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Agricultural waste management, and particularly that related to housed livestock, became a topic of considerable importance to farmers, their advisers and related authorities in New Zealand in the 1960s and 1970s. The passing of the Water and Soil Conservation Act 1967 gave statutory expression to public concern about pollution of natural water, among other concerns.

In the late 1970s, a Dairy Wastes Advisory Committee was meeting under the auspices of the Dairy Division of the Ministry of Agriculture and Fisheries and a Piggery Wastes Committee was working with similar aims under the auspices of the then Pork Industry Council. Members of both committees were concerned at the lack of published, authoritative information in New Zealand related to planning, design and management for agricultural wastes.

The New Zealand Agricultural Engineering Institute, whose staff members David J. Hills, David J. Painter and Alex B. Drysdale, had been at various times among Technical Advisers to the two Committees, offered to prepare a manual "to provide authoritative information for competent designers of animal waste management systems".

The offer was taken up by both Committees. The Pork Industry Council and the Dairy Division of the Ministry of Agriculture and Fisheries each agreed to sponsor, along with NZAEI, a part of the visit costs of Dr Dale Vanderholm, of the University of Illinois U.S.A., who was a visiting staff member at NZAEI in 1980. His time was devoted to compiling a first draft of the manual, with the other five authors. It then became necessary for NZAEI staff to oversee and carry out inter-author review, technical and editorial review, checking, correction and some re-writing before the manual could be finally prepared for publication. This operation, because of unforeseen staffing difficulties, has taken longer than either the NZAEI or the sponsors anticipated.

In the end, however, the manual has turned out to be more comprehensive and in greater depth than was originally intended. It should not only provide authoritative information for competent designers, but should also be useful as a sourcebook for writers of extension publications concerning agricultural waste management and as a reference for those concerned with regulating agricultural wastes for local and regional authorities.

T. D. Heiler
Director, NZAEI
December 1984
This publication has been compiled as part of my task during 11 months as Visiting Research Fellow at the New Zealand Agricultural Engineering Institute, Lincoln College. The project was jointly sponsored by the Institute, the Dairy Division - Ministry of Agriculture and Fisheries, and the New Zealand Pork Industry Council. I am very grateful to these organisations for providing me the opportunity to do this work. I also appreciated the help and cooperation of the staff of both the Institute and the Agricultural Engineering Department throughout the project.

The members of the planning and editorial committee deserve a great deal of credit for their contribution, not only for planning, but also for authoring sections of the manual and for performing a very time consuming but necessary task in reviewing and editing the early drafts. The members of this group, whose names are listed in the title page, were extremely helpful and pleasant to work with, making the effort a pleasurable one throughout.

Through their skilled drafting, timely suggestions and by assisting in the preparation of some sections, Neal Borrie and Lyn Roche made a significant contribution.

A number of Farm Dairy Advisory Officers, Farm Advisory Officers (Agricultural Engineering) and Pork Industry Council Advisory Officers were very helpful in providing information on design and construction practices in use, helping to acquaint some of us with current on-farm situations, and in making suggestions as to the format and content of the manual. We received similar assistance from staff associated with several Regional Water Authorities and the contribution by these groups is greatly appreciated.

Finally, to David Painter, who was instrumental in organising this effort originally and who, along with Andrew Dakers, was left with much of the responsibility for the final stages of producing the manual following my departure, I express my sincere thanks.

Dale H. Vanderholm
September, 1980

We gratefully acknowledge the contributions made by more than a dozen technical reviewers from throughout New Zealand and the three reviewers of the NZAEI Editorial Committee.

Lyn Roche has been largely responsible for the design of the manual. Margaret Eddington re-drew most of the figures and prepared the entire manual for printing.

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Various other NZAEI staff, including Mike Watson, Stan Fitchett, Peter Carran, Stephen Hirsch, John Baird and the Director, Terry Heiler have contributed to the final publication.

Andrew J. Dakers and David J. Painter
July 1984

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Andrew J. Dakers and David J. Painter
July 1984
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planning waste management systems

DALE H. VANDERHOLM
Agricultural waste management is a rapidly changing technology. It is subject to government regulation and sensitive to population growth patterns, community attitudes and land use changes. It is influenced by variables such as soil type, topography, climate, crop and livestock production practices. The trend towards larger and more concentrated livestock operations has accentuated the problems of waste management. This has necessitated better management methods, not only to hold down labour requirements and cost, but also to minimise detrimental effects on the environment.

Where animals are allowed to roam freely on pastures, such as almost all of the country's sheep and beef cattle do, manure from the livestock is deposited directly on the land and recycled, thereby not contributing significantly to pollution. The animals which contribute to the waste disposal problem, are, therefore, those which are regularly confined, such as milking cows, or those which are confined permanently, such as pigs and chickens.

Public concern for environmental pollution has resulted in legislation such as the 1967 Water and Soil Conservation Act which provides measures to "make better provision for the ... quality of natural water". Farmers are required to seek waste management systems which protect the environment, especially natural water. In addition to preventing water pollution, the alternatives also need to be acceptable from an odour and visual standpoint.

It should be noted at the outset that frequent use of the term "waste" in this publication is not intended to imply that we are dealing with material of no value. On the contrary, most agricultural wastes have the potential for reuse in areas such as energy, fertilizer nutrients and livestock feed additives. Feasible management practices to fully realise these and other benefits will be encouraged throughout this manual.

This publication is intended to provide current technical information for planners, evaluators, designers, builders and managers of agricultural waste management systems. These would include:
- those who advise farmers on their waste management problems
- those who plan, evaluate, or select waste management systems
- those who design and build waste management components or systems
- those who teach about handling, utilization, treatment, and disposal of agricultural wastes
- those who legislate for and regulate water quality standards.

The manual may also be useful to some farmers and contractors, but this audience should mainly be served by smaller, adviser-prepared circulars on specific systems. A certain amount of basic waste treatment theory has been included in the manual to provide users with an understanding of the processes occurring. However, this is not intended to be a waste treatment text and users looking for more detail are referred to the references listed in this manual and any others on the subject.

Changes in production practices have made agricultural waste management a much more complex problem than in the past. Increased environmental concern and regulations dictate that these problems be dealt with. This manual should help in implementing practical, effective waste management systems which will allow New Zealand agriculture to maintain efficient production with a minimum of cost and hindrance.
using the manual

A glossary, list of figures, tables and examples, and an index are at the end of the manual.

Throughout the manual, waste management system components and processes are grouped together by function. The different ways of doing each job are discussed together, making comparisons convenient. Component design is included where possible and examples are presented to illustrate use of the data and procedures.

Since the manual has components grouped together by function and a system is composed of components with different functions, some skipping around will be necessary while using the manual to help design a system! The user should not allow this emphasis on components to cloud over the system concept. The important thing in planning is to ensure that components within a system are compatible and adequate for their purpose as well as to ensure that the whole system accomplishes the overall objective.

Data presented on waste production and characteristics are average values for average situations, a condition nearly impossible to define. Where specific values for an individual system can be obtained, these should be used in preference to the manual values. However, the manual values are adequate for most purposes and can be used for planning systems of a reasonable scale when specific information is unavailable.

Recommendations in a publication of this scope and nature cannot possibly be appropriate for all individual situations. The user must be prepared to adapt them to fit specific physical, climatic, and regulatory conditions while maintaining acceptable design standards.

Manual users should attempt to keep abreast of new developments from other sources and should adapt recommendations to suit local conditions and comply with new information as it becomes available. The manual is intended to be used in conjunction with the kind of local knowledge which is available through agricultural advisers.

system selection

Selecting a system and the components to make it work is a process that includes economics, engineering, public regulation, personal preferences and numerous other factors. This manual emphasizes physical facilities - construction and equipment - but the other factors should not be ignored.

Don't make the mistake of thinking the system planning concept only applies to planning new facilities. It can and should be used equally as much when planning modifications to older facilities. This just adds some constraints in order that the modified system is compatible with other existing facilities.

Discussion of one major factor - cost - is very limited, due to variations in different areas and rapid changes in the relative cost of labour, materials, equipment, energy, and borrowed money. An approach for cost comparison of different systems is presented later in this chapter. Some general principles regarding cost considerations can be mentioned however. Try to avoid special equipment that has only limited use or for which spares will be difficult to obtain. Conversely, don't sacrifice
reliability or select ill-suited equipment just to economize. Leave as many options open as possible to allow for equipment breakdown, holidays, sickness, and future changes in agricultural technology. Count all costs, including fair shares of costs borne by other operations (e.g., the tractor needed only part time to drive a pump or pull a tank-wagon).

**system principles**

- No single system is 'best'. Each component, facility, or process has advantages and disadvantages. The 'best' for a given situation depends on personal preferences, available capital and labour, soil type and cropping practices, and other factors. No one salesman, adviser or engineer has the answer for every farm or the whole answer for any one farm.

- All systems are compromises between performance, cost, labour, convenience, and aesthetics.

- Final effluent from almost all systems will end up either in the soil or discharged to a surface watercourse. The extent and nature of treatment required depends upon which of these two options is selected. In some instances, selection may be dictated by the fact that discharge is prohibited.

- Systems can fail, even if only temporarily. Provision for bypassing system components for temporary, emergency storage or discharge is an important part of planning a system.

**evaluating alternatives**

- Stand back and try to look objectively at the current situation, the desired end point, and some likely ways to get there.

- Evaluate the source of the wastes. A large source may suggest mechanisation and some automation. A small source may suggest a smaller investment with a little more labour. Look at all current sources and also any potential sources under consideration.

- Consider waste management alternatives. What are the equipment and building options? Should the source be shifted to better facilitate waste handling and other operations? Will converting to a treatment and discharge system reduce labour requirements and possibly increase productivity per unit of labour input?

- Look at outside influences. What is the soil type? What are the locations of neighbouring residences? Where are streams located? Is there a high water table? What type of future development is likely in this area?

- Involve other interested parties in the evaluation; those who can contribute information and those who might be affected by the proposed system.
labour considerations

To function successfully as planned, a waste management system must be compatible with the amount, reliability and the level of technical competence of the available labour. The following questions are illustrative of types of labour considerations.

- Who will do the waste handling: farm owner, share milker, hired skilled or unskilled labour, other?

- Is waste handling a disagreeable job that workers want to avoid? How can this be minimized?

- Can waste handling be done equally well by a technically competent owner or manager as by unskilled hired labour with a lower competence level?

- Does labour availability on weekends and holidays present a problem?

- What are the consequences of mismanagement (e.g. rough handling or failure to shift equipment) not only to the environment, but also in terms of damage to equipment, production facilities, farmland, and public relations?

- What is the system reliability and can failures be repaired without seriously interfering with other production and farming activities?

- Are there any safety hazards involved and how can they be prevented or minimized?

- Can added cost in equipment and automation free up labour for more profitable production activity?

- Are there peak labour periods such as harvest season when waste handling may be neglected or are there slack labour periods when waste handling can be concentrated, e.g. by storage?

Keeping good labour on farms is always a matter of concern. Techniques which make waste management an unpleasant task, especially if it is a task usually delegated to the hired help, may cause, or at least aggravate, labour problems. Even when no hired labour is involved, quality of life in farming can certainly be improved by techniques which make waste management as pleasant as possible.

waste utilization opportunities

Recycling, reprocessing, and utilization of agricultural wastes in a positive manner offer the possibility of beneficial use rather than simply disposal or relocation. The common method of utilizing agricultural wastes has been to return them to land. Land application costs have risen, however, and convenient land may be limited or costly. Investigations of alternative utilization processes have increased, resulting in a number of possibilities. Whether a process is successful or not depends on a beneficial use, an adequate market, and an economic process. The process does not necessarily have to make a profit, but could be satisfactory if it caused the overall cost of waste management to be less than other alternatives.
Many of the processes discussed in this manual can be used as alternative schemes. These processes include composting, drying and dehydration, by-product development, methane generation, and water reclamation. Examples of by-products would be use of wastes as animal feed additives or use of separated solids as bedding in animal housing.

One problem with some of the alternative processes mentioned is that they are often much more complex than conventional waste handling methods and require higher competence levels and time involvement for operation and management. They tend to be separate manufacturing processes in their own right and unless a farmer understands this and is willing to commit the necessary effort, these should probably be omitted as practical alternatives. A case in point is methane generation, for which automation on a farm-scale unit is not currently well developed.

**System Comparison**

The next few pages present some system options from Figure 1.1. Not all the possible routes from the figure are presented, but several of the more common alternatives are included to illustrate a method of comparison. Some conditions and comments may be applicable to specific situations and others may not, so the planner must be able to sort out the appropriate ones.

**Liquid Waste — Anaerobic Lagoon — Aerobic Lagoon — Discharge to Surface Waters**

**Application**

- Farm dairies: milking equipment and yard wash water, scraped solids with dilution.
- Piggeries: liquid collection system effluent, scraped solids with dilution later.
- Poultry: liquid collection system effluent.

**Farm Conditions**

- Limited land available or drainage too poor for field spreading.
- Suitable soils for lagoon construction.
- Watercourse of suitable standard to accept discharge (e.g. class D).

**Labour Requirements**

- Low. Normal yard and equipment cleaning, but no regular labour requirement for lagoon system.

**Cost**

- Initial cost low to medium depending on site conditions.
- Operation and maintenance cost low - sludge and crust removal may be required at 5 to 10 year intervals.

**General Comments**

- Simple system adaptable to a wide range of conditions. Often more economical than land application.
- Lagoon effluent can be recycled as flushing water where acceptable.
FIGURE 1.1 WASTE MANAGEMENT SYSTEM ALTERNATIVES
LIQUID WASTE — ANAEROBIC LAGOON — LAND APPLICATION

APPLICATION

- Farm Dairies: milking equipment and yard wash water, scraped solids with dilution.
- Piggeries: liquid collection system effluent or scraped solids with dilution later.
- Poultry: liquid collection system effluent.

FARM CONDITIONS

- Farm land available for spreading at suitable times during year.
- Suitable soils for lagoon construction.
- Lack of suitable receiving waters may dictate a no-discharge system.

LABOUR REQUIREMENTS

- Low to medium. Normal yard and equipment cleaning. Some irrigation system operation during periods when lagoon is pumped down.

COST

- Initial cost - medium. Trade-off between automated land application and lower cost, higher labour systems.
- Operation and maintenance cost - low to medium.
- Fertilizer nutrient value may offset some costs, especially on larger piggeries and poultry facilities.

GENERAL COMMENTS

- An easily managed system allowing recycling of nutrients and minimizing water pollution potential.
- Lagoon effluent can be recycled as flushing water where acceptable.
- Possibility of odours from sprayed effluent.

LIQUID WASTE — SOLID/LIQUID SEPARATION — ANAEROBIC LAGOON — AEROBIC LAGOON — LIQUID DISCHARGE, LAND APPLICATION OF SOLIDS

APPLICATION

- Piggeries: Liquid collection system effluent

FARM CONDITIONS

- Limited land available suitable for lagoon construction.
- Water of suitable standard to accept discharge (e.g. Class D).
- Proximity of neighbouring residences requiring reduced odour emissions from lagoon.
- Alternative use for separated solids (e.g. land application).

LABOUR REQUIREMENTS

- Medium. Collection system may be easily automated, but separator operation and maintenance and the handling of separated solids may require regular attention.
COST
- Initial cost medium to high depending upon degree of automation.
- Operation and maintenance cost medium.

GENERAL COMMENTS
- Including a separation step can reduce lagoon size requirements or reduce loading on existing lagoons.
- Separated solids can be land applied fresh, be dried, composted or utilized in other ways.
- Lagoon effluent can be recycled as flushing water where acceptable.

LIQUID WASTE — ANAEROBIC DIGESTION FOR BIOGAS PRODUCTION
LAND APPLICATION OF DIGESTED AND SUPERNATANT LIQUID

APPLICATION
- Piggeries: liquid collection system effluent, scraped solids with dilution.
- Poultry: liquid collection system effluent, scraped solids with dilution.

FARM CONDITIONS
- Farm land available for spreading of liquid supernatant from digester and digested sludge.
- Lack of suitable receiving waters may dictate a no-discharge system.
- Farm use for biogas produced.
- Proximity of neighbouring residences requires low-odour system.

LABOUR REQUIREMENTS
- Medium to high. Collection can often be automated, minimizing physical labour, but farm scale digesters difficult to automate, so daily feeding and other management chores required.

COST
- Initial cost - high to very high, especially when gas compression and storage equipment needed.
- Operation and maintenance cost - high.
- Value of biogas produced can be considerable, but must be efficiently used to realize potential value.

GENERAL COMMENTS
- While anaerobic digestion is a simple process, running a digester is not. It requires time and some technical competence. Can almost be considered a separate manufacturing process instead of a waste treatment method.

LIQUID WASTE — DAILY LAND APPLICATION BY SPRAY IRRIGATION OR TANKER

APPLICATION
- Farm dairies: milking shed and yard wash water.
- Piggeries and Poultry: Liquid collection system effluent.
FARM CONDITIONS

- Farm land available for spreading throughout the year.
- Lack of suitable receiving waters may dictate a no-discharge system.

LABOUR REQUIREMENTS

- Low to medium. Normal yard and shed cleaning. Also shifting of sprinklers or tanker operation, equipment maintenance.

COST

- Initial cost - medium.
- Operation and maintenance cost - medium.
- Fertilizer nutrient benefit may be considerable, especially for piggeries and poultry units, offsetting costs.

GENERAL COMMENTS

- This approach maximises the amount of nutrients saved.

estimating system cost

As noted earlier, many aspects in addition to cost need to be considered in planning a waste management system. Cost must be considered a significant factor, however, and planners should be able to estimate cost reasonably well in order to judge this aspect fairly. Many cost factors are obvious, but some are not so obvious and sometimes omitted when they should not be. An extensive discussion on cost estimating and cost comparisons for a large number of waste systems were prepared by White and Forster (1978), from which some of the following was adapted.

Both variable and fixed costs must be considered when installing a waste management system. Variable or operating and maintenance costs are those costs which vary as waste output from the facility changes. For example if a farm dairy designed for 200 cows is used for only 100 cows, some per unit costs such as labour costs would be less than if the facility would be used to capacity.

FIXED COSTS

Other costs do not change as waste output from a facility changes. For example, the facility loses some of its value each year due to depreciation, and depreciation occurs with or without animals using the facility. Thus, depreciation is an example of a fixed cost. Fixed costs are associated with durable inputs or those capital investments which remain over several time periods. The following items are fixed costs.

DEPRECIATION represents the annual charge for the use of the durable input. In budgeting costs, depreciation is the following:

\[
\text{annual depreciation} = \frac{\text{original investment} - \text{salvage value}}{\text{useful life}}
\]

If the salvage value is zero the formula is

\[
\text{annual depreciation} = \frac{\text{Original Investment}}{\text{Useful life}}
\]
For a non-depreciating input such as land, the annual depreciation is zero. Additional information on depreciation can be found in the Lincoln College Farm Budget Manual, part 2 (the most recent edition).

INTEREST represents the average earnings foregone by having capital tied up in the fixed input. There are several commonly used methods for calculating interest, one of which is as follows:

\[
\text{annual interest charge} = \frac{\text{original investment} + \text{salvage value}}{2} \times \text{interest rate}
\]

If the salvage is zero the formula is:

\[
\text{annual interest charge} = \frac{\text{original investment}}{2} \times \text{interest rate}
\]

To apply this last formula, the input must be a depreciable asset such as buildings or equipment. For a non-depreciating input such as land the formula would be:

\[
\text{annual interest charge} = (\text{original investment}) \times (\text{interest rate})
\]

REPAIRS AND MAINTENANCE are partially fixed and partially variable. The pumphouse needs an occasional painting whether it is used or not. Typically, it is assumed that the building or piece of equipment will be used for production throughout its lifetime, and both variable and fixed repairs are lumped into one charge. The annual charge is assumed a constant percentage of new cost.

\[
\text{annual repair charge} = (\text{original investment}) \times (\text{repair percent})
\]

These repair rates are based largely on repair and maintenance information in farm management publications.

INSURANCE is calculated by multiplying the average investment value by the insurance rate. If the salvage value is zero, the annual insurance cost is:

\[
\text{annual insurance cost} = \frac{\text{original investment}}{2} \times \text{insurance rate}
\]

The salvage value of depreciable assets is often assumed to be zero for the above fixed costs consumptions. Thus, the annual charge is a constant percentage of the original investment outlay.

VARIABLE COSTS

Variable costs are directly related to the amount of waste to be handled and to handling methods. The following items are variable costs.

LABOUR represents the annual charge for manual labour and management time. It is usually given as number of man-hours necessary annually and the expression for calculating is:

\[
\text{annual labour charge} = (\text{number of man-hours annually}) \times (\text{hourly wage rate})
\]

TRACTOR represents the charge made for time during which a farm tractor is used for waste handling such as driving a pump or pulling a muck spreader.
Usually the tractor is used for a wide variety of tasks and the most equitable charge procedure is the number of hours annual use for the specific task multiplied by an hourly use rate, which can be written as:

\[
\text{annual tractor charge} = \text{number of hours waste handling use annually} \times \text{hourly tractor use rate}
\]

ENERGY represents the cost of energy, either electrical or fuel, which is used to drive pumps, provide heat, or for other waste handling processes. Depending upon the type of energy, it is usually expressed in units of MJ or kWh. The charge is calculated by:

\[
\text{annual energy charge} = \text{annual energy use, kWh or MJ} \times \text{energy rate}
\]

**ANNUAL COSTS**

The following example illustrates the procedure for comparing two different waste management systems on an annual cost basis. Cost information was obtained from publications from Lincoln College (1980) and Ministry of Agriculture and Fisheries (1980); these publications are updated periodically and current versions should be used for cost estimating.

**TABLE 1.1**

**ANNUAL COST DATA FOR A TWO LAGOON (ANAEROBIC — AEROBIC) DISCHARGING SYSTEM FOR A 200 COW DAIRY FARM**

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Capital Investment ($$)</th>
<th>Annual Cost ($/Yr)</th>
<th>Annual Returns ($/Yr)</th>
<th>Annual Net System Cost ($/Yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour</td>
<td>365 hrs</td>
<td>-</td>
<td>1095</td>
<td>-</td>
<td>1095</td>
</tr>
<tr>
<td>Repairs &amp; Maintenance</td>
<td>-</td>
<td>-</td>
<td>100&lt;sup&gt;1&lt;/sup&gt;</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Energy</td>
<td>-</td>
<td>-</td>
<td>200&lt;sup&gt;2&lt;/sup&gt;</td>
<td>-</td>
<td>200</td>
</tr>
<tr>
<td>Lagoons</td>
<td>-</td>
<td>2000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lagoon sludge crust removal</td>
<td>every 10 years</td>
<td>-</td>
<td>50</td>
<td>-</td>
<td>50</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1445</td>
</tr>
</tbody>
</table>

Note 1. Original investment ($2000) x repair rate (5 percent)
Note 2. Original investment ($2000) x interest rate (10 percent)
### TABLE 1.2
ANNUAL COST DATA FOR A WASTE WATER SPRAY IRRIGATION SYSTEM FOR A 200 COW DAIRY FARM

<table>
<thead>
<tr>
<th>Component</th>
<th>Quantity</th>
<th>Capital Investment ($</th>
<th>Annual Cost ($/Yr)</th>
<th>Annual Returns ($/Yr)</th>
<th>Annual Net System Cost (Return) ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour</td>
<td>550 hrs</td>
<td>-</td>
<td>1650</td>
<td>-</td>
<td>1650</td>
</tr>
<tr>
<td>R &amp; M</td>
<td>-</td>
<td>-</td>
<td>125</td>
<td>-</td>
<td>125</td>
</tr>
<tr>
<td>Energy</td>
<td>730 kWh</td>
<td>-</td>
<td>36.50</td>
<td>-</td>
<td>36.50</td>
</tr>
<tr>
<td>Irrigation Equipment</td>
<td>-</td>
<td>2500</td>
<td>375</td>
<td>-</td>
<td>375</td>
</tr>
<tr>
<td>Fertiliser Benefit</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>250</td>
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<tr>
<td>Benefit</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>1936.5</td>
</tr>
</tbody>
</table>

Note 1. 10-year depreciation with no salvage value; interest at 10 percent

---

**REFERENCES CHAPTER 1.**


chapter 2

properties of agricultural wastes

DALE H. VANDERHOLM
Animal waste is a highly variable material with its properties dependent on several factors: animal age and species, type of ration, production practices, and environment. The term manure usually refers to faeces and urine only, while animal waste commonly refers to manure with added washwater, bedding, soil, hair or spilled feed. Other agricultural wastes may similarly be mixtures of several components.

For livestock waste system design, the characteristics of both the freshly excreted manure and of collected wastes are important. Tables 2.1, 2.2 and 2.3 contain values for waste production and characteristics for various animals. New Zealand data were used as much as possible in preparing these tables. Where New Zealand data were not available, overseas data which appeared applicable to New Zealand conditions were used. No data were found for some parameters, making it necessary to leave these blank in the tables.

It should be emphasised that the numbers shown in the tables are mean values and only approximate, although usually based upon a large number of samples. Since animal waste is highly variable, periodic analysis of specific wastes at each farm would be more accurate for that situation. The values given are accurate enough for most planning purposes.

In Table 2.2, ranges have been included along with the average values. Experience, observation, or measurement may justify using a value higher or lower than the average in a given situation. The ranges show the extreme values likely to be encountered and any values adjusted by the manual user should probably remain within the ranges given except under rare circumstances.

### TABLE 2.1 CHARACTERISTICS OF VARIOUS SOLID WASTES

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sheep, stored faeces</th>
<th>Rabbit, stored faeces</th>
<th>Poultry, layer, stored battery manure</th>
<th>Poultry, broiler, stored deep litter</th>
<th>Turkey, stored, litter, uncovered</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total solids (TS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average, percent</td>
<td>32</td>
<td>42</td>
<td>29</td>
<td>75</td>
<td>42</td>
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<tr>
<td>Total N</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average, percent</td>
<td>0.8</td>
<td>0.5</td>
<td>1.7</td>
<td>1.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Total P</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Average, percent</td>
<td>0.10</td>
<td>0.27</td>
<td>0.32</td>
<td>0.8</td>
<td>0.43</td>
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<tr>
<td>Total K</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Average, percent</td>
<td>0.29</td>
<td>0.42</td>
<td>0.58</td>
<td>1.25</td>
<td>0.5</td>
</tr>
</tbody>
</table>

1 expressed as percent of wet mass.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Dairy yard wash water (fresh)</th>
<th>Dairy Anaerobic lagoon effluent</th>
<th>Dairy Aerobic lagoon effluent$^1$</th>
<th>Piggery waste flushed (fresh)</th>
<th>Piggery waste undiluted stored slurry</th>
<th>Piggery Anaerobic lagoon effluent</th>
<th>Piggery Aerobic lagoon effluent</th>
<th>Slurry Effluent (grass)</th>
<th>Whole Milk$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total volume produced</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(if applicable)</td>
<td>50$^7$</td>
<td>(footnote) (5)</td>
<td>(footnote) (5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Av., kg/animal.day</td>
<td>20-99</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>Total solids (TS)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Av., kg/animal.day</td>
<td>.36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range, kg/animal.day</td>
<td>? to 0.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Average, % of TS</td>
<td>.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Range, % of TS</td>
<td>? to .36</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatile solids (VS)</td>
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<td></td>
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<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Av., kg/animal.day</td>
<td>1500</td>
<td>156</td>
<td>82</td>
<td>2860-12,600</td>
<td>30,500</td>
<td>801</td>
<td>149</td>
<td>50,000</td>
<td>102,000</td>
</tr>
<tr>
<td>Range, kg/animal.day</td>
<td>1000-5000</td>
<td>93-235</td>
<td>63-129</td>
<td>1900-12,800</td>
<td>293-1110</td>
<td>293-1110</td>
<td>12000</td>
<td>20,000-70,000</td>
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</tr>
<tr>
<td>BIO</td>
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<td></td>
<td></td>
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<td>0.08</td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Average, mg/l</td>
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<td>52</td>
<td>54</td>
<td>80</td>
<td>81</td>
<td>49</td>
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<td>45-56</td>
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</tr>
<tr>
<td>COD</td>
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<td></td>
<td></td>
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<tr>
<td>Av., kg/animal/day</td>
<td>.33</td>
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<td>Range, kg/animal/day</td>
<td>? to .57</td>
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<tr>
<td>Average, mg/l</td>
<td>680</td>
<td>744</td>
<td>503</td>
<td>77,000</td>
<td>2042</td>
<td>110-3000</td>
<td>220,000</td>
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<tr>
<td>Range, mg/l</td>
<td>500-11,000</td>
<td>424-1500</td>
<td>260-787</td>
<td>2700-32,600</td>
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<td>Average g/animal/day</td>
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<td>Range, g/animal.day</td>
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<td>Average, mg/l</td>
<td>298</td>
<td>165</td>
<td>74</td>
<td>1738</td>
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<td>5500</td>
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<td>Range, mg/l</td>
<td>100-325</td>
<td>73-159</td>
<td>32-116</td>
<td>1075-2500</td>
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</tr>
<tr>
<td>Total P</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Average g/animal/day</td>
<td>1.74</td>
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<td></td>
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<td>Range, g/animal/day</td>
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<tr>
<td>Average, mg/l</td>
<td>35.2</td>
<td>31</td>
<td>23</td>
<td>537</td>
<td>2600</td>
<td>69</td>
<td>1000</td>
<td>680</td>
<td></td>
</tr>
<tr>
<td>Range, mg/l</td>
<td>27 to 7</td>
<td>16-34</td>
<td>16-29</td>
<td>109-950</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Total K</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Average, g/animal/day</td>
<td>8.9</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Range, g/animal/day</td>
<td>? to 25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Concentration</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average, mg/l</td>
<td>805</td>
<td>315</td>
<td>54</td>
<td>548</td>
<td>4000</td>
<td>1675</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Range, mg/l</td>
<td>700-1400</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>pH range</td>
<td>8.0-8.5</td>
<td>7.6-7.8</td>
<td>7.8-8.0</td>
<td>7.1-7.9</td>
<td>8.1-8.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Where applicable, quantities shown are for the following animal masses: dairy cattle - 500kg, pigs - 50kg.
2. May contain spilled feed, water leakage, washwater, milk, soil, hair and other wastes besides faeces and urine.
3. If reverse flow equipment washing is used, average volume is 80 litres per cow per day.
4. Assumes aerobic lagoon is preceded by anaerobic lagoon.
5. Under most New Zealand conditions, lagoon seal and seepage losses and gains are negligible. Also, evaporation losses are similar to precipitation gains, so the lagoon effluent quantity is approximately equal to the inflow quantity.
6. Leaky cup or nipple waterers can increase raw waste volume ten to twenty per cent.
7. Actual quantity is usually ten to twenty per cent higher than excreted quantity due to water leakage, spilled feed, etc.
8. While not normally classified as waste, milk may have to be treated as waste in the event transport is interrupted.
<table>
<thead>
<tr>
<th>ANIMAL PARAMETER</th>
<th>Dairy Cow, harvested ration&lt;sup&gt;1&lt;/sup&gt;</th>
<th>Dairy Cow, Pasture</th>
<th>Pig (meal fed)</th>
<th>Pig (whey fed)</th>
<th>Poultry Layer&lt;sup&gt;4&lt;/sup&gt;</th>
<th>Turkey</th>
<th>Rabbit&lt;sup&gt;5&lt;/sup&gt;</th>
<th>Sheep</th>
<th>Goat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal mass&lt;sup&gt;3&lt;/sup&gt; kg</td>
<td>500</td>
<td>500</td>
<td>50</td>
<td>50</td>
<td>2</td>
<td>10</td>
<td>2</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>Raw manure (RM) (urine faeces) kg/day</td>
<td>40</td>
<td>54</td>
<td>3.3</td>
<td>10.3</td>
<td>0.11</td>
<td>0.6</td>
<td>1.5</td>
<td>2.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Bulk density kg/litre</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.9</td>
<td>-</td>
<td>-</td>
<td>1.1</td>
<td>1</td>
</tr>
<tr>
<td>Faeces, % RM</td>
<td>60</td>
<td>54</td>
<td>55</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>50</td>
<td>68</td>
<td></td>
</tr>
<tr>
<td>Total solids (TS) kg/day % RM</td>
<td>4.2</td>
<td>4.4</td>
<td>0.30</td>
<td>0.20</td>
<td>0.027</td>
<td>0.15</td>
<td>-</td>
<td>0.38</td>
<td>-</td>
</tr>
<tr>
<td>Volatile solids (VS) kg/day % TS</td>
<td>3.4</td>
<td>3.2</td>
<td>0.24</td>
<td>0.12</td>
<td>0.019</td>
<td>0.11</td>
<td>-</td>
<td>0.31</td>
<td>-</td>
</tr>
<tr>
<td>COD kg/day % TS</td>
<td>0.68</td>
<td>0.98</td>
<td>0.10</td>
<td>0.12</td>
<td>0.007</td>
<td>0.055</td>
<td>0.36</td>
<td>0.32</td>
<td>-</td>
</tr>
<tr>
<td>Total O&lt;sub&gt;2&lt;/sub&gt; % TS</td>
<td>3.6</td>
<td>4.3</td>
<td>0.29</td>
<td>0.24</td>
<td>0.024</td>
<td>0.077</td>
<td>0.050</td>
<td>0.026</td>
<td>-</td>
</tr>
<tr>
<td>Total N kg/day</td>
<td>0.164</td>
<td>0.240</td>
<td>0.023</td>
<td>0.021</td>
<td>0.0014</td>
<td>0.0083</td>
<td>-</td>
<td>0.015</td>
<td>-</td>
</tr>
<tr>
<td>Total P kg/day</td>
<td>0.029</td>
<td>0.025</td>
<td>0.0075</td>
<td>-</td>
<td>0.00056</td>
<td>0.0023</td>
<td>-</td>
<td>0.0025</td>
<td>-</td>
</tr>
<tr>
<td>Total K kg/day</td>
<td>0.108</td>
<td>0.310</td>
<td>0.015</td>
<td>-</td>
<td>0.00062</td>
<td>0.0027</td>
<td>-</td>
<td>0.011</td>
<td>-</td>
</tr>
</tbody>
</table>

1 These values have been extracted from many sources. There is significant variation particularly with poultry. Where accurate information is required, the actual manure should be accurately sampled and analysed. There is insufficient reliable information for voided rabbit and goat manure.

