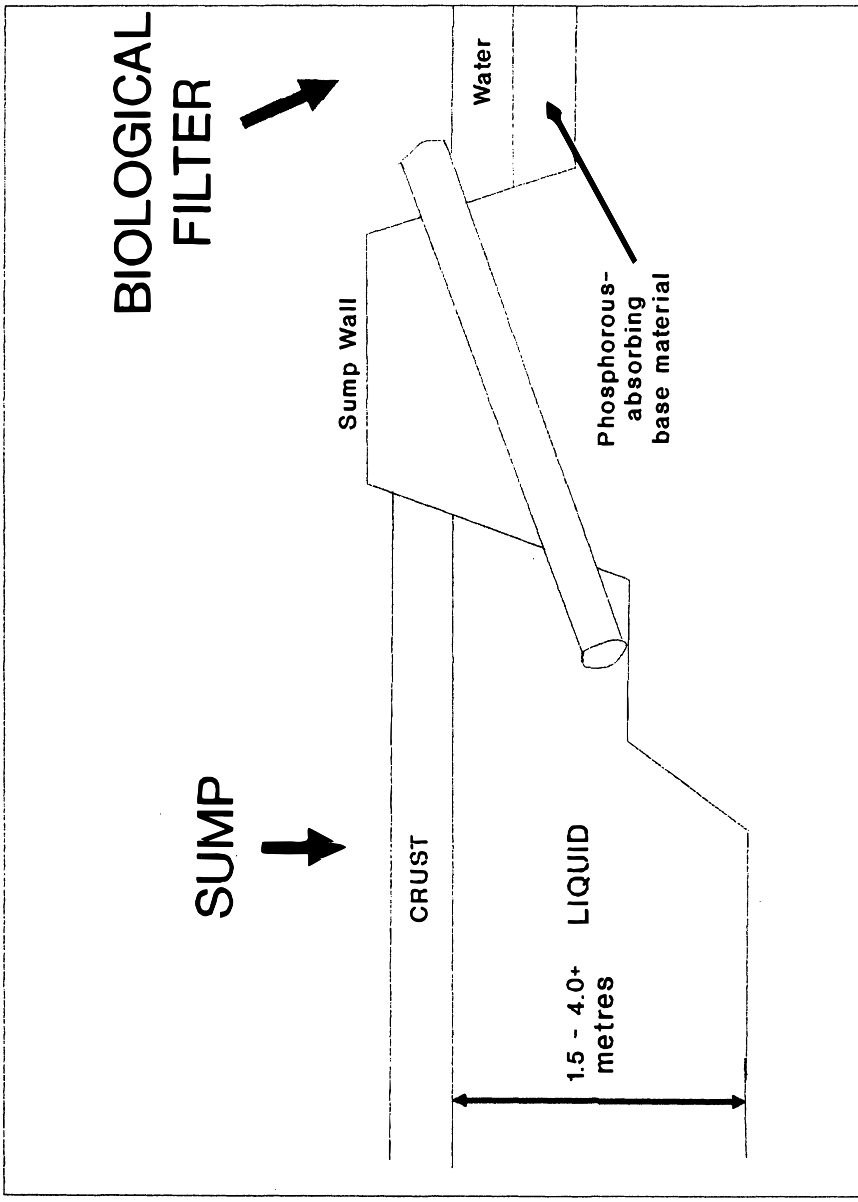

Figure 2 Cross-Section Through Sump/Biological Filter

is reduced. Thus, liquid entering the sump should not be discharged from a height.

If the sump is to be shallow (say, less than 2 metres), it is important that a surface crust be encouraged to form. This will reduce the ability of wind to create surface agitation and add oxygen. If a deeper sump can be constructed (say, four metres), then the presence of a surface crust is less important. However, all sumps should be constructed so that their surfaces are sheltered from strong winds.

The Biological Filter

There are three ways of looking at this second stage of the dairy effluent treatment system.