2 Rations other than pasture, such as maize, silage, hay. Primarily overseas data.

3 Assume all parameters proportional to animal mass. Adjust values accordingly for animals of mass not included in the table.

4 For broilers, the quantity of voided manure depends on live mass and feed conversion efficiency. For typical broiler management the cycle period is 42 days, final live mass 1.8 kg and average temperature 20°C. Then the quality of raw manure per 42 day cycle per broiler is about 6 kg and 28% solids content. For other characteristics of broiler litter refer to Table 2.1.

5 Values shown are for freshly collected rabbit manure but may include some spilled feed and water.
Many of the parameters listed in Tables 2.1, 2.2 and 2.3 are defined in the glossary.

The two measures of the oxygen demand exerted by a waste are biochemical oxygen demand (BOD) and chemical oxygen demand (COD). When a waste is allowed to enter natural waters, the oxygen demand exerted will reduce the oxygen content of the natural water. When oxygen is severely depleted, fish kills, damage to other aquatic life and other undesirable effects can result.

Parameters such as total solids and volatile solids are important in the storage and transportability of the wastes as well as its digestibility in various biological treatment methods. For example, lagoon loading rates are usually specified in terms of the daily quantity of BOD or volatile solids per unit of volume or surface area.

Data on the major fertilizer elements N, P and K are important with respect to application rates and economic value of waste applied to land. The use of these parameters is discussed fully in the appropriate sections later in the manual.

In Table 2.4 typical animal masses have been included to help the reader to estimate total animal masses and waste production.

use of tables

The following two examples illustrate the use of Tables 2.1 through to 2.4. These same examples will be used to illustrate various design procedures later in the manual.

EXAMPLE 2.1 To find the daily waste volume and BOD from a 200-cow, dairy farm, Palmerston North area, cross bred cows averaging 400 kg in mass (Table 2.4) and on pasture. Going to Table 2.3, note that the listed values are for 500 kg cows, so should be reduced proportionately to account for the smaller cows in this example. To do this, multiply each listed value by 0.8 since 400 : 500 = 0.8.

Daily manure production (RM) per cow would be

\[ 54 \text{ kg} \times 0.8 = 43.2 \text{ kg} \]

or 43.2 litres since the density of raw cow manure (faeces + urine) is about 1 kg per litre. In areas where cows are in sheds or on paved yards continuously for winter, the value for cows on harvested rations should be used along with estimates of spilled feed and bedding to calculate manure storage and treatment requirements.

Total daily BOD production per cow would be

\[ 0.98 \text{ kg day} \times 0.8 = 0.78 \text{ kg day} \]

So total daily BOD production is

\[ 200 \text{ cows} \times 0.78 \text{ kg/cow-day} = 156 \text{ kg/day} \]
TABLE 2.4 TYPICAL ANIMAL MASS

<table>
<thead>
<tr>
<th>ANIMAL</th>
<th>TYPICAL MASS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy cow, Friesian</td>
<td>500</td>
</tr>
<tr>
<td>Dairy cow, Jersey</td>
<td>400</td>
</tr>
<tr>
<td>Growing pig (weaning to baconer weight)</td>
<td>45</td>
</tr>
<tr>
<td>Growing pig (weaning to porker weight)</td>
<td>30</td>
</tr>
<tr>
<td>Sow and litter</td>
<td>170</td>
</tr>
<tr>
<td>Sow, gestating</td>
<td>125</td>
</tr>
<tr>
<td>Boar</td>
<td>160</td>
</tr>
<tr>
<td>Goat, milking</td>
<td>55</td>
</tr>
<tr>
<td>Ewe</td>
<td>60</td>
</tr>
<tr>
<td>Poultry, layer</td>
<td>2</td>
</tr>
<tr>
<td>Poultry, broiler</td>
<td>1</td>
</tr>
</tbody>
</table>

1 Average mass in a specific herd may vary significantly from those given here. Use estimates for the specific situation when possible. Note that masses in this table do not correspond exactly to those in Table 2.3.

To estimate the quantity of manure deposited in the farm dairy use the proportion of time that cows are in the dairy and collecting yards. For most dairies, this is about 2 hours per day and approximately 8% of the total manure will be found in farm dairy waste. This can vary a great deal from dairy to dairy, depending upon holding time and amount of stress on the cows (Drysdale, 1977).

From Table 2.2, we find that the average daily waste-water volume per cow is 50 litres. Since over 90 percent of this volume is washwater, it is not modified according to cow mass. If water use records or other factors indicate that a different value is appropriate, this should be used. For this example, the table value will be used and the daily waste volume would be:

200 cows x 50 l/cow = 10,000 litres.

Other parameters such as solids and nutrients can be estimated in the same manner as those parameters just shown.

EXAMPLE 2.2 To find the daily waste volume and BOD from a 200-sow piggery, Hamilton area, meal feeding, some pigs sold as porkers, some as baconers, slotted floor building with flushing. Total animal mass on hand can be calculated as shown below, using Table 2.4:

<table>
<thead>
<tr>
<th>Average mass</th>
<th>Total mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg</td>
<td>kg</td>
</tr>
<tr>
<td>900 growing pigs (porkers)</td>
<td>30</td>
</tr>
<tr>
<td>800 growing pigs (baconers)</td>
<td>45</td>
</tr>
<tr>
<td>20 sows and litters</td>
<td>170</td>
</tr>
<tr>
<td>180 gestating sows</td>
<td>125</td>
</tr>
<tr>
<td>6 boars</td>
<td>160</td>
</tr>
</tbody>
</table>

2-5
Since Tables 2.3 and 2.2 list parameters produced per 50 kg pig, the total mass must be converted to an equivalent number of 50 kg pigs.

\[
\frac{89860}{50} = 1797 \text{ or } 1800 \text{ pigs at } 50 \text{ kg}
\]

Total daily excreted manure volume would be

\[
1800 \times 3.25 = 5850 \text{ kg or } 5850 \text{ litres}
\]

Total daily waste volume must also allow for spilled water, feed, etc. Using a 10 percent increase on the excreted manure volume (Note 7, Table 2.2), we find

\[
5850 \times 1.1 = 6435 \text{ litres}
\]

Where fresh water is used for flushing or washdown, this volume is added when calculating daily waste volume. This is a highly variable quantity and estimates for the specific system used should be made. Values of 30 to 40 litres per 50 kg pig, daily, for flush water are not uncommon. For this example, less frequent flushing will be used and daily flush water is estimated as 10 litres per 50 kg pig equivalent or

\[
10 \text{ l/pig} \times 1800 \text{ pigs} = 18000 \text{ litres}
\]

Total daily waste volume is then

\[
18000 + 6435 = 24435 \text{ litres or } 24.4 \text{ m}^3
\]

Total daily BOD produced would be

\[
1800 \times 0.10 \text{ kg} = 180 \text{ kg per day}
\]

Since this value is for excreted manure only, for adequate design it must be increased to allow for spilled feed, bedding, etc. This increase should usually be from 10 to 20 percent and 10 percent will be used for this example, giving total daily BOD of;

\[
180 \text{ kg/day} \times 1.10 = 198 \text{ kg/day} \quad \text{Use } 200 \text{ kg/day for design purposes.}
\]

**nutrient losses**

Up to 50 percent or more of the nitrogen in fresh manure may be in ammonia form or be converted to ammonia form in a short time following excretion. This ammonia is very volatile and unless it is absorbed by, or reacts chemically with, some substance, most of it volatilizes into the air. This also is a continuing process in treatment and storage facilities where ammonia is produced during manure decomposition and then lost in part by volatilization.

Table 2.5 illustrates some levels of nitrogen losses observed in studies dealing with various types of waste systems. While a great deal of variability is obvious, the main point is that significant amounts of nitrogen are commonly lost from most systems. This may be regarded as an advantage or a disadvantage, depending upon whether the objective is waste disposal with minimum pollution hazard or efficient utilization of the fertilizer nutrient content.

Losses of phosphorus and potassium are not nearly as well documented as those of nitrogen and not nearly as significant. Both can form precipitates in anaerobic lagoons which then settle to the bottom sludges and are not removed with the supernatant.
All three nutrients, N, P, and K are subject to a certain amount of leaching loss due to rainfall on outdoor storage facilities or feedlot surfaces. Davies and Russell (1974) found that 10 to 20 percent N, 7 percent P, and 35 percent K are likely to be lost during a season by leaching from uncovered manure heaps.

Nutrient losses vary a great deal and are difficult to predict for specific situations. Approximate levels of nutrient losses to be expected from some common waste management systems are presented in Table 2.6.

### TABLE 2.5
**NITROGEN LOSSES FROM MANURE AS OBSERVED IN SELECTED STUDIES**

<table>
<thead>
<tr>
<th>Type of facility</th>
<th>Range of observed nitrogen losses, percent</th>
<th>Average of nitrogen losses in reported studies, percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxidation ditch</td>
<td>17 - 75</td>
<td>51</td>
</tr>
<tr>
<td>Aerated storage</td>
<td>10 - 70</td>
<td>45</td>
</tr>
<tr>
<td>Anaerobic lagoon</td>
<td>45 - 67</td>
<td>60</td>
</tr>
<tr>
<td>Anaerobic slurry storage</td>
<td>8 - 75</td>
<td>54</td>
</tr>
<tr>
<td>Sprinkler irrigation</td>
<td>15 - 30</td>
<td>23</td>
</tr>
<tr>
<td>Land application</td>
<td>on surface 20 - 45</td>
<td>33</td>
</tr>
<tr>
<td>Land application by injection or with immediate incorporation</td>
<td></td>
<td>5</td>
</tr>
</tbody>
</table>

(Adapted from Vanderholm, 1975)

### TABLE 2.6  APPROXIMATE NUTRIENT LOSSES FOR VARIOUS WASTE MANAGEMENT SYSTEMS

<table>
<thead>
<tr>
<th>System</th>
<th>Nutrient Loss, Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anaerobic lagoon, effluent applied to land surface</td>
<td>N</td>
</tr>
<tr>
<td>Bedded confinement, solids applied to land surface</td>
<td>35</td>
</tr>
<tr>
<td>Anaerobic storage, slurry applied to land surface</td>
<td>45</td>
</tr>
<tr>
<td>Spray irrigation of fresh wastes</td>
<td>20</td>
</tr>
</tbody>
</table>

(Adapted from Vanderholm, 1975)

\(^1\) P and K are not actually lost, but accumulate in bottom sludges and are not removed with supernatant.
REFERENCES CHAPTER 2.


waste collection, storage and handling

KEN A. SMITH
ANDREW J. DAKERS
DALE H. VANDERHOLM
INTRODUCTION

Collection is the first step in an agricultural waste management system. As with other processes, collection methods have undergone dramatic changes in recent years, although fairly primitive methods are certainly still common. A wide variety of methods is possible for waste systems and care must be taken in planning to ensure that the collection method is compatible with the total system. A major decision is whether the waste is to be handled as a solid or liquid or both. Runoff from open lots is clearly a liquid and will be handled as such. Manure may be handled either as a solid or liquid, depending upon the total system, and each component of the system must be selected to handle the waste in the form selected.

It should be remembered that animal wastes contain micro-organisms and are corrosive. Therefore all materials in contact, whether timber, concrete or steel, should have their surfaces treated appropriately.

SLOTTED FLOORS

Slotted floors provide rapid separation of the manure from an animal. They can be used in conjunction with an underfloor slurry storage tank or with waste removal systems such as scrapers, flushing, or continuous overflow channels. Slats can be made of concrete, steel, aluminium, plastic, and wood. They are currently being successfully used for beef and dairy cattle, pigs, sheep, and poultry.

Recommended size of openings and space between openings depend upon manure properties as well as experience with slipping, foot injury, and other animal responses. A floor may be totally slotted or a sloping solid floor area may be used in conjunction with a slotted floor section. The manure is moved downslope on the solid floor and off the slats through the openings by animal hooves. Unsatisfactory cleaning may sometimes occur as a result of poor configuration, wrong floor slope, incorrect animal stocking density and other reasons.

Wooden slotted floors are almost universal in woolsheds. The following section relates to pigs in particular.

SLAT TYPES FOR PIGGERIES

Examples of slats are shown in Figures 3.1 and 3.2. Concrete slats are the most common and durable, but are heaviest and require the strongest supports. Wood wears, warps and is sometimes chewed by pigs, leaving irregular slat spacing, although ironbark slats have proved very durable in some instances. Manufactured slotted floor systems of steel, aluminium and plastic are more uniform than wood or concrete, but tend to be more expensive. Steel and aluminium slats are subject to metal fatigue and corrosion. While some alloys and shapes have lasted well, others have deteriorated rapidly, pointing out the need for thorough investigation before purchase. Expanded metal mesh and woven metal quarry mesh are successfully used for pigs up to about 20 kilogrammes. These materials are sometimes plastic coated for protection and to reduce foot problems.
CONCRETE AND WOOD

WOVEN WIRE MESH

REINFORCED CONCRETE

STEEL OR ALUMINIUM BARS OR STRAPS

EXPANDED METAL

PERFORATED OR PUNCHED PLASTIC OR STEEL

EXTRUDED ALUMINIUM FIBRE GLASS OR PLASTIC

STEEL OR ALUMINIUM T BARS

FIGURE 3.1 EXAMPLES OF SLATS
Approximate recommendations for slat size and spacings for pigs are found in Table 3.1. When manufactured slats are used, follow the manufacturer's specifications as much as possible.

**TABLE 3.1 SLAT SIZE AND SPACING FOR PIGS**

| Slat type | Narrow slats (30mm - 75mm) | Wide slats (80mm - 200mm) | Expanded | Woven Metal Mesh
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal Size</td>
<td>10mm (25mm behind sow)</td>
<td>10mm (or 24mm)</td>
<td>20mm, 3.5mm material</td>
<td>25-30mm, 3.5mm material</td>
</tr>
<tr>
<td></td>
<td>12 - 30mm</td>
<td>20-25mm</td>
<td>20mm, 3.5mm material</td>
<td>25-30mm, 3.5mm material</td>
</tr>
<tr>
<td></td>
<td>not recommended</td>
<td>25-30mm</td>
<td>not used</td>
<td>not used</td>
</tr>
<tr>
<td></td>
<td>not recommended</td>
<td>25-38mm</td>
<td>not used</td>
<td>not used</td>
</tr>
</tbody>
</table>

1. Needs support every 0.5 to 1 m.
2. Use 25 mm slots behind sow, but cover them during farrowing and for a few days after (see Fig. 3.2). Use 10 mm slots elsewhere.
When selecting slats, factors to consider are initial and replacement cost, predicted life, strength, ease of installation and replacement, corrosion and noise. Tapered slats (greater top than bottom width) tend to pass wastes better than uniform-width slats, especially if the slat depth is more than about 25 mm.

Experience has shown that the following guidelines help maintain clean floors in partly slotted pig pens.

- Have about one third of the pen area slotted;
- Use solid partitions between solid floor area and open partitions between slotted floor areas. Pigs tend to dung where it is damp and cooler and sleep in drier areas away from draughts;
- Locate the waterer over the slats and feed where the floor should remain clean;
- Keep the pens full. Sparsely filled pens are more apt to have dirty floors;
- Slope solid floors 40 to 60 mm per metre towards the slotted area.

FLUSHING AND WASHDOWN SYSTEMS

Hydraulic removal of manure is nothing new, having been initiated by Hercules several thousand years ago. According to legend, he diverted a river through a soldiers' horse stables to clean them. It has been common practice through history to build livestock facilities on slopes near streams so runoff from rainfall would remove the manure. While natural removal to watercourses is becoming less acceptable environmentally, controlled use of water to transport it is widely used and continues to increase. This procedure is usually one of two major types: manual washdown with portable hoses or flushing through designed flush gutters, either manually or automatically.

Hydraulic manure removal is intended to reduce the labour requirements of manure handling. The diluted waste can either flow by gravity or be pumped to storage and treatment components, making any manual handling of the manure unnecessary. However, it also increases the total volume of waste to be handled and requires significant quantities of water unless treated waste water is recycled for flushing.

Flushing is also considered to be an effective means of reducing odour in confinement buildings. Since the wastes are removed frequently, anaerobic decomposition of the wastes within the building and the resultant odours are greatly reduced.

FARM DAIRY AND YARD WASHDOWN

To comply with hygiene requirements, yards and bails must be washed down after each milking. Recent overseas systems have successfully utilized flush tanks to do this. However, adapting existing facilities to flush methods is often very difficult, usually making this method practical only when planned into new dairy facilities. Conventional hose washdown is economical and satisfactory for most facilities and will continue to be the standard method of use in New Zealand. A properly designed washdown system can save a great deal of time and effort as compared to a poorly designed one. Studies in New Zealand (Cross, 1969) and Australia (Trethewie, undated) have indicated that low pressure, high volume systems are most efficient for wash down. In addition to saving time, low pressure systems also cause less splashing on walls and fences. While higher flow rates would seem to cause higher water usage for low pressure systems, this is offset by reduced washing time, so water use is similar to high pressure
systems. The studies resulted in the development of the following guidelines for dairy washdown systems.

- The washdown equipment should be designed for a flow of 13 to 14 m$^3$/h with 10 to 14 m head at the nozzle. Many of the centrifugal pumps presently available will deliver this quantity at the desired pressure.
- The pump should be placed as close as possible to the storage tank to minimize the suction lift.
- The delivery pipe between the pump and the washdown hose (if necessary) should have a minimum diameter of 40 mm and 50 mm is preferable.
- The washdown hose should have a minimum diameter of 40 mm and should be no longer than 9 m. Provide a delivery pipe with multiple draw off points to achieve this if necessary.
- A quick action valve should be fitted at each draw off point and between the hose and nozzle.
- Nozzle diameter should be 19 to 25 mm.
- Provide an overhead gantry or hooks along the yard wall to lift the hose off the ground during use and for storage.

It should be noted that high pressure - low volume washing is an effective method for thorough cleaning of walls, ceilings, floors, and equipment in dairy sheds as well as pig, poultry and other livestock buildings. For removing small amounts of fluid manure adhering to surfaces and for cleaning cracks, crevices, rough surfaces, etc, it is more effective than low pressure - higher volume systems.

**FLUSHING AND WASHDOWN OF POULTRY FACILITIES**

Manure can be removed from shallow pits or channels beneath poultry cages by pressure hose. With this method, hosing down is usually done about every 2 weeks. There must be adequate fall in the channel to allow the slurry to drain to the end of the building or collection sump, from where it is commonly pumped directly to farm land.

As an alternative to hosing out, both shallow (100 to 200 mm) and deep (800 mm to 1 m) channels can be used to temporarily store manure beneath cages. With the shallow channels, some water is left in the channel and the manure is allowed to accumulate for up to 2 weeks. The slurry is then drained to a holding tank or sump. These shallow channels require scraping to remove settled solids.

The deeper channels can store manure for up to 6 months and are gravity drained, again usually to sumps prior to land application by spray irrigation. Some sludge may accumulate with this configuration also, requiring scraping, but usually the slurry flows readily, effectively carrying the solids along.

Although not a common practice, lagoon systems can be satisfactorily used to treat and store liquid poultry wastes from the types of facilities just described, prior to land application or discharge of the effluent.

**FLUSHING SYSTEMS FOR PIGGERIES**

Piggeries are the only livestock facilities currently using flushing to any significant extent, a pattern likely to continue. For this reason, the
flushing system design information contained in the remainder of this section is primarily applicable to piggeries.

Two types of flushing commonly used in pig facilities are: OPEN-GUTTER FLUSHING, which has been successfully used in finishing buildings and open concrete lots, and UNDER-SLAT FLUSHING, which is the only type to use in farrowing and nursery buildings. Under-slat flushing also works well for finishing buildings. Figures 3.3 to 3.5 illustrate the differences in configuration between the two.

FIGURE 3.3
CROSS SECTION OF BUILDING WITH OPEN FLUSHING ON ONE SIDE

FIGURE 3.4
CROSS SECTION OF BUILDING WITH UNDER-SLAT FLUSHING GUTTERS ON BOTH SIDES
Open-gutter Flushing

With open-gutter flushing, the pigs have direct access to the channel and the flush water. Pigs train to use the gutter area for dunging very readily and also help to dislodge manure in the channel, making it easier to flush. Although it has been postulated that hydraulic transport of manure in an open gutter is a potential for disease transmission, continued use of these systems and studies of this aspect have now shown this not to be a problem in facilities for growing market pigs (Miner and Smith, 1975).

The open gutter is lower in cost than under-slat systems since slats are not needed and the gutter is more easily constructed.

Although open gutters have not proved to be a health hazard for older pigs, farrowing and nursery buildings should use underslat flushing as a precaution due to additional disease susceptibility of small pigs.

Under-slat Flushing

This can be used for both totally- and partly-slotted floors. Manure can stick rather tenaciously to a gutter floor since there is no animal hoof action to loosen it, and manure in under-slat gutters is often difficult to dislodge, requiring greater flush water depths and velocities than open gutters. With proper design, however, under-slat flushing systems can function very well and are in common use.

DESIGN AND OPERATION OF FLUSHING SYSTEMS

Operation

Normal flushing frequency varies from once an hour to once a day, depending on operator preference, ration, pig size, and climate as well as the characteristics of the flush wave. Less frequent flushing requires a greater volume of water per flush to remove the accumulated manure. It is common practice for operators to experiment in order to determine a suitable flushing frequency for a particular facility and management techniques, but for planning purposes, it is wise to provide enough water to flush at least twice per day.
Flushing requires significant quantities of water. Fresh water can be used where supplies are adequate and pumping costs are not excessive. This also results in large volumes of waste. To counter this, recycled, treated, lagoon effluent is often used for flush water, thereby reducing water requirements and waste volume. It can be used in both open gutters and for under-slat flushing, but as a precaution, should probably not be used in farrowing facilities.

Gutter Design Considerations

How completely waste is removed depends on the depth, velocity, and duration of flush. These factors are determined by the dimensions and slope of the gutter and the discharge characteristics of the flush device. In general, no gutter should be designed for a velocity of less than 0.6 m per second and under-slat gutters are often designed for a 0.9 m per second velocity. These recommendations are based on both research and experience. There are examples of successful flushing systems using lower velocities, but compensating with larger quantities of flushing water.

Most references indicate that 45 m is about a maximum recommended flushing distance. However, there are piggery systems successfully flushing over 90 m and flume-type beef buildings flushing 300 m. With these longer flush distances, longer flush durations and greater quantities of flush water must be used.

To avoid accumulation of manure piles causing meandering of the flush water, wide gutters, that is those over 1.2 m wide, should be divided into multiple channels as illustrated in Figure 3.5.

Depth of flow is important since to achieve the same cleaning action, a steeper slope is required when depth of flow is shallow. When modifying existing buildings to use flushing, it is usually more convenient to use a mild slope and greater depth of flow.

<table>
<thead>
<tr>
<th>Gutter Type</th>
<th>Minimum flush flow depth, mm</th>
<th>Recommended flush duration, sec</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open</td>
<td>40</td>
<td>10</td>
</tr>
<tr>
<td>Under-slat</td>
<td>62</td>
<td>10</td>
</tr>
</tbody>
</table>

1. For open gutters less than 40 m in length, an initial flow depth of 25 mm may be satisfactory if longer flush durations are used.

2. Tipping buckets may actually empty in less than 10 seconds. Quantity of flush water should be based on a 10 second duration, however.

Conveying waste away from gutters

Sizing of pipes to carry flush water and waste from the flush channel to storage or treatment is important to prevent a 'bottle-neck' which causes ponding and solids deposition near the end of the channel. For example, if a 1 m gutter is flushed with 9 litres of water over a 10 second period, the average flow rate is 90 litres per second. While flowing the length of the gutter, the velocity is reduced and the wave spreads, but peak flow at the
discharge end might still be about 30 litres per second. With 1 in 100 slope, 200 mm pipe size would be required to carry this flow. Table 3.3 provides some approximate guidelines for pipe sizes at higher flow rates.

TABLE 3.3 RECOMMENDED PIPE SIZES FOR GRAVITY TRANSPORT OF HIGH WASTE FLOW RATES

<table>
<thead>
<tr>
<th>Flow Rate litres per second</th>
<th>Pipe slope, metres per 100 metres</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td>5</td>
<td>150</td>
</tr>
<tr>
<td>10</td>
<td>150</td>
</tr>
<tr>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>30</td>
<td>225</td>
</tr>
<tr>
<td>50</td>
<td>225</td>
</tr>
</tbody>
</table>

Flushing Devices

Flushing devices in use include siphon tanks, tipping buckets, trap-door tanks, and others. Some of these are illustrated in Figures 3.6 to 3.8.

The dosing siphon (Figure 3.7) is an automatic device for emptying a tank intermittently into a flush channel. A stationary tank is filled relatively slowly and when a pre-determined amount of water has filled the siphon primes and the water is dumped rapidly into the channel.

The tipped bucket (Figure 3.8) is a simple, almost maintenance-free device for slow filling and rapid discharge. It has a better distribution across a wide channel and higher discharge rates than most siphons. Buckets may be designed to tip and dump automatically when filled to a certain level or to be filled and tipped manually. They are usually designed to be self-righting after tipping. They may pivot on shafts through solid-mounted bearings or on sockets mounted on the tank ends. Due to better flushing characteristics, they are usually mounted to tip in the direction of the wall away from the channel, with the flush water carried into the channel in a curved entrance as illustrated in Figure 3.9. Table 3.4 gives dimensions and capacities for tipping buckets of the type shown in Figure 3.7.

Manually operated flush tanks with a bottom plug as shown in Figure 3.6 are economical and trouble free. A similar concept is to use a trap door on the side of the tank at the bottom, which is opened manually or automatically.

Flushing can also be done with high volume pumped systems, controlled manually or by time switches.

All of the flushing devices described are being successfully used and selection is dependent on operator preference and adaptability to the building where they will be used.

In most cases, the flushing device determines the initial depth of water flow. For instance, an 80 mm diameter siphon will provide only enough for a 25 mm flow depth in a gutter that is 0.75 m wide, whereas 100 mm and 150 mm siphons allow for proportionately greater depths and wider channel widths.
FIGURE 3.6 MANUALLY OPERATED FLUSH TANK WITH FLOAT CONTROL INLET

FIGURE 3.7 AUTOMATIC SIPHON FLUSH TANK
FIGURE 3.8 TIPPING BUCKET FLUSH TANK
(REF. TABLE 3.4 FOR DIMENSIONS AND CAPACITY)

FIGURE 3.9 TIPPING BUCKET AS INSTALLED FOR UNDER-SLAT FLUSHING
### TABLE 3.4 TIPPING BUCKET DIMENSIONS AND CAPACITIES

<table>
<thead>
<tr>
<th>Tank dimensions, mm</th>
<th>Tank capacity, metre$^3$ per metre length</th>
</tr>
</thead>
<tbody>
<tr>
<td>H 0.42H 0.52H 0.6H 1.2H</td>
<td></td>
</tr>
<tr>
<td>400 168 208 240 480</td>
<td>.144</td>
</tr>
<tr>
<td>600 252 312 360 720</td>
<td>.324</td>
</tr>
<tr>
<td>800 336 416 480 960</td>
<td>.576</td>
</tr>
</tbody>
</table>

### TABLE 3.5 SUGGESTED SIZES OF FLUSH DEVICE OUTLETS.

<table>
<thead>
<tr>
<th>Flush Volume m$^3$</th>
<th>Siphon or valved pipe diameter, mm (average head, 1.4 m)</th>
<th>Siphon or valved pipe diameter, mm (average head, 0.9 m)</th>
<th>Trap door or valved pipe on side of flush tank, with the tank bottom at channel level (average head 0.4 m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>.25</td>
<td>80</td>
<td>100</td>
<td>150</td>
</tr>
<tr>
<td>.50</td>
<td>100</td>
<td>150</td>
<td>200</td>
</tr>
<tr>
<td>.75</td>
<td>150</td>
<td>150</td>
<td>0.014</td>
</tr>
<tr>
<td>1.0</td>
<td>150</td>
<td>200</td>
<td>0.027</td>
</tr>
<tr>
<td>1.5</td>
<td>200</td>
<td></td>
<td>0.041</td>
</tr>
<tr>
<td>2.0</td>
<td></td>
<td></td>
<td>0.055</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.083</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>.11</td>
</tr>
</tbody>
</table>

**Note 1.** 10-second flush discharge

Tipping buckets will ordinarily discharge with a satisfactory duration. When siphon pipes, valved pipes, or trap doors are used, their size must be adequate to discharge the flush water in the planned time. Some suggested sizes for these devices are given in Table 3.5.

**Hydraulic Design**

Flush system design factors are:

\[ V = \text{velocity, m/s. Flow velocity of liquid in channel} \]
\[ S = \text{slope, m/m. Longitudinal slope of channel bottom} \]
\[ W = \text{width, m. Channel width} \]
\[ D = \text{flow depth, m} \]
\[ d = \text{total channel depth, m} \]

Gutters are usually designed as simple rectangular open channels using Manning's formula for open channel flow, which experience has proved satisfactory even though this is not a steady flow situation. Manning's formula is:

\[ V = \frac{R^{0.67} s^{0.5}}{n} \]

where \( V \) and \( S \) are defined previously,
The channel roughness coefficient, \( n \), is commonly used. This is a relatively high value, since accumulated manure in channels increases roughness.

\[ R = \text{hydraulic radius, m} \]

\[ R = \frac{\text{stream cross sectional area, m}^2}{\text{wetted perimeter, m}} \]

\[ R = \frac{WD}{W + 2D} \text{ for rectangular channels} \]

In addition to channel design, flush tank design factors are:

- Flush duration: 3 seconds
- Flush rate: \( m/s \)
- Flush frequency
- Flush volume: \( m^3 \) per discharge

To design a system, the following procedure is used.

1. Select - estimated channel size, \( W \times d \)
   - \( W \) may be dictated by width of slatted floor section and how the total width is divided into separate channels. Maximum recommended individual channel width is 1.2 m. See Table 3.2 for minimum depths.
   - Velocity, \( V \)
     - 0.6 m/s minimum recommended, with greater velocities such as 0.9 m/s preferable for underslat flushing

2. Compute
   - \( R = \frac{WD}{W + 2D} \)
   - \( S = \left[ nV/R^{0.67} \right]^2 \)
   - Discharge rate, \( m^3/s \)
     - \( = \text{velocity} \times \text{stream cross sectional area, m}^2 \)
     - \( = V \times W \times D \)

3. Select duration of discharge
   - (10 seconds recommended)

4. Compute volume of flushing water required
   - \( = \text{discharge rate} \times \text{duration} \)

The following example is included to illustrate use of this procedure.

**Example 3.1** Assume: 2 m wide slotted floor section, flush gutter below, divided into 1 m wide sections. \( W = 1 \text{ m} \) and total gutter depth (not flow depth) of 0.5 m.

Use \( n = 0.025 \)

Select:
- \( V = 0.9 \text{ m/s} \)
- \( D = 0.075 \text{ m} \)

\[
R = \frac{1 \times 0.075}{1 + 0.075 + 0.075} = \frac{0.075}{1.15} = 0.065 \text{ (m)}
\]
\[ S = \left[ \frac{(0.025) \times (0.9)}{(0.065)} \right]^{0.67} \]

\[ = \left( \frac{0.0225}{0.16} \right)^2 \]

\[ = 0.02 \]

\[ = 2\% \]

Discharge rate = 0.9 x 1 x 0.075 = 0.068 m³/sec
Assume a tipping bucket is to be used with a 10 second duration of discharge
Volume of flush water per flush for each channel =
\[ 0.068 \times 10 = 0.68 \text{ m}^3 \]
\[ = 680 \text{ l} \]

Table 3.6 has been included to aid in flushing system design. Remember that the velocities, and flush durations shown are considered to be minimum recommended values. Water quantities and flush durations should be increased in cases of long flush distances, extremely shallow slopes or infrequent flushing.

### TABLE 3.6 FLUSH GUTTERS CONSTANT WIDTH, CONSTANT SLOPE

<table>
<thead>
<tr>
<th>Channel slope (m/m) for channel widths (m) of:</th>
<th>Initial depth of flow, m</th>
<th>Flush volume, m³ per m of channel width</th>
</tr>
</thead>
<tbody>
<tr>
<td>.5</td>
<td>1.0</td>
<td>1.5</td>
</tr>
<tr>
<td>Velocity = 0.6 m/sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.037</td>
<td>0.035</td>
<td>0.034</td>
</tr>
<tr>
<td>0.016</td>
<td>0.015</td>
<td>0.014</td>
</tr>
<tr>
<td>0.011</td>
<td>0.009</td>
<td>0.0085</td>
</tr>
<tr>
<td>0.008</td>
<td>0.0065</td>
<td>0.006</td>
</tr>
<tr>
<td>0.0065</td>
<td>0.0051</td>
<td>0.0046</td>
</tr>
<tr>
<td>0.0055</td>
<td>0.0042</td>
<td>0.0038</td>
</tr>
<tr>
<td>Velocity = 0.9 m/sec</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.081</td>
<td>0.075</td>
<td>0.074</td>
</tr>
<tr>
<td>0.036</td>
<td>0.032</td>
<td>0.031</td>
</tr>
<tr>
<td>0.023</td>
<td>0.020</td>
<td>0.018</td>
</tr>
<tr>
<td>0.017</td>
<td>0.014</td>
<td>0.013</td>
</tr>
<tr>
<td>0.014</td>
<td>0.011</td>
<td>0.010</td>
</tr>
<tr>
<td>0.012</td>
<td>0.009</td>
<td>0.008</td>
</tr>
</tbody>
</table>

Note 1. Flush duration = 10 sec, n = 0.025

### GRAVITY DRAIN SYSTEMS

While this is not truly a flushing system to the extent that external flush water is not introduced, gravity drain systems are still of this general category. The concept in this instance is to construct small, under-slat storage pits with hydraulic characteristics which combine short term slurry storage with effective hydraulic gravity removal when the outlet is opened.
These function similarly to flush gutters in that manure is stored only for short periods, minimizing odour and gas production. Normal practice is to drain the effluent to a treatment lagoon, although it can be drained to a slurry storage tank. The storage gutters are usually Y-shaped, a configuration pioneered by Meyer (1977), although rectangular shapes have also been used successfully. They are primarily used in piggery farrowing and nursery buildings and also can be used for slurry in poultry buildings. Storage capacities are commonly 4 to 7 days waste accumulation. The gutters are sloped 0.004 to 0.005 m/m to aid in maintaining velocity to move solids out during draining. Maximum length of gutters is 15 m if less than 0.3 m deep, otherwise 20 m. Examples of gravity drains and representative dimensions are shown in Figures 3.10 and 3.11. When the Y-shaped gutter is used, the slanting sidewall portion must be extremely smooth to allow it to clean properly. To aid in this, coatings of manure resistant epoxy paint, plastic sheets, and other coverings are sometimes used.

**FIGURE 3.10** RECTANGULAR GRAVITY DRAIN FOR FARrowing CRATE

**FIGURE 3.11** Y TYPE GRAVITY DRAIN WITH FRONT DRAIN FOR FARROWING CRATES
An outlet pipe with a manually removable plug is installed at the lower end of the gutter as shown in Figure 3.12. This plug is pulled every 4 to 7 days to empty the gutter. Enough water to cover the gutter bottom and prevent solids from sticking is added after each draining.

**SCRAPER SYSTEMS**

**CABLE SCRAPERS**

Scrapers of various types can be used to collect waste from solid floors or from under slotted floors and to move the wastes to storage, treatment, or spreading equipment. Their main advantage is labour reduction. Figure 3.13 illustrates a common type of scraper used in poultry buildings under laying cages and in piggeries in the channels under slotted floors. The scraper is pulled by a chain, cable, or rope powered by an electric motor. The blade is hinged vertically so that it scrapes in one direction, but when the direction is reversed for return, the blade swings upward and passes over the recently accumulated waste. A cross conveyor or collection pit is usually located at the end of the scraper path to receive the waste. It may then be stored, disposed of through land application, or transported to other treatment components such as lagoons.

Scrapers may operate wet or dry, with the waste handled as a liquid or solid. In piggeries, the waste contains enough urine and spilled water so that it is handled as a liquid and transported by pumping or gravity flow. In poultry houses, water is sometimes added to scraper channels to make the waste more easily scraped and then it is handled as a liquid.

Drinker overflow water is often adequate in quantity for this purpose. In other instances, no water is added and the manure is handled as a solid by conveyors and spreaders.
Scraper channels must be concreted and should be sloped toward the outlet to allow draining and to prevent ponding of liquids. A common practice is to link two scrapers in parallel channels to the same tow line. In this arrangement, while one scraper is scraping, the other is being pulled on a return stroke. Only one power unit is then needed with a reversal mechanism on the drive winch as illustrated in Figure 3.14.

Scraper channels must be operated regularly, usually once or twice daily. Excessive manure accumulations will cause overloading and equipment breakage.

Scraper channels of the type described are commercially available, although many have been built by individual farmers. There are no standard design criteria available for planning and constructing them.

---

**FIGURE 3.13 PUSH-PULL SCRAPER**

---

**FIGURE 3.14 PUSH-PULL SCRAPER WITH REVERSIBLE DRIVE**
In poultry facilities, small tractors with attached scrapers are often used instead of mechanical scrapers. The tractors drive along the alleyways between cages and the scrapers on one or both sides of the tractor pass under the cages, moving the manure. The manure can be pushed to a cross conveyor or outside to a storage area or muck spreader. With this system more manure can be allowed to accumulate than with mechanical scrapers and cleaning would only be done every few months. A scraper tractor of this type is shown in Figure 3.15. Complete units are commercially available or tractors can be fitted with farm-built or locally-built scrapers.

Rear-mounted or front-mounted scrapers for farm tractors can be used to collect manure from solid floors in livestock buildings and open yards such as dairy wintering yards. The manure may be scraped to a ramp for loading into a muck spreader, to a storage area for later removal, or to a treatment lagoon. Since tractors cannot operate efficiently on steep floors, slopes of lots, drives, and storage areas should not exceed 0.1 m/m.

MANUAL SCRAPING

While manual cleaning and shifting of manure by pitchfork, shovel, bristle broom, and squeegee can be considered a technique of the past, few livestock farms manage to avoid it entirely. Many older piggeries, especially those which use bedding, need manual cleaning. Some poultry buildings are still cleaned with shovels and wheelbarrows. Manual cleaning is a time-consuming chore and the time of skilled farm workers can be spent on more productive tasks. Complete elimination of manual cleaning is
unlikely for most operations, but by careful planning, it can be minimised in new, modified and existing facilities.

**RUNOFF COLLECTION AND STORAGE**

**RUNOFF FROM OPEN LOTS**

Runoff from well-managed pasture areas is not currently considered a significant source of pollution. Livestock production areas where no forage is grown and livestock are present for long periods of time at relatively high densities may produce stormwater runoff carrying large amounts of pollutants. Depending upon location, stream classification, and other specific circumstances, it may be necessary to collect this runoff rather than to allow it to be discharged.

Compared to fresh, raw wastes from most livestock facilities, runoff is relatively dilute and inoffensive. The volume of water is small when compared to irrigation quantities. Although pollution potential may be high, economic value as fertilizer or irrigation water is usually very small.

**SIZING COLLECTION CHANNELS**

Runoff can be collected in channels and directed to accepted disposal areas, treatment facilities, or temporary storage. Channels, pipes and pumps should be sized to handle the peak runoff from a design storm of suitable magnitude. Approximate values are adequate for this type of design and these can be estimated using the following procedure.

For sizing, collection and transport components, use a design rainfall of 2 year frequency and 10 minute duration. (Tomlinson, 1980; Coulter and Hessell, 1980). Selected values for this are included in Table 3.7.

**EXAMPLE 3.2** Using the intensity for a specific location from Table 3.7, calculate the resulting flow for the contributing area. Assume the entire area is contributing runoff equally, since areas are usually small with hard surfaces so that delays and infiltration losses are minimal. Design flow can be calculated as follows:

Rainfall (mm per 10 min) x contributing area ($m^2$) ÷ 600 = flowrate (l/sec).

For example, to estimate flow requirements for a channel or pipe carrying runoff from a 20 m by 40 m, concrete-surfaced, farm dairy holding pen in the Palmerston North area, calculate as follows:

8 mm per 10 min x 800 $m^2$ ÷ 600 = 10.7 litres per second. So all channels, pumps and pipes should be designed for this flowrate unless temporary storage is included. To minimise the volume to be handled, clean runoff water from roofs and non-livestock areas should be diverted to another outlet if possible.

Alternatives for handling and disposal of runoff water are shown in Figure 3.16. The most simple method is to divert the polluted runoff, so that, rather than be directly discharged to streams, the runoff goes to pasture, grassed waterway or other agricultural land with grass cover, where it will not be detrimental, but will be filtered, diluted, and infiltrated, before reaching the stream.

Flow in the treatment area may be either overland flow or shallow channel flow. Little design information is available for these systems, but
FIGURE 3.16 ALTERNATIVE METHODS FOR HANDLING RUNOFF.
studies overseas (Vanderholm et al, 1979) indicate that treatment efficiency is directly related to time of travel over the grassed treatment area. For overland flow on mild slopes (less than 1 percent), flow distance should be at least 100 m with design velocities resulting in a minimum of 2 hours travel time. This configuration is similar to border dyke irrigation systems. For shallow channel flow, greater distances are required for equivalent treatment and a 200 m minimum flow distance is recommended. Treatment areas or channels should not carry runoff from other areas, but only the contaminated storm runoff to be treated.

Prior to overland flow treatment or to storing in a pond built specifically for runoff storage, partial solids removal by settling is recommended. This lessens odour potential, sludge accumulation in holding ponds and reduces the chances of killing vegetation in overland flow systems. Planning of settling devices is discussed in the section on solids-liquid separation (Chapter 4).

RUNOFF AND ANAEROBIC TREATMENT SYSTEMS

Runoff may sometimes be allowed to enter lagoon and long ditch systems without detrimental effects. If discharged to a 2-stage lagoon (anaerobic-aerobic) or long ditch system, such as is commonly used for farm dairies, the only effect is to reduce hydraulic detention time. Unless the contributing lot area is exceptionally large, the percentage reduction is relatively small (e.g. 25 percent or less) and no change in design is necessary. For single-stage lagoons with waste storage included and pumped dewatering, additional storage must be provided if runoff water is added. The additional volume is calculated as shown in Chapter 5. If the runoff is to be diverted and discharged, a simple device such as shown in Figure 3.17 can be used.

![Figure 3.17 Runoff Diversion Device](image-url)
### TABLE 3.7 SELECTED RAINFALL CHARACTERISTICS (MM)

<table>
<thead>
<tr>
<th>Location</th>
<th>(Met. Station)</th>
<th>10-minute rainfall of return period 2 years</th>
<th>24-hour rainfall of return period 10 years</th>
<th>Highest mean monthly rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaitaia</td>
<td>(Airport)</td>
<td>12</td>
<td>130</td>
<td>161 August</td>
</tr>
<tr>
<td>Whangarei</td>
<td>(Glenervie)</td>
<td>12</td>
<td>211</td>
<td>220 August</td>
</tr>
<tr>
<td>Auckland</td>
<td>(Mechanics Bay)*</td>
<td>12</td>
<td>117</td>
<td>-</td>
</tr>
<tr>
<td>Auckland</td>
<td>(Oratia)</td>
<td>-</td>
<td>-</td>
<td>181 June</td>
</tr>
<tr>
<td>Hamilton</td>
<td>(Ruakura)</td>
<td>10</td>
<td>115</td>
<td>127 June</td>
</tr>
<tr>
<td>Tauranga</td>
<td>(Airport)</td>
<td>12</td>
<td>166</td>
<td>136 June</td>
</tr>
<tr>
<td>Taupo</td>
<td>(Airfield)</td>
<td>9</td>
<td>118</td>
<td>119 December</td>
</tr>
<tr>
<td>Gisborne</td>
<td>-</td>
<td>8</td>
<td>145</td>
<td>116 July, August</td>
</tr>
<tr>
<td>Napier</td>
<td>(Aerodrome)</td>
<td>8</td>
<td>147</td>
<td>-</td>
</tr>
<tr>
<td>Napier</td>
<td>(Mangaohane Station)</td>
<td>-</td>
<td>102</td>
<td>102 June</td>
</tr>
<tr>
<td>New Plymouth</td>
<td>-</td>
<td>11</td>
<td>179</td>
<td>160 July</td>
</tr>
<tr>
<td>Wanganui</td>
<td>-</td>
<td>8</td>
<td>84</td>
<td>86 June</td>
</tr>
<tr>
<td>Palmerston North</td>
<td>(DSIR)</td>
<td>8</td>
<td>93</td>
<td>99 June</td>
</tr>
<tr>
<td>Masterton</td>
<td>(Waingawa)</td>
<td>-</td>
<td>-</td>
<td>107 July</td>
</tr>
<tr>
<td>Masterton</td>
<td>(Ngaumu)</td>
<td>5</td>
<td>150</td>
<td>-</td>
</tr>
<tr>
<td>Blenheim</td>
<td>-</td>
<td>5</td>
<td>86</td>
<td>68 May</td>
</tr>
<tr>
<td>Nelson</td>
<td>(Airport)</td>
<td>9</td>
<td>105</td>
<td>105 May</td>
</tr>
<tr>
<td>Hanmer</td>
<td>(Forest)</td>
<td>4</td>
<td>120</td>
<td>114 May</td>
</tr>
<tr>
<td>Christchurch</td>
<td>(Airport)</td>
<td>6</td>
<td>94</td>
<td>75 May</td>
</tr>
<tr>
<td>Ashburton</td>
<td>(Winchmore)</td>
<td>4</td>
<td>90</td>
<td>75 April</td>
</tr>
<tr>
<td>Waimate</td>
<td>-</td>
<td>4</td>
<td>90</td>
<td>71 December</td>
</tr>
<tr>
<td>Dunedin</td>
<td>(Airport)</td>
<td>5</td>
<td>102</td>
<td>-</td>
</tr>
<tr>
<td>Dunedin</td>
<td>(Musselburgh)</td>
<td>-</td>
<td>-</td>
<td>74 December</td>
</tr>
<tr>
<td>Invercargill</td>
<td>(Airport)</td>
<td>5</td>
<td>57</td>
<td>105 April</td>
</tr>
<tr>
<td>Milford Sound</td>
<td>-</td>
<td>10</td>
<td>409</td>
<td>622 March</td>
</tr>
<tr>
<td>Hokitika</td>
<td>(Aerodrome)</td>
<td>11</td>
<td>171</td>
<td>-</td>
</tr>
<tr>
<td>Ross</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>333 October</td>
</tr>
</tbody>
</table>

Source: Coulter and Hessell (1980); N.Z. Met. Serv. (1979)

**RUNOFF STORAGE**

Runoff may also be temporarily stored in tanks or earthen ponds constructed specifically for that purpose or for storage of normal daily waste production as well as runoff. It should be borne in mind that runoff quantities can be large and the value as fertilizer quite low, so storage in anything other than relatively inexpensive earth structures is not usually justified.

For storage of runoff, the most simple and economical system is an earthen pond with gravity loading if possible and pumped dewatering. Runoff water is relatively dilute and can be handled with conventional centrifugal pumps after solids removal by settling prior to or during storage. Pump intakes should still be screened to exclude large floating solids. Stored runoff can be applied to pasture or cropland by irrigation methods. Hauling runoff in tankers is not economical unless it has been mixed with higher strength manure slurry.
Sizing Runoff Storage

Runoff storage should have a minimum capacity to store the runoff accumulation for the month with the highest mean rainfall or to store the 10-year frequency, 24-hour duration storm runoff, whichever is greatest. This will give adequate capacity so that emptying of the storage during extremely wet periods should not be necessary. If storage is emptied on a regular basis, capacity is available to store a large individual runoff event without discharging. Therefore provision is made for both normal and extreme events. It may be desirable in some situations to provide storage for longer periods. Due to evaporation, absorption of rainfall by accumulated manure on the lot surface, infiltration into permeable surfaces, and other factors, not all of the rainfall actually shows up as runoff. There are several methods of predicting runoff which are standard engineering procedures and which can be adapted to predict runoff from livestock facilities. Except for very large facilities, it is doubtful whether the increased accuracy from using these is worth the extra effort involved. A simplified alternative is to use the values given in Table 3.8. The values given are approximate percentages of runoff to rainfall for various situations. These are based on overseas data where long term runoff measurements on various types of livestock facilities were made. The proportion of rainfall that goes into runoff for extended periods tends to be smaller than for single storms since rainfall events of all sizes can occur, including small ones which result in little or no runoff.

The depth of rainfall for a 10-year, 24-hour storm of a specific location can be found from Coulter and Hessell (1980) or Tomlinson (1980). Values for selected locations have been included in Table 3.7 to illustrate the variation in magnitude encountered.

Mean monthly rainfall values are also available (N.Z. Meteorological Service 1979). These can be used to calculate storage requirements for periods of 30 days or more for specific locations. Some representative values of mean rainfall during the highest rainfall month have been included in Table 3.7.

### Table 3.8 Percentage of Rainfall Which Runs Off Livestock Facilities

<table>
<thead>
<tr>
<th>Type of Facility</th>
<th>Single Storm Runoff, percent of rainfall</th>
<th>Extended Period Runoff, percent of rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm dairy holding pens - concrete surfaces</td>
<td>95</td>
<td>85</td>
</tr>
<tr>
<td>Piggery - open uncovered pens - concrete surfaces</td>
<td>95</td>
<td>85</td>
</tr>
<tr>
<td>Roof areas</td>
<td>98</td>
<td>90</td>
</tr>
<tr>
<td>Earthen livestock pens (high stock density, no vegetation)</td>
<td>85</td>
<td>70</td>
</tr>
</tbody>
</table>

Note 1. Periods of 30 days or more.
EXAMPLE 3.3 Continuing Example 2.1 from the section on waste characteristics for the farm dairy in the Palmerston North area, the following steps illustrate the procedure for estimating runoff from a 10-year, 24-hour storm. From Table 3.7, the 10-year, 24-hour rainfall for that area is 93 mm and from Table 3.8, 95 percent of the rainfall from a single storm would be expected to leave as runoff.

\[93 \text{ mm} \times 0.95 = 88 \text{ mm} = 0.088 \text{ m}\]

Total volume of runoff from the storm for the 800 m\(^2\) area would be

\[0.088 \text{ m} \times 800 \text{ m}^2 = 70.7 \text{ m}^3\]

From Table 3.7, the highest monthly rainfall in that area occurs in June, when mean rainfall is 99 mm. From Table 3.8, accumulated runoff would be about 85 percent of that amount.

\[99 \text{ mm} \times 0.85 = 84 \text{ mm}\]

In this instance, the 30-day accumulated runoff under normal conditions was almost the same as the runoff from the single large storm event. If the values had been much different, the larger value would have been used as the minimum recommended storage volume. For this example, assume that the dairy is in a highly sensitive situation where no lagoon discharge is allowed. A single anaerobic lagoon will be used and treatment volume for farm dairy wastes, waste storage volume for desired time period, and finally, runoff storage volume must be provided.

Effluent will be pumped out of the anaerobic lagoon and applied to pasture land. The herd size is 200 cows and the minimum lagoon treatment volume required is 3.33 m\(^3\) per cow or 666 m\(^3\) (see Lagoon Volume, Chapter 5). Dairy effluent flow is 50 l per cow daily or a total of 10 m\(^3\) daily. For 30 days storage, the total waste accumulation would be 300 m\(^3\). From the anaerobic lagoon design section, no more than 1/3 of the anaerobic lagoon treatment volume can be used for temporary storage. Total storage needed for this example is:

\[300 \text{ m}^3 \text{ effluent} + 70.7 \text{ m}^3 \text{ runoff} = 370 \text{ m}^3\]

Treatment volume available for temporary storage is

\[666 \text{ m}^3 \times \frac{1}{3} = 222 \text{ m}^3\]

Additional storage which must be provided is

\[370 \text{ m}^3 - 222 \text{ m}^3 = 148 \text{ m}^3\]

so the total lagoon volume needed for treatment and storage would be

\[666 \text{ m}^3 + 148 \text{ m}^3 = 814 \text{ m}^3\]

Lagoon dimensions which provide this volume should be selected. The lagoon storage volume should be periodically pumped out, but it should never be lowered beyond the level where 2/3 of the treatment volume remains. This minimum level should be marked with a post or other means to eliminate the need for guessing where it is each time pumping is done.

For this example, if a discharging two-lagoon system had been used instead of a single lagoon with land application, the runoff could have been allowed to enter the lagoon system with no change in design size.
storage of manures and slurries

The application of farm wastes to the land and the planned utilisation of its manural value by crops has long been accepted as a desirable method of disposal. Storage may form an integral part of a land application system. Storage structures may also be used to hold manure, wastewater and yard runoff prior to treatment.

The advantages and disadvantages of waste storage are summarised below. Some of these will be directly conflicting and their relative importance may need to be assessed in the individual situation.

ADVANTAGES

Ease of management: spreading may be restricted to periods when soil conditions allow easy access to the land and the damage to soil structure and crops will be minimised.

Reduced risk of pollution: complete containment of waste; less risk of surface runoff or percolation to drains, since spreading is restricted to periods when weather and soil conditions are favourable.

Increased flexibility: spreading or disposal needs to be carried out less frequently and, more at the convenience of the operator, e.g. avoiding weekends and holidays.

Increased efficiency: by reducing the frequency of land spreading, greater volumes of waste can be handled at one time, allowing more efficient use of man-power and machines.

Reduced odour frequency: there will be fewer occasions when there is a risk of odour; spreading can be restricted to periods when the weather favours good atmospheric dispersal of odour.

Better utilisation of plant nutrients: waste application can be made to the most responsive crops e.g. potatoes, grass for conservation; at a time when crop conditions are favourable and when the response to manure-applied nutrients will be optimised. Application may be to a seedbed, or as top dressings in the spring, or during the growing season. This better utilisation may be partially offset by nutrient losses occurring during storage.

Reduced health risk: storage of slurry has been shown to have a significant effect on the death of pathogenic micro-organisms and therefore will reduce the health risk associated with the spreading of slurry on pasture land.

DISADVANTAGES

High cost: storage structures are expensive to construct and maintain.

Land occupied by store: the store will normally be sited adjacent to livestock and other buildings. Such space is often at a premium.

Management problems: management to control the separation and crusting of liquid manures during storage increases the costs of manure disposal. The formation of crust and sludge layers can lead to difficulties when the store is emptied.
Lower efficiency: Storage, and subsequent removal of manure from a store, entails one extra handling procedure, compared to direct spreading from the livestock building.

Odour nuisance: Spreading of anaerobically stored manures (with greater odour) may cause more nuisance than fresh manures.

Loss of plant nutrients: Nutrient losses, particularly nitrogen, occur during storage.

Health risk: Poor storage conditions can lead to problems with flies and vermin and, therefore, increased health risk.

Safety aspects: Provision of childproof and stockproof fencing will add to cost; poisonous gases may be a hazard in confined spaces, e.g., below-ground tanks.

**CHOICE OF STORAGE FACILITY**

It cannot be said that a certain type of storage will suit any particular farm type or group of circumstances. Choice of storage system must be made in the context of overall farm management and will be influenced by the following factors:

**COST**

Most farm-made stores are costed individually depending on site conditions. The cost of prefabricated stores may be obtained from manufacturers and meaningful comparisons with farm-made compounds or storage ponds can be made by obtaining estimates from contractors. It should be remembered that farm-made, above-ground compounds require yearly maintenance and may have a higher labour demand during emptying.

**TYPE AND CONSISTENCY OF WASTE**

Semi-solid manures (>20% total solids) are not easily pumped and must be scraped over concrete areas or lifted into the store. Storage should generally be at ground level, on a concrete pad with substantial retaining walls. Water should never be added and it may be worthwhile, in high rainfall areas, considering a light covering over the manure or, complete roofing.

Semi-liquid manures (12-20% dry matter) result from a mixture of dung, urine, and small to moderate amounts of bedding material. Management as a semi-liquid results in less material to handle and haul to the field, since extra water has been excluded or allowed to drain away. The material will generally be too thick to pump but can be scraped easily over concrete and up ramps into store. Storage may be below ground or in above-ground, timber-walled or concrete-panelled stores.

Liquid slurries (<12% dry matter) consist of dung and urine, with little or no bedding and with variable quantities of washing or flushing water. The slurry may be too dilute to scrape and will generally be pumped or flow by gravity to store. Storage may be below ground or in above-ground, pre-fabricated tanks.

In Table 3.9 some suitable storage systems are given for various requirements and conditions.
<table>
<thead>
<tr>
<th>TYPE OF STOCK</th>
<th>TYPE OF HOUSING/SOURCE OF WASTE</th>
<th>WASTE TRANSFER SYSTEM</th>
<th>CONSISTENCY OF WASTE</th>
<th>SUITABLE STORAGE SYSTEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAIRY CATTLE</td>
<td>• Farm dairy effluent</td>
<td>Gravity flow/pump</td>
<td>Liquid</td>
<td>Anaerobic treatment lagoon</td>
</tr>
<tr>
<td></td>
<td>• Collecting yards and open</td>
<td>Hose washing to pump sump</td>
<td>Liquid</td>
<td>Earth-banked compound, above-ground tank</td>
</tr>
<tr>
<td></td>
<td>feeding lots</td>
<td>Flushing</td>
<td>Liquid</td>
<td>Below-ground concrete tank (short term)</td>
</tr>
<tr>
<td></td>
<td>• Cubicle house, little or no</td>
<td>Tractor/automatic scraper</td>
<td>Semi-solid</td>
<td>Timber/concrete-panel, walled compound, earth-banked compound with effluent drainage facility</td>
</tr>
<tr>
<td></td>
<td>bedding</td>
<td></td>
<td></td>
<td>Open-ended concrete/timber-sleeper, walled compound</td>
</tr>
<tr>
<td></td>
<td>• Cubicle house, little or no</td>
<td>Tractor scraper</td>
<td>Semi-solid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>bedding</td>
<td>Tractor loader</td>
<td>Semi-solid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Collecting yards and open</td>
<td></td>
<td>Solid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>feeding lots</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Straw yards, calf pens</td>
<td></td>
<td>Solid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Solids from separators</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PIGS</td>
<td>• Total/partial slatted floors</td>
<td>Flushing</td>
<td>Semi-solid/ liquid</td>
<td>Anaerobic treatment lagoon, above-ground tank</td>
</tr>
<tr>
<td></td>
<td>• Total/partial slatted floors</td>
<td>Gravity flow channel</td>
<td>Semi-solid/ liquid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Total/partial slatted floors</td>
<td>Sluice gates/pumping</td>
<td>Semi-solid/ liquid</td>
<td>In-house storage below slats</td>
</tr>
<tr>
<td></td>
<td>• Straw bedded pens</td>
<td>Tractor loader</td>
<td>Semi-solid</td>
<td>Open-ended concrete/timber-sleeper, walled compound</td>
</tr>
<tr>
<td></td>
<td>• Solids from separators</td>
<td></td>
<td>Liquid</td>
<td></td>
</tr>
<tr>
<td>POULTRY</td>
<td>• Ceiling/floor supported cages</td>
<td>Tractor/automatic scraper and flushing, Pumping</td>
<td>Semi-solid/ liquid</td>
<td>In-house, below-floor storage, below-ground concrete tank</td>
</tr>
<tr>
<td></td>
<td>• Ceiling/floor supported cages</td>
<td>Tractor/automatic scraper, tractor loader</td>
<td>Semi-solid</td>
<td>Below-ground concrete tank with added water. Straw bale compound. Usually direct to trailer/spreader</td>
</tr>
<tr>
<td></td>
<td>• Tiered cages</td>
<td>Moving belt and scraper, cross conveyor</td>
<td>Semi-solid</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Tiered cages over deep pit</td>
<td>Droppings to pit below</td>
<td>Solid</td>
<td>Floor storage in deep pit</td>
</tr>
<tr>
<td></td>
<td>(high rise)</td>
<td>Elevator, tractor loader</td>
<td>Dry litter</td>
<td>Floor storage between crops of birds. Storage, if necessary, on a concrete pad with roofing or covering in high rainfall areas</td>
</tr>
<tr>
<td></td>
<td>• Floor housing with bedding</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note 1. See Table 3.10
Housing type will have some influence on choice of transfer system and will also determine how much, if any, bedding material will be used.

LAYOUT OF BUILDINGS

Storage will normally be sited as close as possible to livestock yards and buildings providing legal requirements for siting are satisfied. Since the space around buildings can be rather limited, the area occupied may be an important factor influencing choice. On a confined site, choice may be limited to a store which can provide the required capacity by means of extra depth.

WATER TABLE

For unsealed, below-ground storage facilities, the effective storage volume is only that above the groundwater table. Lining the store with clay or impervious membrane is very difficult, expensive and may be incomplete. A high water table can also cause empty collection tanks, unless well secured, to "float", resulting in fractured collection channels and feed pipes.

In most cases of high water table, or where the site is liable to flooding, an above-ground storage facility is recommended.

SOIL TYPE

Where there is a risk of untreated effluent escaping into a water course or percolating into an underground aquifer, the storage facility must provide complete containment of the waste. Satisfactory systems would include concrete or steel tanks or an earth basin with impermeable lining.

Choice and size of storage may also be affected by the predominant soil type on the farm, according to the length of period when soil conditions prevent easy access to the land. Storage may be more important in poorly-drained clay areas than on free-draining loams.

FUNCTION OF STORE

A storage structure may be used as a solids-liquid separation device from which liquids can drain, or be removed by pump or tanker; or as a settlement basin, allowing some storage of settled solids.

The incorporation of a picket dam or strainer box into the storage system, will allow the removal of excess manure liquor and rainfall incident on the storage area and, therefore, some reduction in the volume of storage needed. With an efficient system, it is suggested that a 10% reduction in calculated storage volume can be made.

ROOFING OF MANURE STORAGE

Storage of solid or semi-solid manure on sites exposed to rainfall can create problems. It is often necessary to provide some form of cover.

Although difficult to justify economically, the cost of roofing will be offset, to some extent, by removing the need for an effluent tank, and by avoiding the need to handle extra liquid effluent as well as a wet, unpleasant, semi-solid effluent. The losses of plant nutrients occurring during the storage of manures is discussed in the chapter on Waste Characteristics. Davies and Russell (1974), considering the economics of covering solid manure from cattle yarded on straw, considered that a
permanent roofing structure could not be justified. Instead, some form of cheap covering, e.g. polyethylene sheeting, which will prevent losses of plant nutrients by leaching and possibly reduce gaseous losses of nitrogen, may be economically worthwhile. However, the practical application of such a covering may be difficult to achieve.

**SITING**

Particular attention should be paid to ease of filling and emptying of storage but all other farming operations should receive careful consideration. Conveyors or tractor scrapers should be allowed a straight run to the storage compound and advantage should be taken of ground contours so that gravity may be used wherever possible.

Storage should be sited away from high water table situations whenever possible. Below-ground storage should preferably be sited on heavy, impermeable solids and careful soil survey will reveal the best area.

Partial microbial decomposition of wastes during anaerobic storage may result in the production of strong, obnoxious odours. The emission of odours will be particularly marked during emptying operations and storage should therefore be sited well away from living accommodation. A minimum distance of 300 m has been suggested for anaerobic lagoons, but prevailing winds should be taken into account. It may be possible to shield storages from public roads or local housing. If not, consideration might be given to tree planting and landscaping to improve the appearance of the store. Some local authority bylaws specify minimum distances for waste facilities from domestic housing and from animal housing.

**ESTIMATING STORAGE VOLUME REQUIRED**

Storage requirements must allow for maximum rates of waste production and must take into account any future likely increases in stock numbers.

The information included in the chapter on Waste Characteristics may be used for planning purposes, but data specific to the farm in question should be obtained whenever possible.

To keep costs of storage down it is important that the unnecessary addition of water should be avoided. This includes the diversion of roof water and rainfall collected on clean concrete areas and the correct siting and, if necessary, sealing of underground stores. The volume of water used in washing operations may, in some cases, be reduced e.g. by hand scraping of yards with solids removal, prior to washdown. When some dilution water is required to assist in mixing or pumping operations, the system should utilise already fouled water, if possible.

Straw, sawdust, woodshavings, loam/sawdust mixtures and power station ash (suggested for open topped cubicles) are some of the materials that have been used as bedding, under New Zealand conditions.

Except for the use of chopped straw/woodshavings as bedding for broiler chickens (now almost entirely restricted to woodshavings), bedding is only important where the materials are cheap and freely available. Experience in the U.K. (MAFF, 1980) has indicated that the average use of woodshavings or chopped straw for poultry on deep litter is around 1 tonne per crop of 1000 birds. For broilers, use averaged 0.5 tonne per 1000 birds.