Biological filtration. One is to consider building a true biological filter with an impervious base layer and with most of the P in the entering water removed by wetland plants growing within. This method is under active research investigation in the USA (for example, see Hammer et al., 1989). However, some 20 hectares of wetland would be required to accomplish this task, assuming that there was no stock grazing of the wetland plants, or at least 5 hectares with grazing.

Physical filtration. The second way is to build a filter that would have all of the liquid effluent soak into the ground through a material that would extract most of the contained P. Recent work by West Australian companies and government departments have shown that a range of materials with a high Phosphorus Retention Index (PRI) is available to accomplish this.

While high PRI materials include natural materials such as loams and clays, waste products generated by mineral processing industries in the south west are also suitable. At Capel, two companies process ilmenite into synthetic rutile, producing solid wastes (iron oxide solids and neutralised acid effluent) that have a high PRI.

At Wagerup and Worsley, some 50 kilometres to the north east and east of Bunbury, two companies process bauxite into alumina. One of the waste products is commonly known as red mud. It is physically and chemically suited for use as a P-absorbing material.

For materials with a PRI of greater than 1000 mL/g, only about 8 tonnes would be needed to provide a 20 year effective life for a waste treatment system. However, the resulting facility would need to be constructed very carefully and maintained within exacting standards. As well, the basal layer would need to be very accurately laid down, with exactly the correct mixture of sand and P-absorbing material. All in all, this would be a complicated and difficult treatment system to impose upon unsuspecting dairy farmers.

Combining biological and physical filtration. The third concept is to have an appropriate combination of the first two methods. If a biological filter of some 120 square metres in surface area was constructed to give a liquid retention time of about 4 days, this filter area could then be underlain by a mixture consisting of some 30 centimetres of P-absorbing material mixed into the underlying 30 to 60 centimetres of sand. The result would be a clayey sand that would allow a large proportion of the water to soak into it, thus allowing P-absorption to occur, while also having a large surface area covered in wetland plants that would take up P biologically.

At the same time, the aerobic conditions prevailing within this section of the system would allow other biological and physico-chemical processes to occur. Algal and bacterial removal of nutrients would compliment P removal by vascular plants, creating a complex biological filtration system.

This preferred treatment system would require about 40 cubic metres (about 80 tonnes) of suitable P-absorbing material for its base and walls. On the surface of the filter, ordinary sand could be laid in mounds as shown on figure 1, creating a zig-zag flow path and forcing the effluent water to travel the longest possible distance through the filter.

Theoretically, 80 tonnes of iron oxide solids or similar material would give a 200 year P-absorbing life for the entire filter system. In practice, however, some of this material would be used in wall construction, while some water could by-pass some sections of the filter. Overall, however, many tens of years of useful life could be expected. When its P-absorbing capacity has been exhausted, the material could be dug out and spread over sandy paddocks as a fertilizer and soil conditioner.

The base of the filter requires a two to three degree slope so that water will slowly flow from inlet to outlet.

Wetland plants would be best introduced into the filter by a backhoe digging up large clumps of vegetation from existing wet areas and then having them transported and dumped into the filter area. If the clumps contain sufficient soil around the plant's roots (for example, as dug up by a one or two cubic metre bucket), they can be treated quite roughly.

The choice of wetland plants to put in the filter should be left to the individual farmer. Bulrush (*Typha* sp.) should be avoided because of its tendency to dominate shallow wetlands but salt water couch, kikuyu and many of the native sedges and rushes are considered acceptable. Whatever is readily available is often likely to make the best, cheapest and easiest choice.

Trees and shrubs can be hand planted onto the edges of the filter or onto the mounds within the filter. It is not yet known if it is best to plant only smaller growing species, rather than tall, deep rooted species. However, species selection is a decision that the individual farmer should make to suit his or her personal needs. Citrus trees have been reported as being able to thrive in high nutrient conditions.