The foregoing considerations may be summarised in terms of the following formula, which may be used to determine the size of manure storage:
\[ V_s = n \times t \times \frac{V_m \times V_w}{1000} + \frac{A_f \times p \times R_t}{1000} + A_s \times \frac{R_t}{1000} + V_b \]

livestock waste *runoff rainfall + waste

Where

\[ V_s \] = volume of storage (m³)

**n = number of animals confined during storage period

t = storage period required (days)

\[ V_m \] = animal manure production, (litres/animal.day)

\[ V_w \] = cleaning water volume, (litres/animal.day)

\[ A_f \] = farm area (yards, buildings etc) contributing to rainfall runoff (m²)

\[ p \] = percentage of rainfall which runs off livestock facilities (see Table 3.8).

\[ R_t \] = depth of rainfall over livestock facility from a 10-year, 24-hour storm or from the highest monthly rainfall (see Table 3.7); whichever is greater after allowing for percentage runoff (mm)

\[ A_s \] = surface area of storage facility (m²)

\[ V_b \] = volume of waste bedding material (m³)

* detailed consideration is given to calculation of the runoff contribution in the earlier section on 'Runoff Collection and Storage'.

** the number of animals is the average number confined during the storage period, not the total number of animals produced during this period. This figure should take into account any future likely increases in stock numbers.

DESIGN AND MANAGEMENT OF STORAGE FACILITIES

The examples described here do not cover all possibilities but will illustrate the general principles on which to base specific designs for a particular farm site. For ease of description, storage facilities may be considered in the two broad categories of above-ground and below-ground storage.

ABOVE-GROUND STORAGE

Manures are pumped, scraped or otherwise loaded into a structure from which excess liquid may be allowed to drain to separate storage or to treatment, with the residue being managed as a solid. Steel/concrete above-ground tanks, however, are used for the storage of liquids.

For ease of management, the storage of solids should, if possible, be in above-ground structures.
FIGURE 3.18 CONCRETE STORAGE COMPOUND FOR SOLID WASTES
(ADAPTED FROM MAFF, 1980)
Solid Manure Storage Compound (Figure 3.18)

Manure with straw, shavings or other solids/bedding mixtures or the solids from solids-liquid separators having a dry matter content of 20% or more, can be scraped and stacked on flat concrete. To ease management and increase the storage capacity walls should be constructed on 3 sides of the compound and may be of timber or concrete.

Concrete walls can be formed in reinforced concrete blockwork or with reinforced mass concrete, as shown in Figure 3.18. Using timber, the walls of the compound may be of panel construction, with vertical RSJ's set into a substantial concrete foundation (size according to site conditions) and timber members fitting into the web of the RSJ.

In practice the walls may be up to a maximum of 2 m high and must be strong enough to contain the wastes and withstand the action of tractor-driven equipment pushing against them. With 2 m high retaining walls, it will be possible to store manures up to a height of about 3 m.

The concrete base, which should be strong enough to withstand the weight of fully laden trailers and tractor loading operations, should slope towards the open end with a minimum fall of 1 in 100.

Rainfall/effluent draining from the manure will be collected in the cross channel set at the entrance of the store. Care should be taken to ensure that the channel is kept free of solids - the channel should be wide enough to allow a shovel to be quickly run along it to clear solids after scraping/loading operations. If a compound covers a particularly large area, additional drainage may be provided by a channel, with grating, laid down the centre. The concrete floor, as well as sloping towards the entry of the compound should be laid with a gentle slope towards the central channel.

In a well-managed system, the effluent draining from the store will be controlled by one of the following methods:

- With the consent of the Regional Water Board, it may be possible to discharge the drain to a blind ditch or soakaway.
- The effluent may be run into the farm effluent system e.g. anaerobic lagoon.
- The effluent may need to be collected in a below-ground tank before land disposal.
- An overland flow system may be used to treat the effluent.

Timber Sleeper Slurry Compound (Figure 3.19)

The timber sleeper compound already described may be adapted slightly for the storage of semi-solid/slurry. The principle of the store is to retain the solids, while excess liquids and rainfall are allowed to drain away through the walls. The aim is to be able to retain the entire solid waste output for the full wintering/housing period, and long enough for the waste to dry out sufficiently to be handled entirely as a solid manure.

The construction details of this store are similar to those of the timber-walled compound for solids but the floor should be a level concrete pad and the compound will be fully enclosed. The timber sleepers are set apart by spacers so that excess liquor is allowed to drain through gaps of 25-30 mm. The concrete base should be extended all the way around outside the sleeper walls, to accommodate a collection channel, which will allow the liquids draining from the store to run to a holding tank.
LEVEL CONCRETE FLOOR

SECTION

EFFLUENT CHANNEL PIPED UNDER RAMP

BELOW GROUND EFFLUENT STORE

TIMBER SLEEPER WALLS

RAMP UP

ACCESS FOR UNLOADING

PLAN

STEEL COLUMN

25–30 mm GAP BETWEEN SLEEPERS

DETAIL AT CORNER

BLOCKING PIECE

FIGURE 3.19 TIMBER SLEEPER SLURRY COMPOUND
(ADAPTED FROM MAFF, 1980)
collection channel should be about 300 mm in width, i.e. wide enough to allow easy cleaning by shovel and, with a fall of 1:100 towards the holding tank.

If it can be avoided, stock should not be allowed direct access to the sides of the store, e.g. adjacent to collecting yard, since the drainage channel will tend to fill up rapidly with solids and stones and need frequent clearing.

Wall height should not exceed 2 m and the depth of slurry should be limited to not more than 1.7 m, with an allowance of 0.3 m freeboard.

Loading of the store may be by slurry elevator or tractor scraper. In some cases yard levels allow direct filling over one side of the compound. Construction details for the ramp are given later (see Figure 3.24).

Once the slurry has been allowed to dry out the sleepers can be removed from one or more sections of the wall to allow access to the store for unloading.

Prefabricated Concrete Panelled Slurry Storage (Figure 3.20)

A very similar storage facility, incorporating the same principle of solids/liquid separation over an extended period, may be built using prefabricated concrete panels, instead of timber sleepers. This type of store is becoming increasingly popular with U.K. dairy farmers. Although not yet manufactured in N.Z., it is possible that farmers may be willing and able to make the panels and build such a store themselves.

The store walls are made up of pre-cast concrete modules, about 300 mm wide, vertically orientated and set in a purpose-built concrete base and supported by a steel framework. The walls can be up to 2.5 m high and the panels spaced about 20 mm apart, the grooved edges forming a self-cleaning gap which allows effluent and rainfall to drain to a concrete collecting channel, outside the walls. Drainage is from the full depth of the manure and appears to be more efficient than from timber sleeper walls, which are horizontally orientated. Recent experience, however, has suggested that, to minimise the build up of manure around the loading ramp, the bottom 150 mm of the wall should be sealed. This will ensure that a shallow depth of liquid remains on which solid material can slide away from the ramp after loading. It may also help to have a few closely butted panels near the entry point, preventing too much drainage from the manure in this area.

Loading of the store is via a ramp, unless yard levels allow direct filling over the side. Emptying is by tractor access into the compound, after removal of panels, at a convenient point.

Experience (MAFF, 1980) has indicated that about 10% of the volume of slurry entering this type of store (timber or concrete construction), in addition to rainfall incident upon the store surface, will drain off over an extended storage period. At the end of this time, the manure may have lost nearly a third of its volume by drainage and evaporation and will be a stackable solid, which can be excavated and loaded into solids spreaders.

Straw Bale Compound (Figure 3.21)

A simple, cheap compound may be rapidly constructed with high density straw bales. The bales are laid 3 deep x 4 high with a vertical barrier of empty plastic fertilizer bags or paper feed sacks. Loose straw or broken bales are shaken out to provide a layer of straw about 0.3 m deep over the floor.
FIGURE 3.20. CONCRETE PANELLED SLURRY COMPOUND
of the compound. The compound is gradually (i.e. on a little and often basis) filled with slurry, the slurry eventually forming its own seal in the straw. The paper/plastic sacks will help to restrict lateral seepage in the early stages and the sealing process will be assisted by ensuring that the compound is first loaded with slurry or sludge of a fairly thick consistency and, preferably, of at least 10% dry matter content. Once filled, the contents are allowed to dry out over an extended period by evaporation and some drainage, leaving a solid manure which may be cleared and spread using conventional solids handling equipment. Before emptying, the straw walls may be burnt, or, it may be possible to re-use the compound, after minor repairs, if it has been emptied with care.

In cases where more dilute slurries are produced, more than one compound may be built, loading them alternately to avoid flooding with large amounts of dilute liquid slurry. Some loose straw may be added to the compound, with the waste, but large quantities will reduce the compound capacity. Dakers (1977) reported that, where the system had been observed in New Zealand, diluted piggery wastes had been discharged into compounds without regular straw addition, resulting in significant quantities of leakage. Straw bale compounds are NOT SUITABLE for very DILUTE WASTES.

Siting of the compound should be well away from streams or ditches known to harbour vermin e.g. rats, which may burrow through the walls resulting in leakage and possible collapse. The site should also, if possible, be perfectly flat since even a slight slope will result, if the compound is filled rapidly, in a collapse in the lowest corner. Extra support and stability can be given to the compound by the erection of a low galvanised netting fence, immediately around the walls of the compound, or by making a shallow earth bank. Bales tied with poly-propylene string will last better than those tied with ordinary baler twine which tends to rot and break leading to collapse of the walls. If built 4 bales high (about 2 m), construction of the walls will require approximately 12 bales per metre length so a compound of internal measurements 30 m by 10 m needs about 1000 bales or approximately 20 tonnes of straw.

Straw bale compounds are limited in height because of lateral hydraulic pressure on the walls and are mainly used as a temporary storage facility or as a stop-gap measure in an emergency.

Prefabricated Above-ground Circular tanks (Figure 3.22)

Specially designed and constructed above-ground storage tanks are now commercially available in many countries. These tanks are essentially an adaptation of tower silo components to form cylindrical tanks. All types of silo, whether of sheet steel coated with vitreous enamel, galvanised steel, steel and epoxy resin coating, or of concrete stave construction, can be adapted for this purpose. In New Zealand, such tanks are already utilised, with suitable joint sealant, for the storage of water and these could also be used for the storage of slurries, in the right situation.

The stores are designed as a complete containment for slurries or separated liquids. A circular or rectangular concrete or enamelled steel collection sump will normally be required. Size of the sump will vary, according to requirements, but will often be large enough to accommodate 3 or 4 days effluent and may be 2-3 m deep. The waste must be suitable for pumping (no more than 8-10% total solids) and, with dairy cows, a chopper pump is usually installed to ensure that bedding and fodder are well broken down before entering the store.

The slurry is scraped over the metal grill and falls through into the sump where it is pumped into the top of the large storage tank. Thicker solids,
FIGURE 3.21. STRAW BALE COMPOUND

LEVEL FLOOR OF COMPOUND LINED WITH LOOSE STRAW
LINE OF SACKS

PAPER/PLASTIC SACKS

CONSTRUCTION OF WALL

FIGURE 3.21. STRAW BALE COMPOUND
SECTION

PLAN

FIGURE 3.22. PREFABRICATED ABOVE-GROUND TANK
(ADAPTED FROM MAFF, 1980)
long straw etc. are retained by the grid over the sump. The system is often combined with a concrete pad for the storage of solids.

Effluent and rainfall runoff from the solid manure storage pad can be arranged to drain towards the slurry reception pit. Another filling method, commonly used in the USA for beef and pigs, is to use an automatic scraper under slats, scraping directly to the sump.

The slurry reception pit, in addition to the filling operation, is used to receive the output from the tank during recirculation and mixing operations, and for pumping into tankers or direct to land through spraylines. One of the major problems of this system is the separation of slurry contents in store and the resultant crust formation. Regular circulation and agitation is necessary to prevent serious difficulties. (See "Sumps and mixing", later in this chapter).

This system permits a high degree of mechanisation and eliminates seepage losses of plant nutrients from slurries during storage. The system can also present a tidy appearance.

Drawbacks include high initial capital cost and problems which occur if management is neglected.

An ADAS Farm Mechanisation Study (MAFF, 1979) on above-ground storage facilities, prompted by the nature and frequency of problems that have occurred in the past, listed, in its conclusions, a number of management recommendations. These have been summarised in the following advisory guidelines:-

• Planning

Adequate storage capacity: for minimum storage period including water and drainage water. Possible expansion of the livestock unit should be allowed for.

Reception pit: should be sized for a minimum of 2 days input of slurry to allow for weekend working and pump maintenance.

Solids storage: a concrete pad for the collection and storage of solids should be provided adjacent to the reception pit.

Agitation techniques: should be considered at the design stage. If 'jetting' techniques are used the diameter of the store may be limited. Stores above 13.5 m diameter may require provision for jetting from opposite sides. Pig slurries, which are particularly subject to sedimentation, require agitation at a low level - this may be achieved by P.T.O. driven propeller in the side of the tank or by multiple jetting outlets to the full depth of the tank. A large diameter, shallow tank should be avoided since agitation/recirculation is more difficult. Various methods of mixing and agitation are discussed in a later section in this chapter.

Inspection: a good access ladder and working platform will allow regular inspection and safe working conditions when operating on the store from above.

• Management

Filling: attempt to prevent waste feed and fibre from entering the store; foreign objects e.g. wood, bricks, wire, plastic bags, should be kept out of the store.
Inspection and agitation: the store should be inspected regularly and contents agitated at the first signs of crust formation. Regular agitation probably 1-2 hours weekly, may be required to prevent crust formation.

Emptying: slurry should be thoroughly homogenised before emptying; ensure that the store is completely emptied at least once a year.

BELOW-GROUND STORAGE

In general, manures contained in below ground storage will be managed as liquids rather than solids. The use of picket dam structures or strainer boxes, however, will allow the removal of excess liquid, leaving a solid manure residue.

For liquid slurries, most below-ground stores can be filled by gravity, possibly their main advantage.

Earth-banked Slurry Compound

Enclosed compounds (Figure 3.23)

In its simplest form, a storage pond is a relatively inexpensive structure, and can be constructed by excavating a basin in the ground, using the spoil to construct raised banks. The pond depth should be related to site conditions e.g. rock substrata or high water table, and the batter on the sides will normally be 2 horizontal to 1 vertical, similar to that for treatment lagoons in most soils. Clay or other impervious soils are most suited but, where there is any doubt about seepage and possible contamination of watercourses or underground aquifers, ponds should be lined e.g. with clay or butyl rubber sheet. Earth-banked compounds are not generally suitable for use in high water table situations.

Recommended construction techniques are the same as for treatment lagoons and are considered in that section (Chapter 5). Some of the construction details may depend on the intended management and the methods of filling and emptying.

Filling of the compound will usually be by piped inlet or by loading ramp for the thicker slurries. The piped inlet may be above or below the surface. A below-surface inlet can be useful if there is restricted fall between source and storage and if there is any risk of pipes freezing in the winter. Because the velocity of liquid flow in an inlet reduces considerably at the waterline, solids will settle and a below-surface inlet may block. This can be avoided by batch loading, pumping under pressure, or by allowing for easy cleaning of the pipe. (See 'Piping to lagoons' in Chapter 5). Loading from below the surface can also reduce fly and odour problems particularly if a crust forms.

For details of a typical loading ramp design see Figure 3.24. An incline of 1:7.5 is practical for most tractors or, with increased risk of wheelslip, up to 1:5. A safety restraining rail and protective fencing of strong construction will be required to prevent the tractor overshooting the ramp.

Emptying of the compound can be by pumping to slurry tanker or spray system. An area around the draw-off point may be concreted in order to prevent erosion of the banks or fouling of the pump with stones. A concrete apron should also be provided, adjacent to this point, to provide access and a firm platform for the slurry tanker and agitation and pumping operations. Slurry of a thicker consistency, however, may necessitate removal by solids handling equipment working from the bank. In the latter
FIGURE 3.23. EARTH BANKED SLURRY COMPOUND — ENCLOSED
(ADAPTED FROM MAFF, 1980)
CONCRETE WITH REINFORCING MESH

CHILDPROOF GATE

COMPACTED FILL

CONCRETE FOUNDATION — SIZE ACCORDING TO SITE CONDITIONS

SECTION

RAMP UP

WIDTH TO SUIT SCRAPER BLADE

PLAN

CONCRETE BLOCK KERB

ELEVATION

FIGURE 3.24. MANURE LOADING RAMP
(ADAPTED FROM MAFF, 1980)
case, the size of excavator used will have an influence on size of the compound, since the reach of even large machines is limited to a maximum of about 9 m (see Figure 3.25). Such excavators are usually contractors’ machines and it may be worthwhile finding out what machines are available locally, before finally designing the compound. Dragline excavators have a much greater reach.

For large ponds an entry ramp and concrete floor might be necessary to allow machinery access for complete emptying of the store.

Detailed calculation of the volume is discussed under 'anaerobic lagoons' and storage volumes can be calculated using the techniques given in that section.

• Open-ended compounds (Figure 3.26)

In some cases, e.g. where it is not possible to excavate a long narrow store, it may be more convenient to construct a drive-in earth basin of the type illustrated in Figure 3.26. Here the compound is emptied by machinery entering at the open end and may be loaded in the same way, or by a loading ramp at the lower end of the store.

Design details are similar to the enclosed compound but with no machinery access required on the banks width can be restricted to 2 m at the top.

Maximum store depth will usually be 3 m, depending on soil type and site conditions and so larger stores will require an extended flat base at the bottom of the sloping access ramp (max. gradient 1:8). Both the access ramp and the base should be of concrete, 100 mm thick over 150 mm compacted fill base. The concrete should be textured or roughened on the ramp to provide extra wheel grip.

• Drainage of compounds by picket dam facility (Figures 3.27 and 3.28)

Manure may be managed as a solid in an earth-banked compound, using a picket dam or strainer box structure. The natural separation processes of crust formation and sludge settlement within the slurry store will result in a central liquid layer from which much of the surplus liquid may be removed by drainage.

Strainer boxes will hold back solid matter and allow the liquids to pass through to be removed by pump or gravity drainage. The device may consist of a reinforcing steel mesh or perforated metal tower, about 0.5 m in diameter and about 2 m high, or a substantially built wooden picket dam. The mesh tower or picket may be covered with heavy duty plastic netting with apertures or perforations of about 6 mm. The need for this extra cladding will depend on the nature of the manure.

The picket dam is built with pressure-treated timber and railway sleepers or posts set in concrete. Vertical palings or planks are nailed to the supporting rails separated by roughly 20 mm to 25 mm gaps. Experience has shown that vertical slots drain more freely than horizontal slots.

The strainer box or picket dam will need to be located at the lowest point in the store, so that most of the liquid can be removed. This may be either at the opposite end of the compound to the loading ramp, allowing continuous gravity drainage of the manure, or else near the loading ramp (but not directly in front of it). Water will run off accumulated manure to the sidewall and along the edge, to the low point. A strainer box structure located away from the edge of the storage has been found not to work as well as one at the sidewalk. Where the structure is sited adjacent
FIGURE 3.25. BANK EMPTYING OF SLURRY COMPOUND
(ADAPTED FROM MAFF, 1980)
FIGURE 3.26. EARTH-BANKED SLURRY COMPOUND — OPEN-ENDED
(ADAPTED FROM MAFF, 1980)
FIGURE 3.27. TIMBER PICKET DAM STRUCTURE
(ADAPTED FROM MAFF, 1980)
FIGURE 3.28. STEEL MESH STRAINER BOX
(ADAPTED FROM MAFF, 1989)
to the loading ramp a liquid level of at least 0.5 m should be maintained within it to ensure even filling from the ramp. Complete removal of the liquid should be carried out a day or two before the store is due to be emptied.

The liquid removed from the store is a strong effluent and should preferably be utilised by spreading on land. The effluent must not be discharged to a watercourse without further treatment.

• Solids Storage Ditch with Effluent Drainage (Figure 3.29)

One below-ground storage system which has been observed in New Zealand, adjacent to winter feeding pads, consists of a long trench into which the manure is scraped, with any liquid effluent draining into the dairy waste treatment lagoon.

The system is similar to an earth-banked slurry compound with strainer box drainage going directly to the anaerobic lagoon. In examples observed, the levels have allowed them to be filled by direct scraping over the edge of the concrete pad. The system may be improved by providing reinforced concrete or earth bank retaining walls, up to a maximum of 2 m high, with a picket dam facility, through which liquids will drain to a concrete collecting channel. Access, for solids removal, is by ramp at the far end of the compound. The end wall of the trench should be of reinforced concrete or a substantial earth bank, able to withstand the force of tractor driven equipment working against it.

There will be many cases where levels will not allow the solids storage ditch to be accommodated between the concrete wintering pad and the anaerobic lagoon. Where this is not possible, similar results may be achieved by means of above ground timber sleeper or concrete panelled storage, as described earlier.

**Below-ground Concrete Tanks** (Figure 3.30)

Tanks may be constructed with reinforced concrete or concrete block walls. The volume of this kind of storage facility will be limited and the costs are high.

Depth rarely exceeds 3 m and width will depend on whether the store is covered or left open. Covered stores may be wider but will need to be surrounded with a safety fence to protect children and livestock. Length will not usually exceed 10 m unless the tank is divided with cross walls into separate compartments. Internally, walls should be sealed with plaster or cement, and in wet ground, the exterior of the walls should be damp-proofed to restrict water penetration.

When tanks are empty, water pressure can break base slabs unless these are properly reinforced and tied into walls or unless the site is drained. In a high water table situation, as soon as possible after construction, slurry or some water should be added to the tank to counteract uplift caused by the water table.

The stores are filled either by tractor or mechanical scraper over a grid, or by pipeline. Emptying is by pumping, following mixing/agitation of the contents. (See section on mixing and agitation later in this chapter).
FIGURE 3.29. SOLIDS STORAGE DITCH WITH EFFLUENT DRAINAGE
**In situ Storage Within Buildings** (Figures 3.31 and 3.32)

In some slatted floor systems, slurry is removed at regular intervals to separate storage outside the building, whilst in others, below-slat pits provide some storage capacity.

In New Zealand, interest in the use of storage below slatted or perforated floors is principally restricted to pigs and poultry.

Below-floor storage of slurry has the advantage of being in situ and may eliminate the need for double handling of wastes between production and final disposal on land.

A slurry storage pit, which may be used under cow cubicle passageways or slatted pig accommodation, is shown in Figure 3.31. The pit is built of reinforced concrete blockwork or in situ reinforced concrete walls on a concrete base. Width and depth of the pit are variable but, usually, depth will not be in excess of 1.5 - 1.7 m. In practice, overall tank dimensions
FIGURE 3.31. SLURRY STORAGE PIT BELOW SLATS

FIGURE 3.32. ACCESS TO STORAGE PIT
are unlimited if floor supports (beams, columns) and partitions are used. Columns and beams are commonly spaced 2.5 - 3.5 m apart. Agitation is usually effective up to about 12 m and agitation access ports should be provided accordingly. Pit floors are usually laid level, both in cross section and in longitudinal section, to assist in slurry movement and to reduce the risk of solids sticking to the floor. The pit may be flooded with water to a depth of about 150 mm, prior to stocking. This is important when effluent is to be sluiced from the pit. Since it is essential that the effluent can be handled entirely as a liquid, the use of bedding should be avoided or kept to a minimum. Shavings or sawdust are preferable to straw.

An internal plaster or cement seal is sometimes used but the slurry may itself form an effective seal. When ground conditions are wet, external water can penetrate, reducing storage capacity and an external cement seal may be helpful in preventing this.

Provision must be made for direct removal of waste from the pit and access for pump or vacuum tanker intake allowed. This may be done by means of an access pipe through the wall of the dung pit or by an external chamber, linked with the storage pit which acts as a draw-off point (Figure 3.32).

Access to the pit can be effected by the removal of slats but the slurry tanker should not be taken into the building since it is possible that the slats would not be able to withstand the weight, when fully loaded. An alternative is to arrange a series of sluice gates to control the movement of the slurry to an external below ground tank which provides additional storage and easy access.

The storage of poultry waste may be arranged below floor in specialised 'deep pit' or 'high rise' buildings. The lower storey of the house is for storage of manure only and droppings, from the tiered cages above, are collected on the floor and allowed to dry, assisted by ventilation air. The waste is handled as a solid and removed by means of tractor frontloader. Often, up to 2-3 years of manure can be accommodated in these buildings.

**Storage in Waste Treatment Lagoons**

Some provision for the storage of wastes may be made in lagoon treatment systems. It is suggested that up to 1/3 of the treatment volume of an anaerobic lagoon might be used as storage volume for wastes and stormwater runoff (see section on anaerobic lagoons in Chapter 5).

**SAFETY ASPECTS OF WASTE STORAGE**

In common with all other on-farm developments, careful consideration must be given to safety aspects during all stages of the planning, design and construction of a wastes storage system.

**HEALTH RISK**

Well-designed and well-managed storage has been shown to have a significant effect on the death of pathogenic micro-organisms in wastes and therefore will reduce the health risks associated with handling and land spreading practices. However, it has also been emphasised that poor storage conditions can lead to problems with vermin and with flies and, therefore, possible increased health risk.
FENCING/COVERING OF STORAGE FACILITIES

All below-ground manure storage should be covered or surrounded by a safety fence to protect children and livestock. The fence should be sited so as to allow adequate access to machinery.

Where store covers are used, these should be of substantial construction, e.g. concrete slabs or timber sleepers joined together in sections, so that unnecessary removal is discouraged. Grills and covers should be sized so that they cannot fall into the tank. Some tank covers are strong enough to drive on, while others are relatively weak. A vertical distance from the ground to the cover lid of about 450 mm should be adequate to discourage all traffic.

For semi-solid and liquid manure stores a childproof gate should be provided to prevent access to the loading ramp. The need for a safety restraining rail at the top of the ramp and protective fencing up the ramp sides has already been mentioned.

MANURE GAS HAZARDS

The partial microbial decomposition of wastes during anaerobic storage results in the production of obnoxious odours and toxic gases e.g. ammonia, hydrogen sulphide. These gases will remain largely in solution while wastes are undisturbed but are rapidly released during any pumping, agitation or mixing operation. The hazard from gases is particularly marked with enclosed, below-ground storage tanks and pits, where concentrations of carbon dioxide and hydrogen sulphide, both heavier than air, can quickly build up to very high levels with, possibly, fatal results. The concentration of gases can be greatly increased if silage effluent is allowed to reach the stored manure prior to agitation. Several incidents involving death of stock by manure gas poisoning have been reported e.g. (USA) Merkel et al (1969), (UK) Blaxland et al (1978) and tragedies involving human deaths have also occurred. In many recorded cases, the manure was being agitated at the time the deaths occurred and the ventilation was assessed as being inadequate. Hydrogen sulphide is a highly toxic gas and even exposure to sublethal levels, followed by apparent recovery, can be dangerous. Taiganides and White (1969) reported that animals which have been exposed to hydrogen sulphide may become more susceptible to pneumonia and other respiratory diseases.

The hazard from manure gases to livestock and humans may be limited by observing the following precautions:

- Avoid unnecessary agitation of slurry
- Avoid overfilling of pits and storage channels below slats
- Livestock buildings should have an adequate ventilation system which should be maintained in efficient working order at all times.
- Provide an alarm system to warn of power failures in totally enclosed buildings.
- Exhaust some ventilation air from above stored slurries. Even a low volume continuous fan, pulling air from above a tank, will reduce the accumulation of heavy gases, at animal level.
- Provide maximum ventilation, including opening all doors, when agitating or pumping waste from a below-floor pit.
- Inspect stock during agitation or emptying of manure from below-floor storage or, if possible, remove stock from the building.
- Avoid standing over manure tanks during emptying.
- NEVER ENTER AN ENCLOSED TANK DURING EMPTYING.
• A PIT SHOULD ONLY BE ENTERED IF IT HAS BEEN WELL VENTILATED, AND, EVEN THEN, ONLY WITH AN AIR LINE AND SAFETY HARNESS, AND WITH AT LEAST TWO ASSISTANTS STANDING BY.

• Gas traps in pipes leading to outside storage tanks will prevent gases from moving into the livestock building.

• No smoking or flames in the vicinity of slurry storage tanks. Methane gas can collect in the air space in covered stores with only manhole opening, creating explosive conditions.

waste handling and transport

INTRODUCTION

The behaviour of the manure when being handled will depend primarily on the ratio of solids to water, and to a less significant extent on properties such as the particle size and shape, temperature of the liquid, dissolved chemicals and so on.

The solid/liquid ratio is nearly always expressed as the total solids (T.S.). This is usually expressed as the percentage of solids on a wet basis, or sometimes as mg/l.

where

\[ T.S.\% = \frac{D.S.}{W} \times 100 \]

and D.S. = mass of dry solids

\[ W \] = mass of wet manure sample

\[ T.S.\% \times 10^4 = T.S.\ mg/l \ (approx.) \]

For example a typical T.S. value for freshly voided dairy cow faeces would be 6 to 8 percent while the T.S. of washdown water from a hosed farm dairy is generally of the order of 0.5% to 1.0%.

Table 3.10 suggests handling methods for livestock manure in relation to the solids concentration.

TABLE 3.10 HANDLING METHODS

<table>
<thead>
<tr>
<th>TOTAL SOLIDS (%)</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
<th>30</th>
<th>35</th>
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</thead>
<tbody>
<tr>
<td>LIQUID</td>
<td></td>
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<td>PUMP &amp; PIPING</td>
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<tr>
<td>SEMI-LIQUID</td>
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<td></td>
<td></td>
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<tr>
<td>AUGER</td>
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<td></td>
</tr>
<tr>
<td>SEMI-SOLID</td>
<td></td>
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<td></td>
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<tr>
<td>TRACTOR SCRAPER/LOADER</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>SOLIDS</td>
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<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>TANKER</td>
<td></td>
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<td></td>
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<tr>
<td>MUCK SPREADER</td>
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<tr>
<td>SPRINKLER</td>
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</tr>
</tbody>
</table>
PUMPING LIQUID MANURE

Liquid manure is a complex and unpredictable material to pump. Consequently, pumps need to be chosen and operated to minimise the problems that might arise. It is quite likely that a pump will break down sometime during its operating life. It is therefore wise to make provision for breakdown, either by installing a standby pump or incorporating some other approved system of waste handling (e.g. storage of overflow) for use in case of failure.

Liquid manures with total solids concentrations of up to 10% can be pumped satisfactorily with centrifugal and helical pumps which are specifically designed to do so. Up to 4% T.S., the hydraulic performance of the pump is similar to its clean-water performance. Above 4% T.S. the performance deteriorates as T.S. increase.

TYPES OF PUMPS

The most commonly used pumps for liquid manure are the centrifugal and helical rotor pumps. The helical rotor pump, being a positive displacement pump, is generally a low flow, high head pump. The centrifugal pumps used for liquid manure generally develop lower total effective heads than similar clean-water pumps due to larger clearances.

Centrifugal Pumps

There are different types of centrifugal pump, according to the design of impeller and arrangement of components. Figure 3.33 illustrates some of the different types of impellers. In order to prevent blockages, open and semi-closed impellers are generally used for liquid manure pumps. The hydraulic characteristics will depend on the type and design of impeller. For example, impellers with less pitch have flatter head/discharge curves making the pump sensitive to changes in pressure and more susceptible to overloading.

Generally a centrifugal pump designed for clean water will be more efficient, in terms of energy, than a manure pump with larger clearances. Efficiencies as high as 80% have been achieved for clean-water pumps while for manure pumps, 40% would be considered high.

A common impeller arrangement is illustrated in Figure 3.34. An alternative impeller arrangement is the free flow or vortex pump. As illustrated in Figure 3.35, the impeller is offset from the main body of the pump leaving the passage between suction and discharge free.

The centrifugal pump is discussed in more detail in the following section on 'pump selection'.

Positive Displacement Pumps

The different types of positive displacement pumps are the piston pump, diaphragm, screw (or helical rotor), lobe and peristaltic pumps. The diaphragm and helical rotor pumps are illustrated in Figure 3.36. Most commonly used for pumping manure is the helical rotor pump. The other types are not satisfactory because of cost or excessive mechanical wear or failure.

The HELICAL ROTOR pump consists essentially of a resilient stator in the form of a double internal helix and a single helical rotor. This rotor maintains a constant seal across the stator, and the seal travels continuously through the pump giving uniform positive displacement. Like
all positive displacement pumps, the helical rotor is self priming and has the added advantage of being non-pulsating.

The main disadvantage with these pumps is wear of the stator under very abrasive conditions. This causes loss of performance. For this reason, components should be made from high quality material. Generally for manure, the rotor is made of stainless or alloy steel and the stator is made of very high quality natural or synthetic rubber. The wear rate can be reduced by reducing rotor speed and it is undesirable for rotor speed to exceed 600 rpm for the pumping of animal manure.

The significant advantage with these pumps is the high pressure that can be achieved. This is often necessary for spray irrigation systems. Because they are positive displacement it is considered advisable to install pressure relief valves with such pumps as a safety precaution against blockage in the delivery line.

**Air-lift Pump**

Air-lift pumping is another method of lifting a solid/liquid mixture. It is more commonly used for the lifting of dirty water from boreholes and is also extensively used to raise oil from deep bores and to pump corrosive chemicals.

The pumping effect arises from the interaction between fluids of different densities. Air is pumped into the rising main through an ejector, creating within the rising main a liquid/air mixture of lower density than the surrounding liquid thus forcing the mixture up the rising main. Figure 3.37 illustrates a simple layout for the air-lift pump. The main disadvantages with this system are:

- Low efficiency
- The discharge head is low and is dependent on the depth over the ejector (Figure 3.37)
- Rising main needs to be vertical
- Compressors generally expensive

Because of these disadvantages, the air-lift pump is not commonly used. The main advantage would be low maintenance and trouble-free pumping due to no mechanical moving parts in contact with effluent.
FIGURE 3.34 CENTRIFUGAL PUMP

FIGURE 3.35 FREE FLOW CENTRIFUGAL
FIGURE 3.36 POSITIVE DISPLACEMENT PUMPS
The design of air-lift pumps is quite involved and the details are beyond the scope of this manual. The reader is referred to Dakers (1975) for further design detail.

Jet Pump

The jet pump transfers the energy from a high velocity jet to a low velocity flow pattern. Fluid at a high pressure supplies energy to a fluid at a lower pressure so as to deliver the total flow at some intermediate pressure. This transfer of momentum is achieved by converting the energy of the driving fluid into velocity form by a nozzle and then by turbulent mixing with the driven fluid in a mixing chamber. (See Figure 3.38). A diffuser is generally added down-stream of the mixing chamber or throat, to convert most of the velocity head to pressure head. Although this is not an essential part of the pump, its presence significantly improves its efficiency.

The jet pump is an inefficient method of pumping with respect to energy conversion. It is capable only of low discharge pressures (insufficient for sprinkler operation) and has the disadvantage of requiring a water supply for the driving line. By necessity, the medium being pumped will be diluted. This may be a further disadvantage.

The jet pump is not commonly used for pumping farm wastes, particularly in N.Z., and therefore there is little practical relevant information available. The method has the obvious advantage of no mechanical moving parts in contact with the waste. It could well be a sensible technique for transferring waste from a sump to a pond system and recycling the pond effluent for use as the driving liquid.

The design and selection of jet pumps is a specialised topic beyond the scope of this manual.
PUMP SELECTION

In selecting a pump, both the hydraulic and mechanical characteristics need evaluating. Often a compromise between the two criteria must be made, particularly if there is a limited range of pumps available.

Generally the pump is required to pump at a specified flow rate and at a specific pressure head with minimum energy consumed. At the same time the pump should be reliable. Often in the case of manure pumps, efficiency, (i.e. ratio of water power output to mechanical power input), is sacrificed for reliability. Of more interest to the farmer is a pump that is not prone to blockages, and bearing or seal failures, than a pump that will save him a few dollars a year in power costs.

Hydraulic Performance

A particular pump's hydraulic characteristics should be provided by the manufacturer, usually in graphical or tabular form. For a given impeller diameter and speed, these characteristics should show the relationship of pump total head, power consumed and energy efficiency with pump discharge rate. It is then a matter of selecting a pump which will give the required pumping head and flow rate, at an acceptable efficiency.

Many of the following terms are illustrated in Figure 3.39. The PUMP TOTAL HEAD ($H_T$) is the difference between total head at the discharge flange ($H_D$) and the total head at the suction flange ($H_S$) of the pump. In equation form then;
FIGURE 3.39 SIMPLIFIED DIAGRAM SHOWING PRESSURE HEAD TERMS
(VELOCITY HEAD AND FRICTION LOSS IN SUCTION LINE IGNORED)

\[ H_T = H_D - H_S \]

and \( H_S \) may be positive or negative.

If a datum is taken through the pump's centre line, then in most cases \( H_S \) is negative when the water level at the suction inlet is below this datum and is positive when above.

The various pressurehead terms \( (H_T, H_S \) and \( H_D) \) are generally expressed as metres head water gauge and usually abbreviated to metres.

Also:

1 m water gauge = 9.8 kPa (kilo pascal)

As an example, let a pump be sited 2 m above the water level in a sump. \( (H_S = -2 \text{m if velocity head and friction head are negligible}) \) and it is required to pump to a total discharge head \( (H_D) \) of 30 m. Then

\[ H_T = H_D - H_S \]

\[ = 30 - (-2) \]

\[ = 32 \text{ m} \]

or \( 32 \times 9.8 = 314 \text{ kPa} \)

The total discharge and suction head terms must include, by definition, static head, velocity head and friction head. VELOCITY HEAD \( (V^2/2g) \) is often small and is usually ignored. Friction head is the loss of pressure due to friction in pipes and fittings and is obtained from friction charts. STATIC HEAD is the sum of the required gauge pressure and any changes in ground elevation relative to the datum. For short suction lines, with low velocities, velocity head and friction loss are often very small.
In summary then, total discharge head \( H_D \) is that part of pump total head, after allowing for suction requirements, which is available at the discharge flange to overcome friction losses, elevation head and residual head (gauge pressure required at a point in the system), and ignoring velocity head.

If POWER INPUT data are given, these may either be the mechanical power input to the pump shaft or electrical power input to the pump's electric motor, as in the case where the motor is a standard component of the pump. This information should be clearly specified. The manufacturer's data should also clearly define the efficiency term given. EFFICIENCY, in this respect, is the ratio of power output from the pump to the power input and is generally expressed as a percentage. The power input term can either be the input to the pump shaft or the motor. In the latter case, the efficiency given will include the efficiency of the motor and the pump. The WATER POWER OUTPUT from the pump is a function of flow rate \( Q \), and pump total head \( H_T \), according to the equation;

\[
\text{Water power} = \gamma_w Q H_T
\]

Where \( \gamma_w \) = specific weight of the water.

Depending on units and for \( \gamma_w = 9.81 \text{ kN/m}^3 \), the water power equation becomes as follows;

<table>
<thead>
<tr>
<th>( Q )</th>
<th>( H_T )</th>
<th>Expression for Water Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>cumec</td>
<td>kPa</td>
<td>( Q \times \text{pressure in kPa} ) (kW)</td>
</tr>
<tr>
<td>cumec</td>
<td>m</td>
<td>( 9.81 \times Q H_T ) (kW)</td>
</tr>
<tr>
<td>l/sec</td>
<td>m</td>
<td>( 9.81 \times Q H_T ) (W)</td>
</tr>
<tr>
<td>m/\text{h}</td>
<td>m</td>
<td>( 2.72 \times Q H_T ) (W)</td>
</tr>
<tr>
<td>l/min</td>
<td>m</td>
<td>( 0.164 \times Q H_T ) (W)</td>
</tr>
</tbody>
</table>

**EXAMPLE 3.4** If the pump total head is 40 m, flow rate is 15 m\(^3\)/h, pump efficiency is 30% and motor efficiency is 85% then;

\[
\text{Water power} = 2.72 \times 15 \times 40
\]
\[
= 1632 \text{ W}
\]
\[
= 1.63 \text{ kW}
\]

Mechanical power input to pump
\[
= \frac{1.63}{30} \times 100
\]
\[
= 5.43 \text{ kW}
\]

Electrical power input to motor
\[
= \frac{5.44}{85} \times 100
\]
\[
= 6.4 \text{ kW}
\]

A useful technique in establishing the actual operating point of a pump connected into a particular pipe system is known as the SYSTEM CURVE.
method. The head versus discharge relationship for the pipe system is estimated and plotted on the head versus discharge curve of the pump. The point of intersection of the two curves will be the actual operating point.

Finally it should be noted that for an impeller of given design, the hydraulic characteristics will depend on impeller speed \( (n, \text{ rpm}) \) and impeller diameter, \( D \), according to the following relationships:

\[
H_T \propto D^2 n^2 \\
Q \propto D^3 n \\
\text{Power} \propto D^5 n^3
\]

(Note \( \propto \) means "proportional to")

Therefore if \( n \) is doubled (and \( D \) unchanged), then \( H_T \) will increase 4-fold, \( Q \) will be doubled and power increased 8-fold.

**Pump Design Features**

The pump's ability to handle a solid-liquid mixture over a period of time without failure or undue wear is most important.

A manure pump can only be expected to handle certain types of solids in suspension. It cannot be expected to pump wire, syringes, sticks, etc without the risk of blockage or mechanical failure. For this reason some form of treatment prior to pumping, in the form of stone trap and screen or settling pond, is advisable. Stone traps and screens to remain effective must be properly designed, regularly maintained and cleaned.

The pump's ability to handle solids of a certain size will depend on the nature of the solids and the clearances within the pump or any obstructions such as sharp edges or awkward corners that a solid may encounter during its travel through the pump. A common form of blockage is when objects such as a stick or cow's toenail lodges in the pump and long straws become entangled around this obstacle. (Note Figure 3.40). Such blockages could be prevented with good pre-screening.

One method to reduce blockages is to macerate the solid component prior to pumping it. Some pumps have been fitted with cutter bars or macerating units on the pump inlet. Such pumps have been called "chopper pumps". Although less common in N.Z. they have been successfully used in USA particularly for manure containing straw. However, due to this additional macerating function they will draw additional power and might be susceptible to abrasive sediments.

In assessing a pump's tendency to block, examine the path taken by the manure through the pump. This should be simple, smooth and unimpeded.

Performance characteristics given with a pump will be for a new pump, pumping clean water. For some pumps it has been found that the hydraulic performance is significantly reduced after a period of manure pumping. This is a result of mechanical wear on seals and working faces. A pump with good quality seals and hardened working faces will be more reliable in this respect.

A lot of manures contain very fine abrasive materials such as silt, sand and pumice. Sand may be removed by a sand trap. However, it is not practicable to remove the finer particles in suspension. Therefore a pump must be designed to withstand these abrasive materials.
Pump Seals

The component most subject to wear is seals. Failure of seals can cause contamination of bearings and consequent bearing failure and pump leakages which may result in reduced pump performance.

There are three main types of seals:

- Packed gland seals with soft packing requiring a slight leakage of liquid for cooling and lubrications. This type of seal is used in clean water pumps and is not generally suitable for manure pumps.
- Hydrodynamic seals, where rotating vanes keep the shaft free from leakage. These are generally used for low pressure applications.
- Mechanical seals. There are a large number of types of mechanical seals. Commonly used are the simple rubber and the carbon seals which are inexpensive but prone to rapid wear under the harsh conditions experienced with manure pumping. The better type of seals use tungsten carbide and tungsten titanium carbide for the working faces. These are more expensive but longer wearing. Some pumps use these seals with a pressurised grease chamber. The pressurised grease lubricates, as well as preventing contamination by the fine manure particles.

Due to seal failure some of the cellar-type manure pumps have avoided manure contact with seals and bearings by using a suspended overhung shaft. These pumps have been quite successfully used in New Zealand.
Ease of Maintenance

It is most unlikely that within a realistic price, a manure pump can be built such that it requires no maintenance in terms of unblocking, replacing seals and so on, during its operating life. It is wise to use pumps for which spares are readily available. A pump which is easily accessible and easily dismantled makes the operator's task less unpleasant. Submerged or vertically mounted pumps should be easily lifted out. Simple and quick disassembly of the pump to enable clearing of blockages is as important as easy access to seals and bearings. Finally, any greasing or oiling points should be easily identified, accessible and free from potential contamination.

Pump and Motor Matching

Most manure pumps are driven by electric motors. An electric motor is designed for a given power output e.g. 3.7 kW (5 hp). This is defined as the RATED OUTPUT or POWER RATING and must be specified on the RATING PLATE which is fixed to the motor.

When operating at the rated power output, the power input to the motor will be greater due to energy losses within the motor. The maximum allowable power input to the motor is usually expressed in terms of the current input to the motor and this must also be specified on the rating plate. It is termed the RATED CURRENT in amps. Current input in excess of this will cause the motor to overheat. Some motors will have fitted a thermal overload switch which cuts out the motor when it is too hot. A further precaution commonly practised is to install current overload switch gear. This should be set to the rated current.

There are various types of duties for which a motor is designed. They have been specified by the British Standards Institute in BS 2163:1970, "Specification for the electrical performance of rotating electrical machines".

The most relevant duty-types are:

(a) Continuous running duty-type S.1. in which the motor is subject to continuous loading.
(b) Intermittent periodic duty-type S.3. where the motor is subject to intermittent loading.

In accordance with the duty type, the motor is given a specified CLASS OF RATING. These rating classes are defined in BS 2163:1970 and the two most relevant classes are:

1. Maximum continuous rating (MCR). The motor may be operated for an unlimited time at the rated power output.
2. Duty type rating (DTR). The motor may be operated at the rated power output for a specified proportion of the duty cycle of 10 minutes. For example, if rated as 40% DTR the motor can operate for four minutes at rated power followed by a six minute rest and de-energised period. If this motor is operating below rated power output it may run for a period longer than four minutes. The actual length of this period will depend on the current input and the time-rate of temperature rise for that particular motor. The rating class must be specified on the rating plate.

The pump will require a power input which is dependent on discharge rate and pump total head, according to relationships given previously in this section. A pump motor must therefore be capable of supplying sufficient
A. SUBMERSIBLE PUMP.

B. CELLAR — TYPE.

C. SELF-PRIMING. SURFACE MOUNTING.

FIGURE 3.41 TYPES OF PUMP INSTALLATIONS
power without being overloaded. For centrifugal pumps, the maximum power requirement is usually at open discharge. In practice, however, the pump is very rarely operated at open discharge, and smaller motors are fitted to reduce overall cost. In such cases motor overload protection is necessary in the event of say broken discharge pipes or sprinklers. Pump manufacturers should, in such cases, recommend a minimum operating head below which the motor will overload.

In summary, pump motor power or current requirements should be supplied by the manufacturer for various discharge rates. For the discharge required by the field application, the power or current input should be related to the rated power or current of the motor fitted to the pump. In addition the rating class, whether continuous or intermittent, of the motor must be applicable to the field application.

PUMP INSTALLATION

General Considerations

The way in which a pump is installed will depend on the type of pump. Submersible centrifugals can be installed directly in the sump as in Figure 3.41(a) while cellar-type pumps are mounted vertically as in Figure 3.41(b). Surface-mounted pumps should be firmly mounted on a concrete pad so as to be accessible for maintenance. Such pumps may be self-priming types as in Figure 3.41(c) or manually primed.

In planning pump installations a number of aspects should be considered.

• Easy access to the pump for removal or maintenance.
• Protection of pump motor against flooding and rain.
• Minimum cost of piping and fittings.
• Power supply.
• Provision for stone traps and screens.

Stone Traps

The wash down water from concrete surfaces contains solids such as sand, silt and stones which can cause problems in a pump, pipeline or sprinkler. Sand, silt and stones are brought in on cow hooves, for example, and it is very difficult to eliminate this source of contamination.

The system must therefore be designed and managed so as to cope with such material.

A stone trap is designed to reduce flow velocities to enable stones to settle out. Although there is no standard stone trap design, there are certain criteria to be met;

• the stone trap must precede the pump
• maximum water velocity in the stone trap should be less than 0.4 m/s.
• at least 24 hrs storage capacity for settled solids should be provided.
• needs to be accessible for regular cleaning and easy to clean e.g. design the width to at least the width of a square-mouthed shovel.
• should be constructed of permanent non-corrosive material (usually concrete).
• reasonable cost to construct.
FIGURE 3.42 SCREEN AND STONE TRAP
Figure 3.42 shows a possible stone trap in conjunction with a stationary bar screen.

Critical to their success is their management. Not only will stones settle out but also sand and silt. Depending on the amount of such material in the waste water, the stone traps can fill quite rapidly and when full of sediment, the stone trap is completely ineffective. It is normally recommended that the farmer establishes a daily cleaning routine. Also adequate provision should be made for the handling and final disposal of the solids that are regularly cleaned from the trap.

**Screens**

In this section the main concern is with screens suitable for removal of such solids that may cause damage or blockage within the pump or the pipe system downstream. Therefore these screens are generally coarse aperture screens designed to allow pumpable solids to pass through. These screens may be stationary or moving screens.

The **STATIONARY SCREENS** in the form of a wire mesh, mesh basket or parallel bar screen, have been most commonly adopted in New Zealand. The most suitable and easiest to clean is the parallel bar screen. Apertures between 15 mm and 25 mm are generally used. As with stone traps, it is important that these screens are easily and regularly cleared. A suggested bar screen system is illustrated in Figure 3.42. This system has 3 bar screen sections. This number might be increased or decreased to no less than two sections, depending on the quantity of solids to be handled. In this system, as the screen blocks the stream proceeds toward the next downstream section until all screens are blocked and the waste water is diverted to an overflow area which would immediately inspire the farmer to clean the screens. The screen and stone trap should be cleaned at the same time and preferably daily.

A self-cleaning screen, such as a vibrating screen, has the distinct advantage of being a low labour device and relatively foolproof. However capital and maintenance cost will be very high. A self-cleaning vibrating screen has been developed for this purpose by the NZAEI (Drysdale, 1978). This screen, as illustrated in Figure 3.43, has been designed for flows of up to 60 m³/hr and consumes up to 400 watts. The bar spacings can be as small as 3 mm, depending on requirements.

Screens designed for substantial removal of solids are discussed in Chapter 4.

**SUMPS AND MIXING**

**SUMP DESIGN**

**Purpose**

A sump is normally designed to perform one of the following functions.

- Waste collection for immediate pumping
- Waste collection and buffer storage for pumping
- Waste collection and medium term storage for eventual pumping or transporting

The sump is primarily a collection point of liquid waste from the various sources on the farm. If the manure is pumped immediately, with no storage capacity in the sump, then the pumping rate must at least equal the peak
inflow rate to the sump. In some situations, due to high peak inflow rates to the sump, it is more reasonable to install a pump of smaller capacity and to provide some buffer storage capacity in the sump to absorb the difference. Large storage capacity may be required if the manure is to be stored for an extended period prior to pumping or removal.

**Sump Capacity**

No storage: Sump capacity should be sufficient to enable the pump’s electric motor to run long enough to provide cooling and heat dissipation. This running time will depend on the standard of motor insulation. Four or five minutes running time is usually sufficient to dissipate start-up heat for most manure pump electric motors. If the peak inflow rate is $Q_I$, which is less than the pump rate $Q_P$, then the difference flow rate $(Q_P - Q_I)$ represents the rate at which the sump liquid volume is reducing. Generally the pump is turned on automatically when a probe senses the top water level in the sump and is turned off when a lower probe senses the lower water level. If the volume between the top probe (cut-in) and lower probe (cut-out) is $V$ then the pumping time ($T$) will be

$$T = \frac{V}{(Q_P - Q_I)}$$

For example:

- If $T = 4$ minutes
  - $Q_P = 450$ litres/minute
  - $Q_I = 250$ litres/minute

then required sump volume between probes is

$$V = T \times (Q_P - Q_I)$$

$$= 4 \times (450 - 250)$$

$$= 4 \times 200$$

$$= 800$$ litres ($0.8$ m$^3$)

On this basis, some estimate of the minimum volume of the sump can be made. For this type of sump function, it is preferable to keep the sump as small as possible, so as to avoid solids settling out which will eventually cause choking of the pump inlet. Typical sump sizes are 1 to 2 cubic metres for pumps in the 200 litre/min to 450 litre/min pumping rate range. Sumps larger than this may require agitators to avoid solids settling. (Sump agitators are discussed later in this section).

Buffer Storage: Limited sump storage may be a more economical proposition than installing larger pumps to handle large inflow rates to the sump. If inflow rate, $Q_I$, is greater than the pump discharge rate, $Q_P$, then the liquid volume in the sump is increasing rather than reducing. Provided there is sufficient buffer storage, the inflow rate will reduce below $Q_I$ before the sump overflows. To determine accurately the necessary buffer storage, a knowledge of the inflow hydrograph to the sump is required. Having these data and knowing the pumping rate, which will be constant, it is possible to plot, against time, net changes in volume at the sump, thus giving necessary buffer storage. For large confined animal enterprises this approach may be necessary. In most situations it is reasonable to simplify the analysis by assuming a constant and continuous rate of inflow to the sump for a known time interval. By either knowing the total volume
of manure, \( V_T' \), arriving at the sump as a continuous and finite slug over a known time interval \( T_C \) or by estimating \( V_T \) from the inflow rate \( Q_I \) and the equation -

\[
V_T = Q_I \times T_C
\]

the volume of buffer storage \( V_B \) can be determined from the equation.

\[
V_B = V_T - Q_p T_C
\]

or \( V_B = T_C (Q_I - Q_p) \)

\( Q_I \) and \( T_C \) can either be measured for an existing system or estimated using best available data. If runoff from rainfall is included, this needs to be considered.

As an example consider a piggery in which rainfall runoff is diverted and the largest continuous volume input to the sump was measured at an average of 1050 litre/min for 75 minutes. The pump capacity is 800 litres/min, then the necessary buffer capacity will be;

\[
V_B = 75 (1050 - 800)
\]

\[
= 18750 \text{ litres or } 18.8 \text{ m}^3
\]

It would take 18750/800 = 23.5 minutes to pump down this buffer storage after inflow has ceased. Clearly, this buffer storage will need to be above the top probe (cut-in) level. Knowing \( V_B \) it is a simple matter to select a suitable total sump volume.

Medium-term Storage: A farmer might wish to store the waste for 2 days, 2 weeks, or 2 months, prior to removal to disposal or treatment site. The section on storage discusses the various types of storage facilities. Methods of agitation in larger sumps are discussed later in this section. Generally the agitator is started just prior to pumping in order to resuspend settled solids so that they can be easily pumped and removed from the sump.

SUMP SHAPES

The smaller sumps with no agitator or mixer, should be designed with sloping floors (45° angle) in order to deflect settling solids in suspension directly to the pump inlet. Figure 3.41(b) illustrates a typical design for a no-storage pump sump.

Larger sumps can range in shape from long rectangular, to deep cylindrical tanks. For efficient mixing the cylindrical tanks are better. Some points to remember in their design are:-

- avoid sharp corners and dead spots in the tank
- sloping or coned floors enable easier emptying and desludging
- adequate ballasting or drainage is needed in high groundwater table sites
- securely cover for safety reasons

MIXING AND AGITATION

For larger sumps and tanks used for holding dilute liquid manure, it is necessary to agitate the contents to hold settleable solids in suspension and to combat surface crusting. If permitted to settle, without
resuspension during draw off, a solid sludge will progressively build up in the bottom of the tank, reducing the effective capacity of the sump and possibly blocking pump intakes.

Various agitation techniques can be adopted. These include;

- high velocity jet or recirculation. Some manure pumps have a bypass fitted on the discharge which directs a jet of liquid in the region of the pump inlet, causing turbulence and agitation.
- air sparging or air lift pump. Pumping air with a compressor or blower may be used.
- mechanical agitation. These may range from high-speed, small-diameter propellors to large, slow-speed paddles.

The design constraints are capital cost and power requirement. There is very little information relating to agitation of liquid animal manure to assist with design, however there are several general principles that apply. These are:

- Sumps should be circular or at worst square in plan, rather than rectangular.
- Sump diameter should be approximately equal to liquid depth.
- The most efficient and least expensive means of agitation appears to be slow speed rotating or oscillating paddles.
- Offset rotating agitators can impose significant loadings or bearings.
- Agitation characteristics of manure vary with the type of manure, animal feed, pretreatment and so on. Pig manure, for example, is generally easier to agitate than cattle manure.

Various mathematical relationships for mixing have been developed. One such relationship (Weisman and Efferding 1960, and Perry and Chilton 1973) is useful in determining agitator design, speed and power input. Referring to Figure 3.44, the agitator is a 6-bladed disc impeller and:

\[ D \] is the depth of liquid (m)
\[ D_T \] is the diameter of the cylindrical sump (m)
\[ D_a \] is the diameter of the agitator (m)
\[ B \] is the distance from the sump bottom to impeller midpoint (m)

If the following assumptions are made;

- Sufficient mixing required to resuspend medium sand particles from the bottom of the sump
- Sump is cylindrical and not baffled
- Solids concentration (TS) of the mixture is no greater than 3% and liquid density is 1000 kg/m³
- depth, D equals diameter \( D_T \)
- Impeller depth ratio \( B/D_T = 0.5 \)
- Impeller diameter ratio \( D_a/D_T = 0.36 \) to 0.43
By making these assumptions impeller shaft power requirement per cubic metre of liquid is:

\[ P = 0.15 \text{ kW/m}^3 \] and impeller speed \( N \) is given by:

\[ N(\text{rpm}) = 60 \times \left[ \frac{P}{D_a^5} \right]^{0.33} \]

**EXAMPLE 3.5**

\( D = D_T = 2 \text{ m} \)

\( D_a = 0.80 \text{ m} \)

then

Volume of liquid = \( \pi \times \frac{2^2 \times 2}{4} \)

= \( 6.28 \text{ m}^3 \)

Power input to the agitator shaft = \( 6.28 \times 0.15 = 0.94 \text{ kW} \)

Impeller speed

\[ N = 60 \left[ \frac{0.94}{0.80^{0.33}} \right] = 85 \text{ rpm} \]

**FIGURE 3.44 SIX-BLADED MIXER DESIGN**
In many situations the farmer tends to make up his own mixing unit out of whatever hardware is handy to him. This may be an old propeller or a paddle that he has made up in the workshop. A motor is coupled to the mixer and the system installed and tried out. Often the system is modified by changing speed or mixer diameter until a satisfactory performance is achieved. As a guide to making modifications it is useful to note that:

Power input \( \propto (\text{Paddle diameter})^5 \times (\text{rpm})^3 \).

### PIPE AND CHANNEL RETICULATION

#### MANURE CHARACTERISTICS

In a solid/liquid mixture, the presence of the solids will affect the flowing characteristics of the liquid. The significance of this effect will depend on the nature of these solids and their concentration. It is generally accepted that for solids concentrations up to 4% by mass, the mixture's hydraulic characteristics (i.e. pump, pipe flow and gravity flow characteristics) will be very similar to clean water. In New Zealand most animal waste removal methods use water for flushing, (by hose or tipping buckets) which dilutes the wastes, normally well below the 4% solids level. For thicker manures the mixture behaves as a non-Newtonian fluid with rather complex viscosity characteristics. This may well result in higher friction loss in pipes, lower flow velocities under gravity and reduced pumping efficiencies.

#### PRESSURE PIPE RETICULATION

Waste is transported under pressure by pipe for a large number of reasons. It may be for irrigation through a sprinkler or to transfer from a sump to lagoons.

The liquid is pressurised in the pipe by either a pump or by the effect of gravity.

As a liquid flows through a pipe, the pipe walls retard the flow by friction. The degree of this retarding force depends on the flow rate, pipe internal diameter and length and the material the pipe is made of. It is commonly described as the pipe friction loss and will normally be expressed as pressure loss in metres of water head per 100 metres of pipe length. For example, if the friction loss in 50 mm polyethylene pipe is 3 metres/100 metres at 11 m³/h then the loss of pressure over 300 metres of pipe length will be 9 metres of water gauge pressure. (Note: 1m water gauge = 9.8 kPa). In this example, if flow is to be maintained at 11 m³/h, 9 m water pressure or 9 m of gravity head must be available.

Friction loss per unit of pipe length \( (h_L) \) varies with flow rate \( (Q) \) and internal diameter of pipe \( (D_i) \) according to the following relationships:

\[
\begin{align*}
    h_L &\propto Q^2, \\
    h_L &\propto 1/D_i^5.
\end{align*}
\]

Friction loss charts for various types and sizes of pipes are given in Figures 3.45 and 3.46. Such charts are also available from manufacturers.

In addition to friction losses in a pipe section there will be losses across fittings such as valves, bends and tees. These losses can be significant and may be estimated by knowing the average velocity \( (V) \) through the fitting and using the equation:
Based on Lamont's smooth pipe formulae S.3 (Lamont, 1954)

where \( h_L \times D^{4.772} = 9.05 \times 10^9 \times Q^{1.772} \) (water temp. 12.8\(^{\circ}\)C)

- \( h_L \) in m/100m
- \( D \) in mm (internal diameter)
- \( Q \) in l/s

* Pipes are to NZS 7602, polyethylene (type 5). The diagrams have been calculated on the basis of minimum possible bore.

**FIGURE 3.45 FRICTION LOSS CHART POLYETHYLENE PIPE**
NOTES  * Based on Lamont's smooth pipe formulae S.3 (Lamont, 1954)

where $h_L \times D^{4.772} = 9.05 \times 10^9 \times Q^{1.772}$ (water temp. 12.5°C)

$h_L$ in m/100m
$D$ in mm (internal diameter)
$Q$ in l/s

* Pipes are to NZS 7648:1974, "Unplasticized PVC pipe for cold water services". The curves have been calculated on the basis of the average minimum bore.

FIGURE 3.46 FRICTION LOSS CHART P.V.C. PIPE
fitting loss (m) = \frac{kV^2}{2 \ g} \\
with \ V \ in \ m/s \\
g = 9.81 \ m/s^2 \\
k is a factor depending on the type of fitting as given in Table 3.11.

**TABLE 3.11 HEADLOSS COEFFICIENT k FOR VARIOUS FITTINGS**

<table>
<thead>
<tr>
<th>Fitting</th>
<th>k</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bend</td>
<td></td>
</tr>
<tr>
<td>90°</td>
<td>0.33</td>
</tr>
<tr>
<td>45°</td>
<td>0.25</td>
</tr>
<tr>
<td>22 1/2</td>
<td>0.20</td>
</tr>
<tr>
<td>Tee and Cross</td>
<td></td>
</tr>
<tr>
<td>Straight through</td>
<td>0.15</td>
</tr>
<tr>
<td>90° off-take</td>
<td>0.90</td>
</tr>
<tr>
<td>Wye</td>
<td></td>
</tr>
<tr>
<td>Straight through</td>
<td>0.15</td>
</tr>
<tr>
<td>45° off-take</td>
<td>0.50</td>
</tr>
<tr>
<td>Valves (fully open)</td>
<td></td>
</tr>
<tr>
<td>Globe</td>
<td>10.0</td>
</tr>
<tr>
<td>Angle</td>
<td>5.0</td>
</tr>
<tr>
<td>Swing check</td>
<td>2.5</td>
</tr>
<tr>
<td>Gate</td>
<td>0.19</td>
</tr>
</tbody>
</table>

1. Sources various

The velocity of flow (V) can be determined knowing internal diameter \(D_i\) and flow rate Q by using the continuity equation;

\[ V = \frac{Q}{A} \]

where
\[ A = \pi \ D_i^2/4 \] is the cross sectional area perpendicular to flow direction

In selecting pipe size it is important to check water velocity. The recommended velocity range is 1 to 2 m/sec. At velocities just below 1 m/s solids may settle out. At velocities higher than 2 m/s, water hammer can be a problem. Velocities in pipes are often given on friction loss charts, or can be estimated from the continuity equation already given.

When choosing a pipe, the pressure rating of the pipe needs to be checked. The pressure rating is the highest pressure permissible within the pipe. If this is exceeded another class of pipe or a different material may need to be selected. The pressure rating of different pipes should be specified by the manufacturer. Table 3.12 lists the pressure rating for different classes of high density polyethylene and PVC pipe (NZS 7602).
TABLE 3.12 PRESSURE RATING FOR PVC AND HIGH DENSITY POLYETHYLENE PIPE

<table>
<thead>
<tr>
<th>Class</th>
<th>Pressure Rating in m water</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>60</td>
</tr>
<tr>
<td>C</td>
<td>90</td>
</tr>
<tr>
<td>D</td>
<td>120</td>
</tr>
<tr>
<td>E</td>
<td>150</td>
</tr>
</tbody>
</table>

Various pipe materials have been used and include concrete, asbestos cement, steel and ceramics, for the larger pipes. PVC, polyethylene, aluminium, copper and steel are common materials for smaller pipes. Most commonly used are PVC and polyethylene. Aluminium should never be buried because of corrosion. The plastic pipes are light and easy to handle and install.

GRAVITY RETICULATION AND CHANNEL FLOW

Every effort should be made to make maximum use of the fall in land (i.e. gravity force) to reticulate liquid waste material. The alternative, pumping, is energy-consuming and susceptible to mechanical failure and blockages. Therefore, in the siting of animal buildings, consideration should be given to gravity reticulation and liquid waste and other drainage.

The main criterion in the design of a gravity reticulation system is to ensure that there is sufficient liquid velocity to carry the solids which would otherwise settle and block. Transporting dislodged manure requires a flushing velocity of about 0.6 m/s if the depth of liquid is half or more of the vertical dimension of the manure solids. A liquid velocity of about 1 m/s will dislodge fresh manure from a wet surface. The velocity of a stream will depend on:-

- $S$, the slope (as a fraction) of the pipe or channel
- $A$, the cross-sectional area of the flowing liquid
- $P$, the wetted perimeter
- $n$, the roughness of the pipe or channel material

Manning's equation relates these variables as follows;

$$V = \frac{R^{0.67}S^{0.5}}{n}$$

where $V$ = velocity m/s,
$R = A/P$, $A$ in m$^2$ and $P$ in m (see Table 3.13)
$n$ = Manning's roughness coefficient (see Table 3.14)

By using Manning's equation and the continuity equation;

$$Q = VA$$

where $A$ is flow rate in m$^3$/s, $V$ and $A$ as defined, the channel dimensions, slope and capacity can be determined. This analysis will involve a trial and error approach.
### TABLE 3.13. SECTIONAL PROPERTIES OF CHANNELS

<table>
<thead>
<tr>
<th>Channel Shape</th>
<th>Area ( A )</th>
<th>Wetted Perimeter ( P )</th>
<th>Hydraulic Radius ( R )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rectangular</strong></td>
<td>( \text{wh} )</td>
<td>( w + 2h )</td>
<td>( \frac{\text{wh}}{w + 2h} )</td>
</tr>
<tr>
<td><strong>Trapezoidal</strong></td>
<td>( \text{wh} + bh^2 )</td>
<td>( w + 2h \sqrt{\frac{b^2}{b^2 + 1}} )</td>
<td>( \frac{\text{wh} + bh^2}{w + 2h \sqrt{\frac{b^2}{b^2 + 1}}} )</td>
</tr>
<tr>
<td><strong>Triangular</strong></td>
<td>( bh^2 )</td>
<td>( 2h \sqrt{\frac{b^2}{b^2 + 1}} )</td>
<td>( \frac{bh}{2 \sqrt{\frac{b^2}{b^2 + 1}}} )</td>
</tr>
<tr>
<td><strong>Circular</strong></td>
<td>( \frac{r^2}{57} \left( \frac{\theta}{2} - \frac{1}{2} \sin 2\theta \right) )</td>
<td>( \frac{r\theta}{29} )</td>
<td>( \frac{r}{2} \left( 1 - \frac{29}{\theta} \sin \frac{2\theta}{\theta} \right) )</td>
</tr>
</tbody>
</table>

where \( \theta \) (degrees) is the angle whose cosine is \( 1 - \frac{h}{r} \).
In most applications, flow builds up from zero to a peak and then slowly drops off to zero flow. The ideal channel cross-sectional shape is parabolic. This gives relatively constant velocity for different flow rates. However, formers for these are difficult to construct and generally circular, trapezoidal or triangular cross-sections will be used.