Use of Final Effluent Water for a Crop or Tree Plantation

Some nutrients will still be present in water leaving the second stage of the treatment system, and this water would be well suited for crop or plantation use. State government departments and private consultants have much experience in the selection of crop or tree species for plantations, and in irrigation or other methods of using such water. A storage sump could be built at the discharge end of the biological filter and a pump/piping system installed to trickle or flood irrigate trees or other plants.

Note, however, that there may be little or no water leaving the biological filter in summer, since evaporation and uptake by plants may consume all of the available water.

COSTINGS

The need for costs to be kept as low as possible was recognised during the designing process. The recommended system is not expensive to install and its annual operational costs should be lower than the many waste disposal (as opposed to treatment) systems currently in use.

The following cost estimate includes the purchase of plastic sheeting with which to line the base of the sump, although this is considered desirable rather than essential:

Plastic sheeting - 200 m²	$200
Used car and truck tyres 20 tonnes of free tyres transported 30 km at $0.20/t/km	120
Large diameter pipe - 6 metres	200
High PRI material for base assume free ex-works but transport costs of $0.20/km/t for 100 tonnes over a haulage distance of 20km	400
Plants and shrubs as seedlings	200
Machinery use - 6 hours use of a backhoe, front end loader or similar	400
	$1520

The goodwill of the companies that produce the high PRI material should not be taken for granted, since the provision of their wastes involves some costs on their part. Alcoa (Don Glenister, pers. comm., 1991) has suggested that a cost per tonne of between $2 and $5 may be realistic for the longer-term purchase of their amended red mud.

Hence, an additional cost allowance of up to $500 may be necessary when dairy farmers are contemplating the installation of a waste treatment system similar to the above.

NEED FOR FURTHER INVESTIGATIONS

Two areas of investigation remain to be completed.

First, the permeabilities of a range of high PRI material/soil mixtures must be determined, so that a material with a permeability of about 10 centimetres per day per square metre can form the base of the biological filter section of the system. To have a material that has too high a permeability will cause liquid from the sump to soak into only the first part of the filter section. To have a material that has too low a permeability will cause most liquid to flow through the second stage without coming into contact with the P-absorbing material and thus having little of its contained P removed.

Second, the cost of purchase (if applicable), loading, transport, spreading and mixing the high PRI material needs to be worked out jointly by the companies and farmers. While the companies incur a significant cost in their normal disposal of these waste materials, there is still a cost incurred in their preparation of these wastes for treatment systems such as described in this paper.

While there is no reason why dairy farmers should expect to obtain the component materials for free, neither should the companies seek large profits from the better use of an otherwise waste material.

PROPOSED MONITORING

Funds are available within the Vasse-Wonnerup LCDC to allow a series of piezometers to be installed around two waste treatment systems. These bores will be positioned to test the underground water quality upslope, beneath and downslope of the system. In addition, regular collection and analysis of liquids flowing into, through and out of two systems is planned.

The P-absorbing capacity of material laid in the base of the biological filter will require regular monitoring over a number of years, so that an estimate of the effective life of the system can be made.

Monitoring will commence in late 1991 or early 1992, as treatment systems are installed, climatic conditions allowing.

CONCLUSIONS

Agricultural sustainability is an essential goal for all farmers. Installation of waste treatment systems should be supported by dairy farmers if they are to prevent laws being enacted to force them to take action or if they wish to improve the environmental quality of ground and surface waters and associated wetlands in the absence of enforcing legislation.

The treatment system described in this paper is relatively inexpensive to install and operate. It incorporates design concepts that allow it to be modified for use in other pollution control situations, including within remote areas. The outlined system is certain to require modification as farmers install similar systems under a range of dairy, soil and climatic conditions. There is likely to be concern expressed by regulators that the unproven nature of this system should preclude its broader use until detailed research has conclusively shown the system to work.

However, provided that we learn from our mistakes, the use of any dairy waste treatment system is encouraged so that, in time, we will possess the collective wisdom necessary to maintain and enhance environmental values.

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