Finally, if sufficient velocity cannot be obtained, then it is advisable to ensure easy access to the drain to allow cleaning.

### TABLE 3.14 MANNING'S ROUGHNESS COEFFICIENT 'n'

<table>
<thead>
<tr>
<th>Material</th>
<th>Min.</th>
<th>Max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neat cement surface</td>
<td>0.010</td>
<td>0.013</td>
</tr>
<tr>
<td>Concrete, precast</td>
<td>0.011</td>
<td>0.012</td>
</tr>
<tr>
<td>Cement mortar surface</td>
<td>0.011</td>
<td>0.015</td>
</tr>
<tr>
<td>Brick with cement mortar</td>
<td>0.012</td>
<td>0.017</td>
</tr>
<tr>
<td>Concrete, monolithic</td>
<td>0.012</td>
<td>0.016</td>
</tr>
<tr>
<td>Common-clay drainage tile</td>
<td>0.011</td>
<td>0.017</td>
</tr>
<tr>
<td>Wood-stave pipe</td>
<td>0.010</td>
<td>0.013</td>
</tr>
<tr>
<td>Plank flumes, planed</td>
<td>0.010</td>
<td>0.014</td>
</tr>
<tr>
<td>Plank flumes, unplanned</td>
<td>0.011</td>
<td>0.015</td>
</tr>
<tr>
<td>Vitrified sewer pipe</td>
<td>0.010</td>
<td>0.017</td>
</tr>
<tr>
<td>Metal flumes, smooth</td>
<td>0.011</td>
<td>0.015</td>
</tr>
<tr>
<td>Metal flumes, corrugated</td>
<td>0.022</td>
<td>0.030</td>
</tr>
<tr>
<td>Cast iron</td>
<td>0.013</td>
<td>0.017</td>
</tr>
<tr>
<td>Riveted steel</td>
<td>0.017</td>
<td>0.020</td>
</tr>
<tr>
<td>Channels - earth, smooth</td>
<td>0.025</td>
<td>0.033</td>
</tr>
</tbody>
</table>

### SCREW AUGERS AND CHAIN CONVEYORS

#### SCREW AUGERS

Screw augers are suitable for conveying waste with physical properties ranging from solid to liquid although they are not recommended for cohesive material. Common applications in handling farm wastes are as a cross-feed at the end of scraper collection systems and for unloading land-spreading trailers.

The action of the helix is to scrape material along the axis and up the side of the trough until the material drops back into the trough.

In constructing a screw auger the pitch is generally made equal to the diameter, \( D \) (m). Hence the average speed of material in the conveyor, \( V \), is

\[
V = \pi D \times n \text{ (m/s)}
\]

when \( n \) is the rotary speed of the screw (n rev/s). The capacity (C) is a function of the material speed and the cross-sectional area of the auger, modified by a loading factor (K).

i.e. \[ C = V \times \frac{\pi D^2}{4} \times K \text{ (m}^3\text{/s)} \]
In farm waste applications K would have a value of 15-20%.

Augers are operated at revolving speeds up to 2.5 revolutions/second. The higher speeds are suitable for free flowing material. Excessive speed will simply rotate the material rather than convey it.

Power requirements, P, in horizontal augers can be approximated by

\[
P = \frac{C \times g \times l \times \rho \times \mu}{1000} \quad \text{(kW)}
\]

where

- \( g \) is the gravitation constant = 9.8 (m/s²)
- \( l \) is the conveyor length (m)
- \( \rho \) is the bulk density of the material (kg/m³)
- \( \mu \) is the internal friction of the material

The factor will vary with different materials, however a value of 1 will give a conservative answer to P. In any case, a factor of 3 should be applied to the theoretical power required in order to overcome energy losses due to friction between the flighting and the trough. The central shaft would be designed to withstand this power input.

The screw auger's capacity is increased and maximum elevating efficiency occurs at inclinations of 40 to 60 degrees.

CHAIN CONVEYORS

The drag-chain conveyor consists of a wide endless chain with open links which serve to move the material within a special trough. They operate at slow speeds, 3 to 6 metres/minute, and are more suitable than augers for cohesive material. They also have low mechanical efficiency and can be noisy.

CHAIN AND SLAT CONVEYORS

These are an adaptation of the drag-chain principle. Two or more parallel chains are joined across by narrow wooden or steel slats.

HAULING WASTES

SOLID WASTES

Livestock wastes with 20 percent or more total solids can usually be handled as a solid. Solid manure spreaders include box types, open tanks, dump trucks, and farm wagons.

Box type muck spreaders may be towed (Figure 3.47) or mounted on trucks. They usually have a rear flail spreader and a chain drag in the bottom to move solids rearward to the flail. They sometimes have a rear slurry gate which can be closed to prevent the more liquid portions from dripping during transport to paddocks and then opened when spreading is begun.

Spreader capacity may be rated in kg of waste or in m³ of waste volume. (1 m³ volume will hold approximately 950 kg solid manure or 1000 kg slurry). Capacities of spreaders commercially available range from 2.5 m³ to 15 m³. The smaller pull-types usually have ground-driven spreader mechanisms while larger sizes are usually PTO-driven.

3-82
Open tank spreaders (Figure 3.48) can handle solid manure and also those wastes which more nearly approach slurries. Some have lids to prevent splash-out of the more liquid wastes during transport. Open tank spreaders usually are cylindrical in shape, with about 1/4 of the cylinder wall removed. The cylinder lies on its side and the opening is from the top of the tank down about halfway on one side.

A PTO driven shaft is located near the opening and parallel to the main axis of the tank, usually parallel to the direction of travel. Chains on the shaft flail as the shaft turns and throw the wastes out to the side.

LIQUID WASTES

Liquid wastes with up to about 10% total solids can be pumped and hauled in tankers mounted either on trailers or trucks. The tankers may be filled by high capacity pressure pumps or by vacuum pumps.

Vacuum tankers (Figure 3.49) usually have a PTO-driven air pump mounted on the tanker. This is used to create a vacuum in the tank and an intake hose from the tank is placed in the liquid waste. With adequately sized vacuum hose (e.g. 75 to 150 mm diameter) and good vacuum, filling time for common tanker sizes is short, often 5 minutes or less.

Vacuum tankers can be pressurized to aid unloading or to pump air into storage tanks for agitation.

Pressure pump filled tanks may unload by gravity or may have some type of pumped unloading and mechanical agitation.
FIGURE 3.48 A FLAIL TYPE OPEN TANK MANURE SPREADER

FIGURE 3.49 A VACUUM SLURRY TANKER
Tankers may range in size from about 2000 litres (2 m$^3$) up to 20 000 litres (20 m$^3$). The larger tankers may require tandem axles and high flotation tyres to reduce compaction and disturbance of wet soils.

Concern in the U.K. about odour following surface application of slurries has resulted in an increase in direct injection of liquid wastes into the soil with chisel-type injector shanks. This conserves fertilizer nitrogen and significantly reduces odour following spreading. Injector systems may be mounted on the tanker or on tractor-mounted tool bars.

Liquid wastes should be thoroughly agitated prior to hauling to ensure that settled solids do not accumulate in storage facilities.

The tankers and muck spreaders described in this section are in common use overseas. Their availability in New Zealand is somewhat limited, so it may be necessary to specially build or import a specific type if not available.

REFERENCES CHAPTER 3


Farm Mechanisation Study 32. Ministry of Agriculture, Fisheries and 
Food (Publications), Tolcarne Drive, Pinner, Middlesex HA5 2DT, U.K.

Farm Waste Management. Ministry of Agriculture, Fisheries and Food, 
Great Westminster House, Horseferry Road, London SW1P 2AE.


Extension Publication A2884, Agricultural Engineering Dept, 
University of Wisconsin, Madison, Wisconsin, U.S.A.

Miner, J.R. and Smith, R.J. eds (1975). Livestock Waste Management with 
Pollution Control. Midwest Plan Service Pub. No. MWDS-19, Iowa State 
University, Ames, Iowa, U.S.A.

New Zealand Meteorological Service (1979). Rainfall parameters for 
163.


animal units. Trans ASAE 12 (3): 359.

Tomlinson, A.I. (1980). The frequency of high intensity rainfalls in New 
Zealand, Part I. MWD, Water and Soil Technical Publication No. 19, 
Wellington.

Trethewie, R.J. (undated). Pressure systems for cleaning yards. 
Unpublished mimeographed report. Dairy Division, Department of 
Agriculture, Victoria, Australia.

U.S. Environmental Protection Agency Pub. EPA-600/2-70143.

chapter 4

physical treatment

DALE H. VANDERHOLM
solid-liquid separation

Under some waste management systems, solids and liquids can be kept separate and can be handled separately throughout. In many systems, however, liquid and solids are mixed as a slurry. The ratio between the amount of solids and liquid depends on many factors, with the addition of water for flushing or washdown being one of the most significant. It may still be advantageous to handle the liquid and solids separately at a later point, therefore requiring some means of separation.

There are two basic methods of solid-liquid separation. One uses the difference in density between the solid particulate matter and the liquid (settling and centrifuging) and the second uses the shape and size of the particles to cause separation (screening and filtration). After solids are removed, they can be applied to land immediately or after storage, dried, composted, or used for other purposes such as refeeding or as bedding. The liquids are easier to pump and land-apply through irrigation systems. If the liquid is added to a lagoon, the lagoon loading rate and potential solids accumulation are reduced and lagoon sizes can be reduced proportionately.

Solid-liquid separation seems to be most applicable for piggeries with flushing or manual washdown. A separator is used to remove the solids prior to lagooning or land application of the liquid. Settling for removal of grit and stones from farm dairy waste before spray irrigation is also common; it is discussed in the sections on pumping and spray irrigation systems (Chapter 3). Porous dams can be used to allow liquid drainage from scraped manure from dairy yards (see section on storage, Chapter 3). Runoff control systems may use settling to remove solids prior to land application or storage of the runoff water. Settling can also be used to remove solids in effluent from livestock truck-washing stations prior to discharge or treatment of the liquids. These examples illustrate the wide variety of situations in which solid-liquid separation is currently used or has potential use.

SETTLING

Solids with a density greater than water can be settled out by holding the liquid waste in a tank or allowing it to pass through a tank or channel at low velocity. Fast-moving liquids pick up and transport solids; when velocity slows such as in a settling tank, solids settle.

A typical settling tank is rectangular or cylindrical, made of concrete and has short term detention capacity, about 20 to 30 minutes. Detention time equals settling tank volume divided by liquid flow rate (volume, m³/ Q, m³ per time unit), and measures the average time the liquids are in the settling unit. Settling is most effective on dilute wastewaters such as flushing and washwater or lot runoff (Miner and Smith, 1975). Settling in these dilute wastes occurs fairly rapidly, with most occurring during the first 10 to 20 minutes of detention.

Settling tanks are normally full of liquid, but there is often some provision for removing or draining the liquid to expose the settled solids. The solids, which are usually semi-liquid (Table 3.10), are removed by pumping, scraping, or bottom drain. Figure 4.1 illustrates a simple settling tank. Tank outlets may be weir notches or pipes which are
sometimes baffled or screened to prevent floating solids from passing. Adequately sized settling tanks should remove 50 to 75 percent of the suspended solids in the original slurry.

SETTLING TANK DESIGN

To provide adequate surface area without excessive depth, settling tanks should have at least 0.8 m² surface area for each m³ per hour loading rate. Detention time should be about 30 minutes. Capacity should be provided for storage of solids unless cleaned out frequently. The following example illustrates the procedure for sizing a settling tank.

EXAMPLE 4.1

A piggery owner desires to remove solids by settling from effluent flushed out of several production buildings. The settled solids are to be stockpiled for land application later. Average waste flow from the piggery is 24 m³ per day. For low waste flows such as this, the capacity required for detention time and the required surface area are very small, making the volume required dependent primarily upon solids storage desired. To calculate the solids accumulated, assume that, in this example, the waste averages about 3 percent solids and a 60 percent removal by settling is expected. The quantity of solids removed daily is (using density 1000 kg/m³)

$$24 \text{ m}^3 \times 1000 \text{ kg per m}^3 \times 0.03 \times 0.6 = 432 \text{ kg}$$
The settled sludge will average about 15 percent solids (Table 3.10) so the daily volume of solids is

\[ 432 \div 0.15 = 2880 \text{ m}^3 \]

For 30 days storage, volume required would be

\[ 30 \times 2.88 = 86.4 \text{ m}^3 \]

This volume would be provided by a tank 4.5 m x 4.5 m x 4.5 m. If solids are removed daily rather than stored, the tank size can be based on required detention time and surface area. Assume most flushing and washdown occurs during 3 hours of the day so flow rate for design is

\[ 24 \text{ m}^3 \div 3 \text{ hour} = 8 \text{ m}^3 \text{ per hour} \]

Required surface area is

\[ 8 \times 0.8 = 6.4 \text{ m}^2 \]

For 30 minute detention time, required volume is \( 8 \text{ m}^3/\text{hr} \times 0.5 \text{ hr} = 4 \text{ m}^3 \). However, daily volume of accumulated solids was 2.88 m\(^3\), so to provide adequate detention time considering a portion of the total volume occupied by the accumulated solids, this storage must be added making the required volume

\[ 4 + 2.88 = 6.88 \text{ m}^3 \]

A tank 2 m wide by 3.5 m long with 1 m effective depth would provide adequate volume. The solids will still be in slurry form and can be removed by a vacuum tank wagon or pumped to a tank wagon by a solids handling pump.

**SETTLING SOLIDS FROM LOT RUNOFF**

As noted in the section on controlling storm runoff from open lots, it is usually desirable to separate solids by settling prior to storage or land application of the liquid. A settling basin for this purpose is illustrated in Figures 4.2 to 4.4. Recommended volume for basins of this type is 1.4 m\(^3\) of basin volume per 100 m\(^2\) of runoff contributing area. Following a runoff event, liquid drains through the outlet, leaving the settled solids which can be removed with a front-end loader. Screens and outlet riser slots may also need cleaning periodically.

**SCREENING**

Screening separates solids by trapping them on a screen that permits liquids and small particles to pass through. Large screen openings permit more solids to pass but plug less and require less frequent cleaning. Small screen openings trap more solids but require more cleaning.

There are several methods of screening. One uses a slow relative motion between the slurry and the screen. With this method, the screen is stationary and mounted on an incline with the slurry applied to the top edge of the screen. The liquid passes through the screen and is drained away, while the solids move down the face of the screen, finally dropping to a storage area or moving onto a conveyor. This is the configuration used for wedge-wire screens, discussed in more detail later in this section.
FIGURE 4.2 CONCRETE SETTLING BASIN FOR RAINFALL RUNOFF TREATMENT
SLOTTED PIPE OUTLET RISER,
0.6 TO 1 M HIGH,
25 BY 100 MM VERTICAL SLOTS

NO. 9, 20 MM EXPANDED METAL
SCREEN ON AN ANGLE IRON FRAME

FIGURE 4.3 OUTLET SCREEN AND SLOTTED RISER PIPE FOR RUNOFF SETTLING BASIN.

FIGURE 4.4 ALTERNATIVE CONFIGURATION FOR SETTLING BASIN OUTLET.
A second screening method uses a rapid vibratory screen motion. This vibration is intended to aid movement of the solid fraction across the screen and reduce clogging. One configuration of these is circular, with centre feed onto a flat screen with solids discharged at the periphery and liquid to a pan beneath the screen. This configuration is illustrated in Figure 4.5.

Rotary screen separators as shown in Figure 4.6 use a perforated rotating screen onto which the slurry is deposited at a controlled rate. Some of the liquid fraction drains through the perforations and the wet solid remains on the screen surface, to be next squeezed by rollers and finally cleared off by a scraper. Screen perforations 3 mm in diameter have been successfully used.
FIGURE 4.6(a) ROTARY SCREEN (CONTRASHEAR)
FIGURE 4.6(b) ROTARY SCREEN SEPARATOR WITH PRESS ROLLERS

Other stationary and vibratory screens are discussed in Chapter 3 (see Figures 3.42 and 3.43). Flat belt separators (Figure 4.7) use a thin flat woven fabric belt running horizontally between squeezing rollers. Mesh sizes used have been 1 mm for cow slurry and 0.35 mm for pig slurry. Performance of several types of separators is reported by Pain et al (1978).

FIGURE 4.7 FLAT BELT SEPARATOR
WEDGE-WIRE SCREENS

Most experience in New Zealand has been with using wedge-wire screens to screen flushing piggy wastes prior to lagooning. Design information for one such installation was given by Dakers (1979). The screen consists of parallel stainless steel wires which have a wedge-shaped cross section as illustrated in Figure 4.8. Fully assembled screens of this type are available commercially or screen material can be purchased from well screen or wire companies and the remainder of the assembly farmer-built. Plans for a unit similar to that shown in Figure 4.9 are available from Agricultural Engineering Advisors, Ministry of Agriculture and Fisheries.

Various screen openings or apertures have been tested on pig wastes, with 1 mm generally proving the most successful. A loading rate of 12.5 litres per second per metre of screen width is recommended for planning purposes. Wastes are usually drained first to a sump, then a manually or automatically controlled pump is used to load the screen. Pumping rate and screen size must be matched to achieve the correct loading rate. For example, a 50 m$^3$ per hr flow (14 l per sec) would require a screen width of 1.1 m.

Solids drop off the screen to a storage area or transport. The solids may be land-applied directly or further treated by composting. The liquid portion is treated separately by land application or discharge to a lagoon system.

A problem periodically encountered with wedge-wire screens is the build-up of a bacterial slime on the wedge-wire, causing the gaps between the wires to block. Washdown with a chlorine-free bactericide, a process taking about 10 minutes daily, has been successfully used to deal with this problem.
FIGURE 4.9 WEDGE WIRE SCREEN CONFIGURATION
CHARACTERISTICS OF THE SOLID-LIQUID FRACTIONS

It is sometimes useful to know the proportion of various waste constituents that remain in the solid or liquid phase after separation occurs. While these can vary with the separation process and type of waste, an example of values as observed in separation trials has been included in Table 4.1. Table values can be used to estimate quantity, pollution characteristics and fertilizer value of separated fractions.

It can be seen from the table that nutrients tend to separate with the solid and liquid fractions in the same proportion as the volume.

TABLE 4.1 AN EXAMPLE OF DISTRIBUTION AND REMOVAL OF VARIOUS WASTE CONSTITUENTS AFTER SEPARATION BY SCREEN AND DRUM TYPE SEPARATORS

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Percent of original in:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Solid</td>
</tr>
<tr>
<td>Volume</td>
<td>30</td>
</tr>
<tr>
<td>Total Solids</td>
<td>40-60</td>
</tr>
<tr>
<td>BOD</td>
<td>55-65</td>
</tr>
<tr>
<td>COD</td>
<td>30-50</td>
</tr>
<tr>
<td>Total N</td>
<td>30</td>
</tr>
<tr>
<td>Total P</td>
<td>30</td>
</tr>
<tr>
<td>Total K</td>
<td>20</td>
</tr>
</tbody>
</table>

Note 1. Actual values will vary depending upon initial waste characteristics and separation process.

Note 2. Data from both screen and perforated drum separators.


drying, incineration and pyrolysis

DRYING

Evaporation dries, or dehydrates solids, reducing the total volume of wastes to be handled. Evaporation can be natural as in a pond or can be aided by supplemental heat in a drier. Due to initially high dry matter content, poultry manure is more readily dried than most other wastes, although solids separated from slurries may dry reasonably well. Extensive research has been conducted overseas on drying poultry manure and recycling it as a feed additive in other livestock rations (Miner and Smith, 1975).
Fuel costs for dehydration are high. Drying can produce an inoffensive, easily handled material for fertilizer and other uses. However, the economics of drying are not good unless a low cost fuel source is available (e.g. combustible waste materials) or the commercial value of the end product is high (e.g. protein supplement in livestock ration).

INCINERATION

Incineration is a process in which the volume and mass of organic matter is reduced by burning. The combustible fractions of the waste are burned and the mineral matter is left as ash. Materials having a high moisture content, such as most types of livestock wastes, will not support combustion and require a supplemental fuel supply.

Incineration can be used where human population is dense and land is not available for waste spreading. Nitrogen in the wastes is discharged as ammonia (NH₃) in the flue gas, while phosphorus and potassium remain in the ash. As smoke from the incinerator can carry odours, water spray systems, fly-ash collectors, and electrostatic precipitators are often used to control air pollution.

Incinerating equipment can be either batch-loaded or continuous-flow. Batch loading requires more labour and is somewhat inefficient as the incinerator cools each time it is charged. Continuous-flow equipment is more expensive.

Little or no information is available on the costs of incinerating livestock waste. Incineration is generally a very expensive process and unlikely to be practical for livestock waste treatment.

PYROLYSIS

Pyrolysis is a chemical change brought about by controlled heat input. It is a process of destructive distillation and is carried out in a closed reactor without oxygen. The process has been used for several hundred years to make charcoal and is used commercially to make such products as methanol, acetic acid, and turpentine from organic compounds.

Pyrolysis can also be used to recover useful by-products from agricultural wastes. It not only reduces the volume of livestock wastes so there is less material for disposal, but produces combustible gases and other useful by-products (Loehr, 1974). Studies with beef cattle waste (Garner et al, 1972), however, concluded that the pyrolysis process was uneconomical due to high process cost and relatively low market value of the end products. In addition, some of the volatile liquid fractions had objectionable odours requiring removal from the exhaust gases.
REFERENCES CHAPTER 4


anaerobic treatment

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Biological treatment is used to convert organic matter (feed, bedding, excreted manure) in livestock waste to more stable, less offensive forms. Biological treatment is classified as aerobic or anaerobic, depending upon the presence or absence of free oxygen during the degradation process and the type of micro-organisms involved.

Anaerobic processes occur without free oxygen and are more commonly used in treating high strength wastes.

Aerobic processes require free or dissolved oxygen, either supplied by natural or mechanical aeration. They operate virtually odour-free, a definite advantage.

Facultative micro-organisms can function either anaerobically or aerobically, depending upon their environment, and can be found in both types of treatment systems. These adaptable micro-organisms do not require ideal conditions at all times thus reducing the environmental constraints for successful treatment systems. However, extreme changes in environment or food supply can stress micro-organisms, causing malfunctions of the waste treatment process and undesirable odour emissions.

This chapter deals with treatment systems involving anaerobic decomposition and digestion. Recent detailed reviews are in Stafford et al., 1980; Hashimoto et al., 1980 and Hobson et al., 1981.

**anaerobic decomposition**

While the composition of animal waste varies, the predominant compounds are carbohydrates and polysaccharides, proteins, lipids, and inorganic matter. Anaerobic degradation occurs in two stages. (Both stages may occur simultaneously). The first stage is performed by bacteria classed as acid-formers. These are mostly facultative and anaerobic bacteria that split the first three classes of compounds into short-chain fatty acids, ammonia, hydrogen sulphide and carbon dioxide as shown in Figure 5.1. The acids formed are mainly acetic and propionic with several others in much lower concentrations.

![FIGURE 5.1 ANAEROBIC DECOMPOSITION OF ORGANIC WASTES – FIRST STAGE](image_url)
An example of the acetic acid formation route from glucose is
\[ \text{C}_6\text{H}_{12}\text{O}_6 + 2\text{H}_2\text{O} \rightarrow 2\text{CH}_3\text{COOH} + 2\text{CO}_2 + 4\text{H}_2 \]

The second and final stage of the anaerobic process is the production of methane and carbon dioxide by the methane-forming bacteria. The reaction requires good environmental control and is given by the relationship shown in Figure 5.2

\[ \text{CH}_3\text{COOH} \rightarrow \text{CH}_4 + \text{CO}_2 \]

The methane-formers have much longer generation or reproduction times than the acid-formers. A slug load of waste can easily be handled by the acid-formers, producing large amounts of the fatty acids and lowering the pH of the waste. However, methane-formers do not function well outside a pH range of 6.4 to 7.2 so can be severely inhibited by a lowered pH and be unable to metabolize the fatty acids as rapidly as they are being produced. This imbalance can result in offensive odour emissions and poor lagoon performance, a situation discussed in the section on lagoon management.

When waste such as livestock waste is digested anaerobically, the gas produced from the overall reaction is primarily \( \text{CO}_2 \) (from 25 to 40 percent) and \( \text{CH}_4 \) (from 60 to 75 percent). This is discussed more completely in the section on anaerobic digestion.

**lagoon systems**

Anaerobic and aerobic lagoons can be used singly or in various combinations to treat livestock wastes of all types. Examples of several possible configurations are schematically shown in Figure 5.3.

If effluent is to be directly discharged to waterways (even if waterway flow is only periodic or seasonal), a two-lagoon (anaerobic-aerobic) system is necessary. While anaerobic lagoons are effective treatment systems, their effluent is still relatively strong and must be further treated by an aerobic lagoon before the effluent is suitable for discharge. Aerobic
Lagoons can be used singly, but excessive size requirements for treating livestock wastes generally make this an uneconomical alternative. Aerobic lagoon principles and design are presented in the aerobic treatment chapter.

If lagoon effluent is to be applied to farmland and no discharge to surface waters will occur an aerobic lagoon is usually unnecessary and it is more economical to use only an anaerobic lagoon. Temporary storage can be provided in the anaerobic lagoon. A possible exception to this is in areas where odour from land spreading the anaerobic lagoon effluent is of concern. In odour-sensitive areas, aerobic lagooning prior to land spreading may be justified.
Other variations sometimes used are two-cell anaerobic lagoons to provide better quality flush water (for cleaning) or to reduce aerobic lagoon loading. Location, size of operation, and other factors must be considered in order to select a lagoon system, but a conventional anaerobic-aerobic, two-lagoon system is likely to be suitable for the majority of situations.

ANAEROBIC LAGOONS

Anaerobic lagoons, used singly or in conjunction with an aerobic lagoon, are well suited to treating livestock wastes. The anaerobic process can decompose more organic matter per unit volume than the aerobic process and is normally used for initial stabilization of strong (high BOD) organic wastes. (See Fig. 5.4). Therefore, even when aerobic treatment is used, it is common to first treat strong wastes by anaerobic lagoons to reduce aeration requirements in the aerobic section. (See Figures 5.5 and 5.6).

**FIGURE 5.4 ANAEROBIC LAGOON PROCESSES.**

**FIGURE 5.5 ANAEROBIC STAGE OF A TWO-STAGE LAGOON SYSTEM.**
A properly installed and managed anaerobic lagoon should remove 70 percent of the influent BOD, and liquefy the waste for easier handling. A sludge remains in the lagoon and requires periodic removal.

Currently, the most common farm use of anaerobic lagoons is for initial treatment of raw dairy and piggery wastes. The anaerobic lagoon is followed by an aerobic lagoon, which would produce an effluent suitable for surface water discharge in most situations.

When two anaerobic cells are used alone, so as to provide flushing water, the first cell would be sized to provide the full treatment volume and the second to provide storage, if needed, plus 1/3 the treatment volume i.e., 1/3 of the first cell (Jones and Sutton, 1977). If all effluent is land-applied, a 2-cell anaerobic system cannot be justified.

TEMPERATURE

Anaerobic digestion is very temperature-dependent with the maximum efficiency of the most commonly found bacterial species occurring at about 35-36°C. Since lagoon temperatures vary with air and soil temperature they usually are operating at temperatures well below optimum. At liquid temperatures less than 13°C to 14°C, microbial activity and gas production is minimal, nearly ceasing below 10°C. Best lagoon performance occurs when temperatures are above 17 to 19°C (Loehr, 1974). During winter months in cooler climates, lagoons tend to function only as storage and settling devices. With the advent of warmer temperatures in spring, microbiological activity resumes, usually with an abundance of food accumulated during the cool period. During this unstable, Spring start-up period, increased odour
emissions are common, but these usually dissipate in a few weeks. Management procedures to counter this condition are discussed under anaerobic lagoon treatment.

CRUSTING

Heavily loaded poultry and dairy lagoons may form crusts, although lagoons treating piggery wastes almost never do. There is little information to indicate clearly whether crusts are beneficial or detrimental to lagoon performance. Crusts may be beneficial in reducing odour emissions. Older crusts may support vegetative growth, which tends to create a potential safety hazard to humans and livestock since it gives the appearance of solid ground.

ODOUR

A well-functioning lagoon may emit unpleasant odours from time to time. Common causes of this are emissions of hydrogen sulphide gas (H\textsubscript{2}S) (with the characteristic rotten egg smell) and ammonia or amines. These tend to be more common with piggery lagoons and the sulphide comes from either the sulphur-containing organic matter in the waste, the sulphur in the water supply, or both. A group of anaerobic photosynthetic bacteria called purple sulphur bacteria of the family RHODOSPIRILLINEAE that can reduce H\textsubscript{2}S to elemental sulphur will sometimes naturally become established in anaerobic lagoons. Prolific growth of these can occur during warm weather, giving lagoons a distinctive pink or purple colour. They are considered helpful in reducing H\textsubscript{2}S odours.

ADVANTAGES AND DISADVANTAGES

Anaerobic lagoons, used independently or in a two-lagoon (anaerobic-aerobic) system, offer the following advantages:

- construction cost is relatively low
- little or no labour required to operate
- low maintenance and operating cost
- lagoon effluent can be applied to land or treated by aerobic lagoon prior to final discharge
- lagoon effluent can be reused for waste removal from buildings with flush-type waste handling
- storage provision allows flexibility in land application

The disadvantages include:

- objectionable odours
- sludge accumulation requiring removal and disposal
- ground or surface water pollution from improper construction and/or management
- removal of land from agricultural production
- fertilizer value is reduced through ammonia volatilization losses and settling of phosphorus and potassium compounds to bottom sludges. For discharging systems with no land application, no fertilizer value is realised.
FIGURE 5.7 RECOMMENDED ANAEROBIC LAGOON LOADING RATES.
DESIGN OF ANAEROBIC LAGOONS

**Loading Rates**

Anaerobic lagoon designs should be based on a loading rate of organic material per unit lagoon volume (Loehr, 1974). This can be expressed in terms of either daily BOD or daily volatile solids (VS) loading per unit volume. A BOD loading rate has been traditionally used in New Zealand and this convention will be continued in the following recommendations.

In recent years, most livestock waste lagoon systems have been designed according to criteria contained in Lagoon Treatment of Farm Wastes (Ministry of Works, 1972). This has been expanded and additional material presented in later publications such as that by McGee (1976).

Temperature is most important in anaerobic lagoon performance and mean temperatures are significantly different from one end of the country to the other. Because of long detention times and relatively low loading, anaerobic livestock lagoons actually tend to function as facultative lagoons and temperature corrections for facultative lagoon design are well documented (Gloyna, 1971). Using mean temperature data (Gentili, 1976) and adopting the facultative lagoon temperature corrections, recommended loading rates which account for temperature differences were developed. These are shown in Figure 5.7. The gradation in loading rates with temperature is comparable to that recommended for anaerobic livestock lagoons overseas (White, 1977; U.S. Dept. of Agriculture, 1975). These should not be regarded as completely rigid values. Local conditions or specific circumstances may justify modifications to these loading rates. For example, lagoons constructed at higher elevations in mountain areas will be operating at lower temperatures and loading rates should be reduced in the range of 15 to 25%.

Lagoon volumes based on these loading rates also do not allow for waste storage. It is often desirable to collect and store wastes for periods of several days or even months, primarily in instances where lagoon effluent is applied to land. This allows more flexibility so that spreading does not have to be done during wet periods or so that spreading can be coordinated with grazing, crop planting and harvesting, and as labour is available.

**Lagoon Volume**

The total lagoon volume required will vary with the type of final effluent disposal. For a continually discharging anaerobic-aerobic lagoon system, the minimum anaerobic lagoon volume is simply the recommended treatment volume as illustrated in Figure 5.5. If storage of wastes or of stormwater runoff and direct rainfall is needed, these must be compared with the treatment volume. A portion of the treatment volume can be used as storage volume and be pumped out periodically, but this quantity should not exceed 1/3 of the treatment volume. This concept is illustrated in Figure 5.8.

This sizing procedure for storage is based on the premise that it is acceptable to exceed the design loading rate of the lagoon for temporary periods following pump-down which reduces the treatment volume. Anaerobic lagoons are capable of handling increased loading for limited time periods without adverse effect and overseas experience with this procedure has been successful. The most serious consequence is the potential for increased odour during the period following pumpdown, but this has not been observed to be a problem so far. As more systems of this type are installed, these criteria will be re-evaluated and modified if necessary.

5-8
When sizing lagoons, do not neglect to add capacity for any planned expansion of livestock numbers. It is much easier and more economical to include added capacity during initial construction than to enlarge at a later date.

Estimating Waste Load

Where measured data are not available, BOD production values as listed in Tables 2.1 and 2.2 may be used to predict total BOD load.

Shape

Lagoons should be uniform in shape, preferably approaching square. Rectangular and circular shapes can also be used. For elongated shapes, length should not exceed twice the breadth. Keep in mind that some time, sludge removal from the lagoon may be necessary. This can be done by excavators, which usually have a maximum reach of about 10 metres, draglines with longer reach, or pumped after mechanical or hydraulic agitation to bring settled sludge into suspension.

In general, batter slope on banks should not be steeper than 2 horizontal to 1 vertical. Slope of interior banks under the normal water level can be steeper (e.g. 1 1/2:1 or 1:1) in some silt and clay soils, but this should only be upon the recommendation of a qualified specialist with a knowledge of the specific soil characteristics. Unless local authorities specify otherwise, batters on exterior banks should be 2:1 if grazed or if cover is left uncut. If banks are to be mowed, a 3:1 batter should be used.

Bank tops should be wide enough to allow vehicle access for maintenance. Top widths of 2.5 to 4.0 metres are adequate with the 4 metre width providing greater ease of access for large cleaning equipment. Grading of embankment tops away from the lagoon reduces the amount of runoff to be accommodated by the system and avoids surface ponding which might result if an attempt is made to grade them level.
Depth

Anaerobic lagoons should have a liquid depth of at least 2 m. The presence of oxygen in lagoons less than 2 m deep inhibits the anaerobic bacteria and reduces the rate of decomposition. Also, gas bubbles rising from the biologically active bottom sludge are the main cause of natural mixing and because of greater bubble path length and larger bubble size, mixing due to rising gas bubbles is greater in deep ponds than in shallow ponds. Deep ponds accumulate more heat than shallow ponds and have a more uniform temperature (Oswald, 1968), and so have a more stable performance. If water table and soil conditions permit, lagoons can be as deep as 6 m, although depths of 3 to 5 m are satisfactory and are most common. A free-board of at least 0.3 m and preferably about 0.6 m, should be provided above the normal liquid depth for all lagoons.

The following examples illustrate the procedure used to determine required lagoon sizes under different circumstances.

EXAMPLE 5.1  200-cow dairy farm, Palmerston North area,
average cow size 500 kg
BOD/day = 200 x 0.08 = 16 kg (Table 2.2)

Use an anaerobic lagoon followed by an aerobic lagoon with discharge to a stream (aerobic lagoon sizing shown in section on aerobic lagoons).
Recommended anaerobic lagoon loading (from Figure 5.7), 24 g BOD/m³ day

\[ \text{treatment volume required} = \frac{16,000}{24} = 666 \text{ m}^3 \]

(= 3.33 m³ per cow)

There are several methods to determine necessary lagoon dimensions. Two of these will be illustrated.

- Mid-depth method:
  This method is relatively quick in providing the lagoon dimensions but the volume estimate obtained will be about 5 to 10 percent less than actual, i.e. it oversizes the lagoon.
  Site conditions permit an effective liquid depth of 3.6 m (depth from bottom to outlet level).
  Then area needed at mid-depth = \( \frac{666}{3.6} = 185 \text{ m}^2 \)
  and dimensions at this depth can be 13.6 m x 13.6 m.
  With 2 to 1 batters and 0.6 m freeboard, total depth would be 3.6 + 0.6 = 4.2 m.
  Bottom dimensions would be 6.4 m x 6.4 m.
  Top dimensions would be 23.2 m x 23.2 m.
• Prismoidal method:
  An exact calculation of lagoon volume can be made using the prismoidal formula,
  \[ V = h \times (A_b + 4A_m + A_t) / 6 \]

where

\( V \) is volume
\( A_b \) is area at bottom
\( A_t \) is area at top (water surface)
\( A_m \) is area at mid-depth
\( h \) is depth

Using this formula to calculate the actual lagoon liquid volume from the dimensions estimated by the mid-depth method yields:

\[ V = 3.5 \times (41 + 740 + 433) / 6 = 728 \text{ m}^3 \]

This is about 9 percent larger than estimated by the mid-depth method. To select dimensions using the formula, a trial and error process must be used until correct size is selected. The mid-depth method can be used to obtain a first estimate. In this example, the following dimensions would be adequate:

mid-depth dimensions \hspace{1cm} 13 m x 13 m

top dimensions (with free-board) \hspace{1cm} 22.6 m x 22.6 m

EXAMPLE 5.2 200-sow piggery, Hamilton area
(see Example 2.2, Chapter 2)

A single anaerobic lagoon will be used with land application of the lagoon effluent.

From Example 2.2, we find the estimated daily BOD production to be 200 kg (200,000 g). For Hamilton area, allowable lagoon loading is

\[ 28 \text{ g BOD per m}^3 \text{ per day (Figure 5.7).} \]

Treatment volume required = \[ \frac{200,000}{28} = 7143 \text{ m}^3 \]
The farmer wants to provide storage capacity for 3 months waste accumulation in the anaerobic lagoon. Effluent from the lagoon will be pumped out periodically and applied to cropland and pasture. From Example 2.2, the total daily manure produced is 6435 l and dairy flush water is 18,000 l making the total daily waste volume to store

\[ 18000 + 6435 = 24,435 \text{ l} = 24.4 \text{ m}^3/\text{day} \]

For 3 months or 90 days, storage volume needed is

\[ 90 \times 24.4 = 2196 \text{ m}^3 \]

This volume is less than one third of the minimum treatment volume \((7142 \div 3 = 2381 \text{ m}^3)\) so a portion of the treatment volume can be used for storage and no additional storage volume need be provided. If longer term storage had been desired, up to one third of the treatment volume \((2381 \text{ m}^3)\) could be classified as temporary storage and additional storage required would have to be added to the treatment volume. For example, six-month storage would require:

\[ 2 \times 2196 = 4392 \text{ m}^3 \]

Extra storage to be provided would be

\[ 4392 - 2381 = 2011 \text{ m}^3 \]

The total volume required would be treatment volume + extra storage or

\[ 7142 + 2011 = 9153 \text{ m}^3 \]

However, since only 3 months storage is desired, the original treatment volume calculated will be used. Using the mid-depth method and an effective depth of 4 m, permitted by site conditions, the area needed at mid-depth is

\[ 7142 \div 4 = 1786 \text{ m}^2 \]

Dimensions at mid-depth can be 40 m x 45 m. With 2 to 1 batters and 0.6 m freeboard, total depth would be

\[ 4 + 0.6 = 4.6 \text{ m} \]

Bottom dimensions would be 32 m x 37 m

Top dimensions would be 50.4 m x 55.4 m

In areas where amounts of direct rainfall on lagoons during the storage period can be significant (e.g., greater than 250 mm), extra depth to provide storage for this should be added to the freeboard depth.

The preceding examples illustrate procedures for two very different types of situations. Specific circumstances may dictate the use of different design values from those shown here, sometimes based on experience and judgement of the designer. This is not undesirable if done on a sound basis.
In planning lagoon locations, consideration should be given to the direction of prevailing winds and the likelihood of odours being carried towards residences. To avoid complaints, lagoons should be located at least 300 m from neighbouring residences and longer separations are desirable, especially for large piggery waste lagoons. High, gusting winds tend to dilute and disperse odours, while slow breezes on warm days with high humidity can carry odours for great distances.

Locate the lagoon near the waste source. Lagoons must be located at least 45 m from farm dairies to comply with the Milk Production and Supply Regulations (1973). For piggeries, they can be immediately adjacent to animal housing if site conditions and local regulations permit. When possible locate the lagoon downhill from the source to allow gravity transport of the waste. In some situations, high water table, topography, or land availability might make it necessary for the lagoon to be higher than the waste source. A sump and solids-handling pump can be used to transport waste to the lagoon in this case.

The following construction guidelines are adapted from McGee (1976) and other publications. Recommendations may vary somewhat according to local regulations, climate and soil conditions. Specific information for each area may be obtained from the local Ministry of Agriculture & Fisheries (M.A.F) or Catchment Authority Offices.

**Soil Type**

Research and practice have shown that anaerobic lagoons are effectively self-sealing in most soils (Hills, 1976). In coarse sands and gravels, they would not be likely to seal well. However, it has been observed that aerobic lagoons frequently do not seal in many soils, with the result that effluent is lost by seepage rather than surface discharge. This is not considered a problem, except perhaps in areas where increased nitrate levels in groundwater are of concern.

Silt and clay soils are good for anaerobic lagoon construction as they allow rapid self-sealing. Even silty and clayey gravels are fairly impervious when compacted and are suitable for construction. Coarse gravels with little or no fines will not naturally seal and can have serious leakage problems, resulting in inadequate treatment volume and groundwater contamination. If a gravelly site must be used, it is advisable to install a clay, PVC or rubber liner in the lagoon. Bentonite clay for mixing with the lining material can be purchased or sometimes clay soils in the vicinity of the lagoon can be hauled in to form a clay blanket. Plastic or rubber liners are effective but are relatively expensive and susceptible to damage if sludge removal by excavation is necessary. Liners have functioned well in free-draining pumice soils where the soil behind the liner remains relatively dry, but have experienced failure problems in some soils due to movement of fines stretching the liner and damage from exposed stones after movement of fines (Cameron, 1980).

Unless soil characteristics are well known in the proposed lagoon location, it is advisable to conduct soil borings to look at underlying materials to beyond the proposed lagoon depth. From these, depth to water table and underlying permeable and impermeable layers will be known and no surprises encountered during construction. More specific advice on soil types and on sealing methods is available at MAF offices.
Construction

For economical construction, earth from the excavation should be used to form the above-ground banks. Effluent level in the lagoon will often be higher than the surrounding natural ground elevation. Banks must be well constructed to prevent seepage, excessive settlement, and deterioration with time. Before the banks are constructed, a key trench should be dug 600 mm deep and 2 m wide beneath the centre of the bank. Fill should be compacted over the entire surface after each 150-200 mm layer is added. If soil is too dry to compact, water should be added. Best compaction is obtained with heavy rubber-tyred vehicles and with sheepfoot rollers. Track vehicles have their weight spread over a large track area and are not effective in compaction, so should be used for compaction only on small fills for small lagoons.

All topsoil should be stripped from the lagoon and bank area and stockpiled to be replaced later on the banks to improve regrassing. After covering the constructed banks with a lightly compacted layer of topsoil, they should be planted to achieve a good stabilization. A mixture of Phalaris, rye, timothy, and clover should produce a satisfactory turf. Planting of low shrubs in the natural ground area surrounding the banks may also improve lagoon appearance, but shrubs should not be planted on banks due to the weakening effect of roots. The effect of wind on anaerobic lagoons is not clearly understood. Mixing due to wind is beneficial to lagoon performance, while lowering wind velocities may reduce convective heat loss and oxygen uptake, thus improving anaerobic decomposition. The net effect of planting tall trees around an anaerobic lagoon is lowered wind velocity and this might or might not be desirable. The effect of trees filtering out odours usually is desirable. Aerobic lagoons definitely benefit from wind action and the planting of tall trees in the surrounding area is not recommended.

Lagoons should be fenced for safety reasons. The banks may be grazed for grass and weed control, preferably by sheep or goats.

Piping to Lagoons

Buried PVC pipe is usually the most economical and troublefree method to carry liquid waste to lagoons, although open concrete channels may be more easily used in some instances. Pipe should be buried 300 to 600 mm to prevent damage and deterioration.

For dairy wash-down systems, recommended flow rates are about 14 m$^3$ per hour and most systems would deliver this amount or less. Washdown hoses for piggeries will have similar flow rates. If gravity flow piping to the lagoon is used, for flows of this size, 100 mm PVC will be adequate to handle the effluent where fall is at least 1 in 100 (1 percent). Falls of less than 1 in 100 should be avoided and falls of 1 in 50 (2 percent) are recommended where possible.

For systems with higher flow rates, such as piggeries with flush tanks, pipes to lagoons must be large enough to carry peak flow at the end of the flush gutter or combined flows from several gutters. If too small, the restricted flow will cause temporary ponding of the flush water at the gutter outlet and allow solids to settle and accumulate. Recommended pipe sizes for this situation can be found in the flush gutter section.
Inlet pipes should preferably discharge below the lagoon water surface and should extend at least 6 m into the lagoon or should terminate directly above the base of the slope as illustrated in Figure 5.9. Loading then is done in a deep area where maximum bacterial action occurs. Experience has shown that mixing from wind and gas is adequate in livestock waste lagoons so that loading in the exact lagoon centre is not necessary.

Inlet pipes should be supported by a rectangular or V-shaped channel made of treated timber. The channel should be supported by treated timber posts every 2 to 3 m. Alternatively, a flexible pipe inlet can be supported by floats and positioned by guy wires.

![Diagram of lagoon embankment and inlet configuration](image)

**FIGURE 5.9 CROSS SECTION OF LAGOON EMBANKMENT AND INLET CONFIGURATION**

Piping between lagoons should be 100 mm PVC. Various configurations can be used to prevent floating solids from being carried to the aerobic lagoon. Three of these are shown in Figures 5.10, 5.11, and 5.12. The straight pipe shown in Figure 5.10 should have the inlet about 300 mm lower than the outlet. For cleaning, this type is easily rodded from the second-stage lagoon side (outlet end). The second type uses a tee fitting to prevent solids from entering. The bottom of the tee should be about 300 mm below the water surface and the tee should be within about 1-1.5 m from the bank to allow cleaning. The third type uses a treated timber baffle nailed to treated posts driven into the bank. Pipe slope on the latter two types should be about 1 in 100.

The size of the discharge pipe from the last lagoon cell must be large enough to handle the average discharge flow and any peak flows expected. Also it should not be susceptible to clogging. Although floating solids should not normally be present in aerobic lagoons, it may still be advisable to install the discharge pipe so as to prevent clogging from these.
FIGURE 5.10 REVERSE SLOPE LAGOON OVERFLOW PIPE.

FIGURE 5.11 OVERFLOW PIPE WITH TEE INLET BAFFLE.

FIGURE 5.12 OVERFLOW PIPE WITH TIMBER INLET BAFFLE.
Stone Traps

Stone traps are often provided at the entry end of the pipe carrying waste from the yard to the lagoon. These may reduce chances of pipe clogging, but must be diligently maintained by regular cleaning to be of value. They are not considered necessary for open channel conveyances. Where pumps are used, stone traps or other devices are recommended to protect the pump and these are discussed in the pumping section.

Anaerobic Lagoon Management

If possible, fill the lagoon with water to its minimum design volume before adding any waste. Loading should then be gradual (say, reaching full load in a month) so that the proper balance of bacteria types will develop. Temporary alternative disposal might be preferable to overloading a lagoon during start-up.

The best time for start-up is early Spring (August - September) to allow bacteria to become well established over the Summer before colder temperatures occur the following winter. Lagoons started in Autumn and heavily loaded all Winter may develop serious odour problems the following Spring and Summer and it could take several years before good operation is possible.

Anaerobic lagoons are not easily upset and can accept variable BOD and solid loadings from accidental spills, process variations, or intermittent operation such as no waste input over weekends or longer, without adverse effects (Loehr, 1974). However, if temporary overloading or other factors causes pH to drop below 6.4 and septic conditions with excessive odour emission occur, add slaked lime or caustic soda (lye) daily at a rate of 1.6 kg per 1000 m of lagoon volume until the pH is about neutral (7.0) (Midwest Plan Service, 1975). Determine the cause of the problem if possible and take action as necessary to correct.

Where very little dilution water is regularly added to lagoons, particularly with piggeries using scrapers, salt concentration in the lagoons can become high enough to interfere with performance. If tests show that inorganic dissolved salt concentrations exceed 5000 milligrams per litre (comparable to a specific conductance of 7600 micromhos per cm) the lagoon should be partially pumped out and fresh water added (Miner and Smith, 1975).

Lagoons which have storage volume included and are meant to be pumped down periodically should have this done before the water level is higher than the freeboard line. Equipment and application rates for this are discussed in the land application section. As noted previously, the volume allotted to storage can be emptied, but lagoons should never be pumped below a level where 2/3 of the treatment volume remains, except during sludge removal.

Anaerobic Lagoon Sludge

Sources and Composition

In this section, the term sludge is used to describe the variety of materials that accumulate in anaerobic lagoons. It includes the indigestible organic fraction of animal wastes, clays, silts, sands and gravels as well as material washed from animals, feet and farm machinery. The organic fraction contains lignified cellulose which is resistant to
decomposition by the micro-organisms present. Organic material is the major component (30-60% of total solids) of anaerobic lagoon sludge. A typical farm dairy sludge has a total solids of 5-9% and piggery up to 15% total solids, both with volatile residue of about 50%. Volatile solids of up to 80% have been reported for newly deposited sludge reducing to 50% 4-5 years after deposition (Nordstedt and Baldwin, 1975). The loss of volatile solids results from anaerobic digestion of the sludge. The easily digested organics are consumed by bacteria leaving only the most resistant material. Sludge is an important source of nutrients. A cubic metre of wet sludge from farm dairy and piggery lagoons contains approximately 5 kg of nitrogen, 2.5 kg of phosphorus and 3.8 kg of potassium. (Drysdale, 1980; Vanderholm, 1980).

Accumulation Rates

• Farm Dairy Lagoons:

An investigation in Florida USA (Nordstedt and Baldwin, 1975) reported a sludge accumulation rate of 0.0038 m³ per kg VS added (m³/kg VS) with a daily lagoon loading rate of 0.115 kg VS/m³. Preliminary investigations on a farm dairy lagoon at Lincoln College (Drysdale, 1980) show a sludge accumulation rate in the order of 0.006 m³/kg VS with a lagoon loading rate of 0.08 kg VS/m³.day. This accumulation rate is very high, about 0.8m³/cow.year and could result from the low loading rate. Further investigations are being carried out to clarify this point. The variability of lagoon loading rates due to changes in farm management and feeding regimes coupled with variable rates of sludge digestion due to seasonal temperature changes make it difficult to predict sludge accumulation rates.

Practical experience indicates that farm dairy lagoons do need desludging after about 5-10 years' operation when loaded at recommended rates. Under-sized lagoons and lagoons in cold regions are being desludged annually. In some cases this involves removing a thick surface scum (Figure 5.13), consisting of sludge particles brought to the surface by gas release from the bottom sludge. Aerobic lagoons do not collect significant quantities of sludge under normal operation.

• Piggery lagoons:

The sludge layer in an 18-year-old anaerobic lagoon receiving wastes from a finishing unit at Ames, Iowa has not filled as predicted and has stabilized at about 270 mm (Smith, 1980).

When to desludge

As a general rule the anaerobic lagoon should achieve at least 70% reduction of the volatile solids from the incoming wastes. Should the VS reduction fall below this, the cause is likely to be either sludge carryover indicating the need to desludge, or lagoon overloading indicating the need to check the compatibility of the loading rate and lagoon size.

The actual level of accumulated sludge does not necessarily indicate its effect on lagoon performance. After 4 years of operation the anaerobic lagoon at Lincoln College dairy was 3/4 full of sludge, but no loss of performance had been detected. To check lagoons, two steps are needed. Sludge levels should be checked annually by probing with a long pole or similar methods. When significant sludge levels (e.g. 1/2-full or more) are observed, lagoon performance in terms of volatile solids reduction should be checked. Obviously, this won't be done by farmers, but a service of this type could be provided by regional water boards or catchment authorities with analytical laboratories.
Until this type of service is provided, a rule of thumb to follow is that sludge removal should be done when sludge has accumulated to about 2/3 of the normal lagoon depth.

Reducing the sludge accumulation rates

In some situations indigestible material can be screened or settled out of the waste flows entering the anaerobic lagoon. Suitable methods are described in the solid-liquid separation section, but once removed the screened solids still have to be dealt with. In general, screening or settling are not needed prior to lagooning but may be justified in some situations.

Sludge removal

Before commencing desludging operations consider the alternative methods described. In some cases it may be more effective to combine various aspects of each option to achieve the best results.

- Option 1:
  Crust Removal. In heavily-loaded lagoons a thick crust often forms. This is made up of the same indigestible organic material that normally forms a portion of the bottom sludge. The crust can be removed by using a drag line or an excavator as shown in Figure 5.13. Different bucket configurations are available and local contractors usually have experience in most appropriate methods to satisfy local conditions.

![FIGURE 5-13 EXCAVATOR REMOVING SURFACE CRUST FROM A LAGOON](image-url)
Some drain cleaning buckets are able to scoop up the floating scum, but have difficulty retaining the material whilst being lifted high enough to load the material on to trucks. In some cases it may be useful to use a floating boom to collect the floating sludge and draw it closer to where the machine is operating.

- **Option 2:**
  In cases where the sludge to be removed is under water, the water is best pumped off before removing the sludge with a drag line or excavator. If all the inflows can be eliminated for a period the bulk of sludge can be reduced considerably by pumping out as much water as possible. The remaining material, although sloppy, is more easily handled by digging machines than if the water had not first been removed.

- **Option 3:**
  Hydraulic dredging, using a large capacity pump (5 m$^3$/min) to mix the whole lagoon contents and keep solids suspended while pumping the slurry to a land disposal site has been used successfully (Sweeten et al, 1980). Either wild flooding or large diameter sprinklers can be used to spread the slurry on land. Although not readily available at the moment, this option is potentially the cheapest and most convenient method of sludge removal and land application.

- **Option 4:**
  Twin anaerobic lagoons can be used. The first will accumulate sludge while the second is being dewatered. This system is widely used to dewater sludge from municipal waste treatment plants. It is a practical solution where space and time are readily available.

It has recently been suggested (Gunn, 1982) that it is advisable to leave thin sludge layer, say 300 mm, after desludging as lagoons completely de-sludged have been observed to perform less effectively for some time.

**Land Application**

The sludge contains valuable nutrients which can be utilized by spreading the sludge on land. For details on application rates refer to the land application section.

As sludges have high TS contents they are unsuitable for pumping over long distances so either trucks, slurry tankers or solid manure spreaders will be needed.

**Lagoon start-up procedure**

After being emptied the anaerobic lagoon must be refilled prior to receiving any wastes. Start-up procedures are detailed earlier in this section. An alternative source of water to fill the anaerobic lagoon is that held in the aerobic lagoon. Aerobic lagoons can be safely lowered to about 300 mm deep, provided no effluent is discharged from them until they have regained their normal operating depth of about 1-1.5 metres.
long ditches

In the early 1970's some interest was shown in the use of internal farm drains as a treatment system for farm dairy wastes. Some of these ditches were monitored and, often, a reduction in pollutant load, with time and length of ditch could be shown. However, drainage and runoff from the catchment area was usually present and, with no account taken of flow rate, the effects of treatment and dilution could not be separated (Sloan, 1974). Large volumes of drainage water would also tend to flush out the solids from such ditches, reducing detention times and the level of treatment.

The U.K. system of "barrier ditch" treatment of effluent (MAFF, 1975) aims at the total exclusion of extraneous water and has formed the basis of subsequent attempts at "long ditch treatment". Monitoring has demonstrated the success of a number of these systems (Thornton, 1978; McGee, 1980) but it should be noted that, when compared to lagoon treatment systems, long ditches are still relatively untested. However, the long ditch system has shown promise and can be considered as a viable alternative to lagoon treatment, in certain cases.

There are four distinct types of channel which may be considered loosely as "long ditches". These are the internal farm drain, the blind ditch, the solids retention ditch and the retention and treatment ditch.

INTERNAL FARM DRAIN

This is usually part of the field drain system, with an outfall into a water course. If the ditch is free-flowing some purification of the effluent occurs by dilution and by the activity of bacteria and algae, the same natural purification process that occurs in rivers. There will be some settlement of solids in pockets and during periods of low flow. However, drainage and paddock runoff water will later tend to flush out the solids. A monitoring study involving 4 such ditches, (Nelson, 1974) showed that, in all but one case, there was evidence of solids being carried out with the drainage to pollute neighbouring drains.

Additional solids retention and treatment may be achieved by erecting weirs across the ditch but in some cases this will interfere with the prime function of the ditch as a drainage channel. It is generally agreed that this is not an effective treatment system and is, therefore, not recommended in this configuration.

BLIND DITCH

The blind ditch, or soakaway, has no outfall to a watercourse. "Treatment" is provided by allowing the solids to settle out and the liquid fraction to be removed by seepage and evaporation. Accumulated solids must be cleaned out of the ditch, from time to time, and spread on land. The surface area of such ditches is normally insufficient to account for total loss of liquids by evaporation and seepage must play a major role. Thus, only pervious soils are suitable and, with these, there will often be a risk of ground water pollution, especially in alluvial areas where farm water supplies may be drawn from shallow aquifers.

Blind ditches may give rise to serious odour problems at times, with the accumulation of partially dewatered and decomposing solids.
SOLIDS RETENTION DITCH

The idea of using the basic long ditch design for the purpose of solids removal only was put forward by Gerritsen (1978). The difference is that sufficient volume is provided, within the structure, for settlement of solids only and biodegradation of the effluent is likely to be minimal since the ditch will be over loaded relative to current treatment standards. The outfall from the ditch will still be of poor quality and may require further treatment before discharge. The main criteria for the design of a solids retention ditch are:

- Retention must be of sufficient time to allow settling
- Flows must be low to avoid flushing of solids
- Volume must be sufficient to hold solids accumulated for at least 1 year

The last point is the limiting factor. From Table 2.2 of Chapter 2, the daily solids load in farm dairy effluent is 0.36 kg/cow. Over a 280 day lactation the effluent contains 0.36 x 280 = 101 kg solids. If the solids settle in a sludge of about 10% dry matter, the volume will be approximately 1 m³. The system allows 1.0 m³/cow capacity. (Considerably less than long ditch and other treatment systems).

Sufficient hydraulic retention is provided to allow proper settling. It has been suggested (Gerritsen, 1978) that a solids retention ditch may replace the anaerobic lagoon and may be combined with an aerobic lagoon to produce a satisfactory effluent. However, at the present time, there is insufficient experience under New Zealand conditions, to predict the performance of these systems and recommend their adoption.

RETENTION AND TREATMENT DITCH

The 'retention and treatment ditch' is here taken to imply a ditch which is distinct from the farm drainage system and which has been specifically designed and constructed for the retention and treatment of effluent prior to discharge to a watercourse.

The excavated ditch is divided by barriers, e.g. earth, wood, concrete, into a series of sections, each of which overflows into its adjacent, lower neighbour. The upper sections are primarily settling chambers, affording high BOD reduction, as the solids are removed. The remaining sections function essentially as 'mini-facultative lagoons', with the lower depths of each section anaerobic and the surface zone aerobic.

LONG DITCH AS TREATMENT SYSTEM

A long ditch is only suitable for treating dilute liquid wastes, and is generally unsuitable for raw wastes e.g. undiluted cow or pig manure. Experience has suggested that the range of 2000 - 3000 mg/l BOD is the maximum strength waste that can successfully be treated (MAFF, 1980). High strength wastes such as silage effluent and waste milk must be excluded from the system. Roof water and clean yard runoff should be drained separately since periods of high rainfall intensity will result in excessive flow and flushing of solids from the ditch. Stormwater diversion from fouled areas should also be provided and clean water could usefully be channelled to the end of the long ditch system for dilution of the final discharge. Field drainage (tiles and ditches) should be excluded from the barriered sections of the long ditch.
Successful experience with the long ditch system in New Zealand so far appears to have been limited to treatment of farm dairy wastes but it seems likely that, in appropriate circumstances, DILUTE piggery wastes could also be treated in this way.

The long ditch may be a viable alternative to lagoon systems, particularly under certain circumstances e.g. where there is difficulty in lagoon siting, where an existing ditch may easily be adapted, or if a farmer has ready access to ditch cleaning equipment.

ADVANTAGES AND DISADVANTAGES

The long ditch, when compared to other treatment systems and methods of disposal, offers a number of advantages:

- cost of excavation will often be less than for anaerobic-aerobic lagoon systems due to reduced volumes
- excavation is relatively simple. Farm ditching equipment can be used
- BOD reduction up to 95% is possible (Thornton, 1978)
- usually the ditch will not disrupt the paddock layout. This may ease fencing requirements
- low maintenance and operating costs compared with land disposal
- solids removal much easier than for anaerobic lagoons
- flexible, can be combined with anaerobic or an aerobic lagoon; sometimes additional sections may be added if treatment proves inadequate.

Disadvantages are:

- inadequate design and construction and improper management may result in problems with pollution of ground and surface waters and in objectionable odours due to excessive solids accumulation
- possible problems of siting in areas with intensive drainage schemes due to drainage layout
- higher labour requirements than lagoons due to the need for much more frequent solids removal
- the fertilizer value of the wastes is mostly lost if the effluent is discharged to a water course. Settled solids, however, are returned to the land.

LONG DITCH DESIGN

The basic requirement is for access to a long strip (the longer the better) of gently sloping land. Details such as length, depth and number of sections are often not critical but some general guidelines are included here.

Site

Generally, any restrictions relating to siting of anaerobic lagoons will also be applicable to long ditches.

All parts of the drain must be a minimum of 45 m from the dairy and its water supply source. Long ditches may smell, especially during cleaning operations and should, therefore, be sited well away from neighbouring residences - a minimum of 300 m has been suggested for anaerobic lagoons. Consideration should also be given to the direction of prevailing winds.
As a safeguard, local authority bylaws should be consulted about these points at an early stage.

Ideally, gently sloping land is best suited for the barried sections of the ditch, with the general slope towards the watercourse. At least 1:100 grade is necessary for adequate flow to occur. A steeper slope requires ditch sections to be shorter and a greater number of barriers will be necessary to achieve the desired capacity. On steeply sloping land, or if space is limited, the ditch may often be accommodated by a zig-zag layout along the site contour.

The use of an existing ditch for the barried sections should be avoided. The lower, free-flowing section, however, may utilise an existing ditch with advantage since any addition of clean water from field drains will help to improve the final effluent discharge by dilution. The free-flowing section of the long ditch may also be over much steeper grades.

Soil type and groundwater table are other important considerations. The base of the ditch must be above the water table and, therefore, low-lying, poorly-drained sites with a high water table should be avoided. Siting should be such as to prevent possible contamination of shallow aquifers and any nearby water supply boreholes. Some seepage of pollutants is likely to occur in light, sandy soils which, in any case, would probably be unsuitable for ditch construction due to structural instability.

Siting should allow construction of a ditch of sufficient capacity and, if possible, expansion of the system by the addition of further sections later, if necessary.

Overhanging trees and hedges should be well clear of the ditch since falling leaves will increase the treatment load and good access for cleaning must be allowed for.

Size

The long ditch must be designed to suit the needs of the particular farm. No clearly defined design criteria are available for long ditch systems at present. White (1977) has advised detention times of 30-60 days for anaerobic lagoons during periods of active decomposition, i.e. lagoon temperatures above 15°, and 20-30 days for facultative lagoons. Fluid retention periods of 60 days were suggested by MAFF (1975), based on laboratory and field observations, following the extensive monitoring of barrier systems over several seasons. Revised recommendations (MAFF, 1980) now suggest that 90 DAYS IS PREFERABLE but in N.Z., with generally higher temperatures and greater evaporative losses than U.K., it seems that, in many circumstances, 60 DAYS RETENTION MAY BE ADEQUATE.

Although not critical, section length might be 30-50 m and it is suggested that the ditch should comprise at least 3 sections. This will allow the bulk of the sludge and scum to be retained in the upper section, which can be cleaned out at regular intervals. The length of free-flowing section below the barred sections is not critical either, but a minimum of 300 metres prior to final discharge is suggested.

Long ditches to this specification have been monitored and proved successful in the treatment of farm dairy effluent, both in N.Z. and the U.K.

Systems in use in New Zealand (Thornton, 1978; McGee, 1981) commonly have a working depth of 1.5 m. Ditch depth should not be less than 1.5 m in the
first 2 sections. A ditch cross section is shown in Figure 5.14. In practice, this may be altered, depending on soil type and the type of machinery used for construction and cleaning.

No allowance for runoff has been made. There should be sufficient capacity for runoff from open areas of fouled concrete e.g. collecting yards, although stormwater diversion is desirable. The ditch should be designed on the basis of maximum flow conditions. This will usually be in the summer months, since there will be zero effluent flow from factory supply herds in the winter and minimal flow from town supply herds, milking fewer cows. Runoff contribution should be assessed from the wettest 60 days
during the milking season or from the 10-year frequency, 24-hour duration storm runoff, whichever is greatest. Calculation of the runoff contribution is detailed in the section on runoff from open lots.

**Long Ditch Sizing Examples**

The examples outlined in the section on anaerobic lagoons are used here also.

**EXAMPLE 5.3**

200-cow dairy farm, Palmerston North area

Daily output farm dairy effluent = 50 litres/cow

Allowing 60 days retention,

volume required = 50 x 60 = 3 m$^3$/cow

It should be noted that the ditch volume is close to the volume of 3.33 m$^3$/cow recommended for anaerobic lagoons in the same area.

To this volume must be added the 60 days yard runoff volume (from the wettest period of the year)

For 200 cows ditch volume = 200 x 3 = 600 m$^3$

Allowing for runoff from collecting yards and concrete immediately adjacent to dairy, say 800 m$^2$ concrete. Rainfall for wettest 60 days of year, June - July = 189 mm (N.Z. Met. Service, 1979); allowing 85% runoff from concrete (Table 3.8):

volume of rainfall = 800 x 0.189 x 0.85 = 129 m$^3$

Considering the 10-year frequency, 24-hour duration storm, rainfall = 93 mm (Table 3.7): 95% runoff (Table 3.8).

volume of rainfall = 800 x 0.093 x 0.95 = 71 m$^3$

Taking the higher figure for runoff contribution:

total volume of effluent = 600 m$^3$ + 129 m$^3$ = 729 m$^3$

Allowing ditch section an area of 3 m$^2$ (Figure 5.14), REQUIRED LENGTH

= 723 m$^3$ / 3 m$^2$ = 241 m

This might be arranged in 5 sections of about 50 m each.

The average BOD concentration of farm dairy effluent is 1500 mg/l (Table 2.2), i.e., within the range permissible for long ditch treatment (MAFF, 1980).

**EXAMPLE 5.4**

200-sow piggery, Hamilton

Total livestock converted to equivalent number (1800) of 50 kg pigs (see Example 2.2)

From Table 2.3, daily excreted manure per 50 kg pig is about 3.3 l
Adding 10% for spilled feed and water

Daily waste volume = 1800 x 3.3 x 1.1
= 6534 l

The farm uses 18000 l of water per day for flushing and washdown

total waste volume = 18000 + 6534
= 24534 l/day
Consider BOD of the waste

\[ 1800 \text{ pigs} \times 0.1 \text{ kg BOD/pig.day} = 180 \text{ kg BOD} \] (Table 2.3)

Allowing 10\% for spilled feed, bedding

\[ \text{BOD} = 200 \text{ kg/day} \]

Waste volume = 24534 litres

\[
\text{Influent BOD} = \frac{200 \times 1000 \times 1000}{24534} \text{ mg/litre} \\
= 8,152 \text{ mg/litre}
\]

Maximum permissible BOD is in the range 2000 - 3000 mg/l (MAFF, 1980) and the influent BOD is therefore too high for effective treatment by long ditch. If larger volumes of flushing water were used, reducing effluent strength, the size of the ditch would need to be considerably increased to provide adequate retention and a long ditch, in this example, would therefore be unsuitable. The use of the long ditch system will only really be appropriate on very small units or, in larger units, for the treatment of yard runoff and pen washings when most of the waste has been removed as a solid.

**Settling**

An initial settling treatment may be included to remove coarse solids from the effluent before it reaches the head of the long ditch. This will also remove stones and grit and help prevent pipe blockage.

The provision of a simple stone trap has already been discussed in connection with anaerobic lagoons. Larger settlement tanks have also been described under solid-liquid separation. Desludging an underground tank is often managed more easily than the removal of solids from the first ditch compartment and cleaning of the ditch itself will be less critical following pre-settling. However, the drawback is that the chambers of the tank need desludging regularly, perhaps once a week, to maintain efficiency, and the pre-settling will not allow any reduction in ditch dimensions to be made. Unless the effluent has to be piped over an appreciable distance to a site suitable for a long ditch, the justification for any sizeable settling facility is open to question. Under normal circumstances, a simple stone trap will give adequate assurance of avoiding pipe blockages and might be considered worthwhile.

**LONG DITCH CONSTRUCTION**

**Stone trap/settlement tank**

A simple stone trap configuration is illustrated in Figure 3.42, in the section relating to waste pumping. Settlement tank construction is illustrated in Figure 4.1 under solid-liquid separation. The stone trap or settlement tank will normally be constructed alongside the yard, at the head of the pipe/channel leading to the ditch.
Ditch

The ditch has the same basic requirements as a lagoon in terms of soil stability, embankments and fencing. Excavation of the ditch is normally carried out using conventional ditch digging equipment with spoil used to provide above-ground banks if necessary. On sloping sites, excavations can be placed on the uphill side of the ditch to divert paddock runoff from the ditch. Banks should be stabilised by compaction and regrassed. If possible, access to both sides of the ditch should be allowed. The barriers may be of earth, timber, or concrete. Two types of barrier are illustrated in Figures 5.15 and 5.16.
The cheapest and most effective barrier is the undisturbed earth dam. When a new ditch is cut, excavations should be carried out between the sites of barriers, rather than constructing a channel and then building barriers across. Earth barriers can also be strategically placed to double up as bridges for vehicle and stock access across the ditch. If the soil is permeable the banks should be compacted and the ditch should then self-seal reasonably well in most cases.

PVC pipes through the banks should have a vertical tee-piece on the inlet side to reduce the risk of blocking by floating scum and debris. The lower part of the tee-piece should be extended down from the surface so that effluent is drawn off at a position well below any surface crust. An easily removable sleeve fitting can be used which will allow rodding of the pipe, if necessary. On the outflow side, the pipe should overhang the earth barrier sufficiently to avoid erosion of the sloping bank. Compaction of earth around the pipe during installation should be sufficient to prevent leakage.

A further measure to limit the movement of surface scum along the ditch may be taken with the provision of internal scum barriers between the main barriers. These may be of timber sleepers or boards placed across the ditch, extending a little way below the surface, so that free flow within the ditch is allowed below the surface crust and above the bottom sludge layer.

Reinforced concrete blockwork and reinforced mass concrete have both been used to construct barriers. Adequate foundations should be provided to prevent the dam from sliding and the barrier should be extended well into the banks of the ditch. A waterproof seal of cement or plaster may be provided on the upstream side of the dam.

Timber sleepers should be bedded well in at the sides and base of the ditch, with vertical sleeper supports set in concrete. Sealing of timber dams can be improved by lining the upstream face with heavy duty polythene sheeting. The polythene sheeting should be well bedded into the soil at the bottom and sides of the dam. Compacted earth around the base and sides will improve the sealing of the barrier into the banks and floor of the ditch. With concrete or timber sleeper barriers, a baffle board should be provided in front of the throat of the barrier to retain floating debris (Figure 5.16).

**Piping**

Detailed consideration has already been given to piping, in the section on anaerobic lagoons. 100 mm PVC pipe will normally be satisfactory for the transport of effluent from the dairy to the ditch, and for piped connections through earth barriers. A minimum fall of 1:100 is needed. At the flow rates likely for dairy wash-down systems (about 14 m³ per hour), using 100 mm PVC pipe, recommended fall is 1:50, with a minimum of 1:100. (See also Table 3.3).

**Fencing**

The long ditch should be securely fenced against both children and stock. It should be decided, from the outset, whether access to the ditch is required from outside, or within, the safety fence. Ditch cleaning equipment or the vacuum tanker pipe should be able to reach over the top of the fence for cleaning purposes. Thus access is allowed to either side of the ditch shown in the plan view of Figure 5.14.
LONG DITCH MANAGEMENT

The system is not recommended unless the farmer is prepared to put in the management and maintenance work that is required.

The settlement tank, if included, must be desludged frequently, perhaps weekly, to maintain its efficiency. Desludging is normally achieved either by sucking out the contents of the tank by vacuum tanker or by pumping out following agitation. If this operation is left for too long, the tank will become ineffective and the sludge would probably require digging out, after compaction. A simple stone trap may be cleared with a shovel in a couple of minutes, perhaps on a daily basis.

Solids accumulation in the first two sections of the ditch will be rapid and experience has suggested that the sludge should be removed AT LEAST ONCE ANNUALLY to maintain efficiency. The liquid portion is first removed by vacuum tanker or by pump and accumulated solids are later removed by ditching bucket and spread on land. The barriers should by inspected for blockages and leaks regularly and any needed repairs to banks or barriers could be carried out at the same time as cleaning operations.

It should be noted that the lifespan of timber barriers is likely to be less than earth or concrete and their maintenance requirements higher.

Vegetation on the banks of the ditch should be kept cut down. Growth of water weeds/algae, commonly in the lower sections, may help to improve effluent quality by uptake of nutrients and by photosynthetic oxygenation of the water. However, excessive growth should not be allowed, since this may completely choke the flow in the ditch and may later impose an oxygen demand on the water due to plant death and decaying vegetation. Herbicides should not be used to control weeds on the ditch/banks since these may kill the bacteria responsible for treatment.

In most cases, where these systems have been observed in New Zealand so far, the management in general, and sludge removal in particular, has been sadly lacking or non-existent. It must be emphasised that a neglected long ditch soon loses efficiency and becomes useless.

anaerobic digestion

INTRODUCTION

Anaerobic means devoid of oxygen. Digestion is the process of decomposition taking place in a 'digester' and a digester is a sealed container maintaining anaerobic conditions. If a liquid mixture of organic material is held in a sealed container which is devoid of air or oxygen, anaerobic bacteria will grow, feeding on the organic material and converting the organic carbon to methane (CH₄) and carbon dioxide (CO₂). This process occurs naturally in swamps, causing 'marsh gas'. Originally man developed this process primarily for treatment of sewage and other wastes, but more recently as a method for producing energy, or as a combination of waste treatment and energy production.

'Biogas' is a term used to describe the mixture of methane and carbon dioxide produced. A normally operating digester will produce 65-70% methane by volume, but more carbon dioxide might be produced under less favourable conditions.
BIOLOGICAL CONSIDERATIONS

As discussed previously in this chapter there are two basic stages of bacterial degradation. The methane-forming bacteria are particularly sensitive and every effort is made to maintain favourable conditions for them in a digester. Such conditions are:

- pH 6.8 to 7.5
- Alkalinity 2500 to 5000 mg/l
- Temperature 30 to 35°C and constant
- Total solids concentration 4 to 10%
- Solids retention time 10 to 30 days
- Nutrients most animal manures contain satisfactory balance of the various nutrients. High ammonia concentrations (say 800 mg/l) can be toxic to the bacteria

Toxic materials such as antibiotics or heavy metals may significantly inhibit gas production.

ANAEROBIC DIGESTERS

There are several types of digesters and a number of different ways of operating them. Digesters for agricultural wastes will usually be smaller than 200 m³ and in this size range the three main designs are:

- (a) continuous and mixed digester
- (b) batch load system
- (c) plug flow system

CONTINUOUS DIGESTER

The continuous digester is regularly fed, at least daily or more often, with a specific volume of liquid and an equal volume is displaced from the digester. The volume of input may depend on the hydraulic detention time required. For example, if it is required to operate a 45 m³ digester on a 10 day hydraulic detention time, then 4.5 m³ is fed daily to the digester. The continuous system is operated as a completely mixed system. That is, the digester contents are maintained in a homogeneous state by some form of agitation which may be continuous or intermittent. Some systems with intermittent agitation extend the SOLIDS retention time by allowing a quiescent period prior to loading. By this means, the solids are allowed to settle out so that during loading a relatively solid free liquid (supernatant) is discharged. For this system it is necessary to make provision to draw off the settled solids (sludge) from the digester floor to prevent excess accumulation. Alternatively, if digester contents are fully mixed during loading and displacement, the solids retention time can be increased by passing the digester effluent through a settling tank, from which a portion of the settled solids can be recycled through the digester. This latter system has the advantage of minimizing the accumulation of floatable, less biodegradable solids (e.g. ligneous material and feathers), which can cause a thick crust or build up in the digester.

The continuous digester is normally operated at 30-35°C (mesophilic digestion), being maintained at these temperatures by heat exchangers which may use some of the methane gas produced by the process. Although operation at 50-60°C (thermophilic digestion) can significantly reduce
digestion time, practical considerations make mesophilic digesters most common in waste treatment practice. All of the systems being used on farms in New Zealand are operated in the mesophilic range.

**BATCH LOAD SYSTEM**

The batch load system is loaded once with the organic liquid and left to digest for a period of time (say 30 days) during which biogas is given off. The system is usually mixed and operated in the 30 to 40°C temperature range.

**PLUG FLOW SYSTEM**

The plug flow system operates as a longitudinal reactor where no forced intermixing occurs during the passage of the waste through the digester although natural mixing will occur. These systems may or may not be heated to the mesophilic temperature range.

The recommended hydraulic detention for the plug flow system is longer than for the batch system which is longer than for the continuous system. The respective relative ratios of detention times for equal energy output in the mesophilic range is about 3:2:1. Thus the volume of a plug flow digester would be about 3 times that of the continuous system for equal energy output.

**POLLUTION CONTROL**

From a waste treatment point of view, controlled anaerobic digestion achieves a basic stabilization of organic material. While there is no significant reduction in the volume of waste to be ultimately handled (there could in fact be an increase in volume if dilution, prior to digestion, is required), the digester effluent will be relatively odourless and the sludge more easily dewatered. It is unlikely that the digester effluent will be suitable for discharge into natural waters however.

Hobson (1976) reports on findings with regard to pollution reduction. Table 5.1 lists his findings. Also listed from Rowett Institute are results as reported by Bousfield et al (1979). This illustrates the variability that can occur and the number of dependent factors, such as treatment (e.g. storage) prior to digestion, solid content of influent, detention time and type of animal feed. Because anaerobic digestion involves the conversion of carbonaceous material to methane and carbon dioxide, there are substantial reductions in BOD and COD. However total nutrient content is virtually unchanged, although there may be conversion from a bound organic state to an available inorganic form e.g. protein nitrogen to ammoniacal N.
TABLE 5.1 POLLUTION REDUCTIONS FOR MESOPHILIC CONTINUOUS DIGESTION AT VARYING DETENTION TIMES (D.T.) AND INFLUENT TOTAL SOLIDS (T.S.)

<table>
<thead>
<tr>
<th>Ref.</th>
<th>30 Day D.T. 3.3% T.S.</th>
<th>10 day, 6%</th>
<th>20 day, 6%</th>
<th>20 day, 7.8%</th>
<th>20 day 14%</th>
<th>15 day, 6%</th>
<th>20 day, 6%</th>
</tr>
</thead>
<tbody>
<tr>
<td>COD</td>
<td>82.5</td>
<td>43.7</td>
<td>71.4</td>
<td>43</td>
<td>94</td>
<td>81.3</td>
<td>84.1</td>
</tr>
<tr>
<td>CO2</td>
<td>53.2</td>
<td>16.1</td>
<td>20.6</td>
<td>35</td>
<td>50</td>
<td>40.0</td>
<td>48.4</td>
</tr>
<tr>
<td>T.S.</td>
<td>36.0</td>
<td>17</td>
<td>23.2</td>
<td>45</td>
<td>61</td>
<td>17.5</td>
<td>22.6</td>
</tr>
<tr>
<td>VFA</td>
<td>92.6</td>
<td>65.2</td>
<td>77.6</td>
<td>59</td>
<td>90</td>
<td>69.7</td>
<td>83.3</td>
</tr>
<tr>
<td>NH₃-N</td>
<td>15.6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>29</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(a) Slurry stored 10 days prior to digestion, fed on barley ration
(b) (1) Hobson 1976
     (2) Bousfield et al 1979
FIGURE 5.17 CONTINUOUS FULLY MIXED HEATED DIGESTER — FLOW DIAGRAM
DIGESTER OPERATION

Figure 5.17 illustrates the general layout of a heated, continuous and mixed digester. Some of the more important operational factors are as follows -

- The feed input should be of the right consistency, depending on the type of feed. For example, vegetable material dry matter content should be about 7 to 10 percent and animal manure 5 to 7 percent. It is a simple operational procedure to add water if necessary and this is usually done in the balance tank. Removal of water is far more difficult.

- The digester should be fed at least daily and preferably more often. The volume fed daily will depend on the recommended detention time.

- In order to detect system failure at an early stage, gas production rate should be regularly monitored. This rate is indicative of system operation. A number of factors such as antibiotic contamination, temperature fluctuation or toxic inputs can cause quite rapid drop off in gas production and if not corrected may result in biological failure within the digester. Further understanding of the failure could be achieved by analysing the gas components.

- Provision should be made for the disposal or utilization of the liquid discharge from the digester.

- The most critical operation stage is the starting up of the digester. Unless done properly problems may be encountered. However, once initiated, digester operational requirements are generally routine and simple.

SAFETY ASPECTS

Mixtures of biogas and air can be explosive and certain precautions should be taken. A methane/air mixture within the range of 5% CH₄ to 14% CH₄ is explosive. This would correspond to 7.5% to 21% biogas, if the biogas contained 67% CH₄.

The precautions necessary are generally common sense. For example 'No smoking' signs adjacent to the plant or facilities using the gas, care with electrical wiring, earthing a metal digester, installing lightning conductors, having a water source available for cleaning and fire fighting, and siting the plant a safe distance from other buildings.

Where the gas is used or stored in enclosed sheds, good ventilation is necessary. The density of air is 1.29 g/l, CH₄ 0.27 g/l and CO₂ 1.98 g/l. Thus biogas with greater than 60% CO₂ is more dense than air, and can accumulate in cavities.

Flame traps should be installed in all gas pipe lines to prevent blow back. These can be made out of asbestos or metal gauze placed in the pipeline. An alternative flame trap is by bubbling the gas through water.

When repairing a digester all biogas should be purged out of the digester and pipelines but not by using air. Sewage works commonly use the exhaust gas from diesel engines.

When starting or restarting a digester the initial gas produced should be vented until all air is removed from the digester and pipelines.
Pressure relief valves should be installed to prevent pressure build-up and excess gas should be burnt at a safe distance from the plant.

Finally, some of the constituent gases are a danger to man. Carbon monoxide is fatal to man in four hours at 0.1% while hydrogen sulphide at 0.06% is fatal within half an hour.

BIOGAS UTILIZATION AND ENERGY VALUE

Energy requirement, energy production and utilization of biogas are discussed in detail in Chapter 8.

REFERENCES CHAPTER 5


aerobic treatment

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DAVID J. WARBURTON
principles of aeration

The principle of aerobic treatment is the use of free or dissolved oxygen by microorganisms in the degradation of organic wastes. The aerobes use the oxygen as a hydrogen acceptor, whereas anaerobic bacteria can use combined oxygen from sulfates, carbon dioxide, or organic compounds. An example of an aerobic reaction is the breakdown of glucose.

\[ C_6H_{12}O_6 \rightarrow 6CO_2 + 6H_2O \]

The generalised reactions within an aeration system are shown diagrammatically in Figure 6.1. The two important aspects of the system are the bacterial growth phase and the removal of the biological floc. If not removed, the floc is flushed out in the final discharge resulting in a poorer quality effluent (as measured by BOD). The failure to remove these suspended solids is a major reason for systems not achieving optimum treatment efficiencies.

Floc removal is generally achieved by sedimentation and the principles are similar to those presented in the solid/liquid separation section. The exception to this would be the removal of any algae from anaerobic stabilization lagoon discharge. Although often disregarded, should removal be required, filtration or coagulation followed by sedimentation (or flotation) are satisfactory systems of removal.

Aerobic treatment has many advantages which include:
- minimum odour when properly loaded and maintained
- large BOD removals providing a good quality effluent
- high rate treatment allowing smaller scale systems, e.g. less land required
- the final discharge contains dissolved oxygen (DO) which reduces the immediate oxygen demand on a receiving water
- the aerobic environment eliminates many pathogens present in agricultural wastes.

The main disadvantage of aerobic treatment is the energy cost of aeration at an adequate rate to maintain the dissolved oxygen levels needed to maintain aerobic conditions for microbial growth. In addition, some organics can not be efficiently decomposed aerobically. Should these be a problem, alternative treatment combinations would have to be investigated.

The changes in the bacterial reaction over time are presented in Figure 6.2. The implications of these curves are crucial in the design of aeration systems. If high-rate CONTACT STABILIZATION is desired, then an effective aeration system is required to meet the peak dissolved oxygen demand. This system would have a high aeration capacity but a small plant volume or liquid detention time (i.e. operation within the phase B zone of Figure 6.2). Conversely EXTENDED AERATION has a lower peak oxygen demand but due to the length of the aeration period, requires a larger investment for plant capacity (i.e. operation within the phase D zone of Figure 6.2).

The main advantage is in removing the need for primary sludge settlement. There is also greater total BOD removal and autolysis, (cell destruction by its own enzymes resulting in lower biological floc production). Sludge volume for further treatment or disposal is reduced and this is a major advantage in many applications.
FIGURE 6.1: GENERALIZED REACTIONS AND PROCESSES FOR AEROBIC TREATMENT
Phase A: Dispersed growth; substrate absorption.

Phase B: Rapid growth; substrate decomposition. High oxygen demand; contact stabilization treatment.

Phase C: End of growth period; reduced substrate decomposition; moderate oxygen demand; normal activated sludge-type aeration.

Phase D: Autolysis; endogenous respiration; low oxygen demand; extended aeration.

**FIGURE 6.2: PHASES WITHIN AN AEROBIC TREATMENT SYSTEM. DESIGN CRITERIA ARE SELECTED TO ALLOW OPERATION IN A PARTICULAR PHASE OF THE CYCLE.**
aeration systems

Aeration systems may be categorized by the method of supporting the microorganisms in the aeration basin or by the method of aeration. There are two categories of microbial support; film reactors and floc reactors, while aeration may be achieved by natural methods or mechanical aerators.

Film reactors include trickle filters and rotating biological contactors. In this group the microorganisms grow on fixed media (stone, plastic) and are provided with wastewater and air to maintain aerobic conditions in the biological film. As the film grows on the media it is naturally sloughed off and may be removed in a clarifier.

Floc reactors maintain the biological mass in suspension as flocs. Everything from high-rate activated sludge systems to aerobic lagoons are classified in this category and the principles of design have been satisfactorily applied to livestock waste treatment systems. The various types of aeration system are considered in the following section.

NATURAL AERATION

In naturally aerated systems (aerobic lagoons) oxygen from the atmosphere enters the lagoon liquid naturally, by diffusion, and by algae using waste nutrients and sun energy to produce oxygen by photosynthesis. The oxygen input by diffusion is aided by turbulent conditions while the algal contribution is influenced by sunlight, nutrient levels and other factors controlling photosynthesis. To maintain an odour-free operation, loading rates are usually planned to maintain a dissolved oxygen concentration in the lagoon of at least 1 mg/l. Even aerobic lagoons may go through short-term anaerobic conditions, or at least oxygen deficiencies, in the spring. Accumulated waste due to slower winter digestion may cause bacteria growth during rising spring temperatures to increase more rapidly than oxygen supply. While some odours may result, this condition should only persist for a short time and usually is not a problem for smaller, farm-scale lagoons.

During daylight hours, photosynthesis is often adequate to produce a supersaturated oxygen concentration in upper layers of the lagoon. However, there is still usually a bottom layer of anaerobic sludge, but decomposition products from that area are aerobically metabolized in the upper zones of the lagoon (Figure 6.3).

Naturally aerated lagoons are best adapted to treating relatively dilute effluents such as discharges from anaerobic lagoons. They are most commonly used in conjunction with an anaerobic lagoon for treating dairy or piggery wastes prior to discharge or land application. While they can be used by themselves to treat strong wastes such as livestock wastes, the required surface area for adequate oxygen intake is usually much too large to be economical. Furthermore, the high solids levels in the influent is not recommended for naturally aerated systems as they reduce light penetration and cause excessive sludge accumulation in the shallow lagoons.
PLANNING AND DESIGN

Design depth for a naturally aerobic lagoon should be 1 to 1.5 m. 1.5 m should be used for lagoons receiving raw wastes to provide sludge storage, while 1 to 1.2 m is adequate for pre-treated wastes with lower solids content. In lagoons less than 1 m deep, bottom growing aquatic weeds can grow, reducing the lagoon treatment capacity and adding to the loading in the form of dead plants. At about 1.5 m depth, the mixing of oxygen and water becomes limited, because natural, thermal and wind currents cannot satisfactorily mix dissolved oxygen down to these depths. Also, sunlight penetration for algae growth is negligible at depths beyond 1 m.

Aerobic lagoons are sized on the basis of BOD load per unit surface area per unit time. A loading rate of 8.4 g BOD per m² per day has been used nation-wide for some years. (This places the system in the extended aeration phase of zone D in Figure 6.2). Studies have confirmed that this loading rate has been satisfactory and this is the current Ministry of Works standard for municipal sewage lagoons (MWD, 1974). Aerobic livestock waste lagoons should be sized based on a loading rate of 8.4 g BOD per m² surface area per day.

Aerobic lagoon layout may be conducive to short-circuiting of flow in some instances, thereby reducing treatment effectiveness, and resulting in poorer effluent quality. This may be overcome by the use of a better shape, or baffles constructed of earth or other material to force the flow into a desired pattern. Under some conditions concentrating the load in a reduced area can cause overloading.
Two or more aerobic cells can be arranged in series. With this arrangement, the first cell should still be sized for the recommended loading rate of 8.4 g BOD per m² per day (MWD, 1974). The second cell may be sized to provide 20 days detention based on average waste flows, or designed on BOD loading rate allowing for the reduction in the first aerobic lagoon. This increases the total lagoon area over a single cell system and can only be justified when stringent effluent quality requirements exist.

Sludge accumulation in aerobic cells results both from incoming waste and from dead bacteria and algae cells. The rate of accumulation is slow and for correctly sized and managed aerobic lagoons, cleaning frequency should not be more often than 10 to 20 years if at all.

A properly sized and operating aerobic lagoon should remove 80% or more of incoming BOD (Loehr, 1974). The total removal by an anaerobic-aerobic 2 lagoon system should be about 95 per cent. Most of the solids and BOD in aerobic lagoon effluents are in the form of algal cells, rather than the original organic waste, and to achieve higher reductions, algae must be filtered out before discharge. Nutrient balance studies on aerobic lagoons in New Zealand have shown virtually no reduction in phosphates, although losses in total nitrogen of between 40 to 60 per cent have been recorded (MWD, 1974).

CONSTRUCTION

Construction recommendations are the same as for anaerobic lagoons. Since sun and wind action are important to aerobic lagoon performance, the planting of tall trees or windbreaks in the near vicinity, particularly up-wind, should be avoided. However, it is sometimes necessary to locate lagoons near standing trees. This should not be a major problem unless excessive shading or sheltering of the lagoon is envisaged.

Aerobic lagoons are not as effective in self-sealing as anaerobic lagoons and it is common in some areas to find aerobic lagoons losing all effluent by seepage rather than by surface discharge. The effect of this seepage on ground water quality must be considered. The other aspect of concern is that if seepage leaves exposed sludge in the aerobic cell, undesirable odour emissions may result from anaerobic decomposition. If these problems arise, lining methods similar to those described for anaerobic lagoons should be considered.

AEROBIC LAGOON EXAMPLE

The following example illustrates aerobic lagoon sizing.

EXAMPLE 6.1 (continued from Example 5.1, anaerobic lagoon sizing section).

Assuming a 70% BOD reduction in the anaerobic lagoon, BOD input to the aerobic lagoon

\[ = 0.3 \times 16,000 \text{ g per day} = 4800 \text{ g per day}. \]
Since the recommended aerobic lagoon loading is 8.4 g per m² surface area per day, the required surface area is

\[
\frac{4800}{8.4} = 571 \text{ m}^2
\]

This area would be provided by dimensions of 20 m by 29 m at the water surface. With a depth of 1 m and 2 horizontal to 1 vertical batter, bottom dimensions would be 16 m x 25 m. With 0.6 m freeboard, top dimensions would be 22.4 x 31.4 m.

**MECHANICAL AERATION**

**FILM REACTORS**

**Trickling Filters**

The plant consists of a vertical tower filled with media (stone or plastic) over which the wastewater (from which primary solids have been removed) is continually passed (Figure 6.4). The title is a misnomer as the action of a trickling filter is biological extraction by the growing film not removal of suspended solids by mechanical filtration. The design and reaction kinetics of a trickling filter are complex and vary with the type of waste, the media, the treatment efficiencies required and the environmental conditions. Bed depth for stone media filters (50-100 mm diameter rock)

![Diagram of a Trickling Filter Treatment System](image)

**FIGURE 6.4: SCHEMATIC DIAGRAM OF A TRICKLING FILTER TREATMENT SYSTEM.**
range from 1.5 m to 2.0 m while systems using plastic media may be up to 6 m deep. Increased filter depth allows a smaller diameter for a given reaction volume. The advantages of plastic media are the high voids volume (80-90%), the high specific surface area (10-15 m²/m³) and light weight. The increased cost of the media may offset these advantages depending on the nature of the waste. The loading rates for trickling filters are presented in Table 6.1.

**TABLE 6.1 TYPICAL LOADING RATES FOR TRICKLING FILTERS**

<table>
<thead>
<tr>
<th></th>
<th>Low-rate Stone Media</th>
<th>High-rate Stone Media</th>
<th>Typical Plastic Media</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>BOD load</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(g/m³·day)</td>
<td>100-400</td>
<td>500-1500</td>
<td>400-2400</td>
</tr>
<tr>
<td><strong>Hydraulic Load</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(m³/m²·day)</td>
<td>2-5</td>
<td>10-30</td>
<td>10</td>
</tr>
</tbody>
</table>

Note: Information derived from Hammer (1977) and Melcer (1980).

Treatment efficiencies are influenced by temperature, the amount of recycling over the filter, the BOD loading rate and the type of waste. BOD removals of 70% to 90% may be achieved with trickling filters depending on filter design and the extent of solids removal in a clarifier.

Assuming good design, i.e., satisfactory loading rates, good ventilation and adequate distribution over the filter, the system requires minimum operator input or maintenance and is resistant to shock loads or varying operating conditions - a factor of importance when dealing with agricultural waste.

The application of trickling filters to agricultural wastes has been limited. The greater strength of agricultural waste, as compared with municipal wastewater, has resulted in higher flows relative to BOD load to ensure film sloughing in the filter, thus providing blockages. Typical loading values for dairy waste (after some pretreatment) fed into a stone media filter would be 200 g BOD/m³·day at approximately 20 m³/m²·day. High recycle ratios are required to maintain this balance but the low total daily volumes does not make this a major problem.

**Rotating Biological Contactors**

The Rotating Biological Contact process consists of rotating inert media on which the biomass grows. The rotation allows the media to be submerged in the wastewater and exposed to the atmosphere alternately thus allowing aerobic decomposition (Figure 6.5). The media may be a series of discs mounted on a common shaft or a cylindrical cage filled with plastic media i.e., analogous to a trickling filter except the media moves through the waste water.
Most of the design criteria have been established using municipal wastewater hence care is required in extrapolating into treating agricultural wastes. Generally the contactors are 40% submerged, 1 to 3 m in diameter and have a peripheral speed of 0.3 m/s. The rate of rotation is important for maintaining aeration, mixing the wastewater, providing biomass - waste contact and creating shear forces for film sloughing. Treatment efficiencies depend on loading rate (hydraulic and BOD loads per total contact area of discs). Removals of over 90% may be achieved if loadings are kept below 10 g BOD/m².day, or about 0.02 m³/m².d if the rotating biological contactor receives the discharge from an anaerobic lagoon treating dairy wastewater.

Commercial and municipal use of rotating biological contact units is increasing overseas because of their simple, reliable operation. It is generally considered that the plants may be better suited for smaller scale systems where a high standard of treatment is required. Typical configurations involve 3-4 units in series to ensure no short-circuiting and allow a selective development of microbial film, i.e., the first unit acts like a roughing filter with the latter ones performing a "polishing" function. The operating costs are similar to or possibly slightly less than those for a trickling filter. Like trickling filters, rotating biological contactors have not been widely used in treating agricultural waste.
FLOC REACTORS

Basic Principles

The micro-organisms are similar to those in fixed film reactors. The important difference is that the biomass is maintained in suspension providing continuous contact between the micro-organisms and the waste water, as compared with the intermittent contact of the fixed film systems. This has the main advantage of reducing the plant volume for a specified contact area compared with fixed film units, thus making it most suitable for large scale systems.

The suspended biomass, often called activated sludge, must be supplied with adequate nutrients and oxygen to maintain it at optimum conditions. The nutrient supply is usually adequate for livestock wastes but some deficiencies may exist if processing wastes are to be treated. Overloading, imbalanced condition or toxic compounds, e.g., copper salts and bactericides, may cause the activated sludge to "bulk", i.e., fail to settle in the final clarifier resulting in poor quality effluent. Consequently the plant is more sensitive to fluctuating operating conditions than fixed-film systems.

The food to micro-organism ratio (F/M ratio) is a primary design variable for all floc reactors. It is measured as organic input (kg BOD) per mass of microorganisms (kg Mixed Liquor Volatile Suspended Solids - MLVSS). Optimum F/M ratios can be established which provide the best sludge settling characteristics and therefore optimum effluent quality. F/M ratios to be used depend on whether high rate, conventional or extended aeration is used. The actual values are temperature-dependent and are not yet well established for agricultural wastewaters.

Mechanically Aerated Lagoons

In mechanically aerated lagoons, oxygen is furnished by some mechanism that beats air into the liquid or exposes more liquid surface area to the air with a portion of the oxygen dissolving during the process (Figures 6.6 and 6.7). The mechanically aerated lagoon, therefore, is not dependent on natural aeration, wind, or algae growth. Because oxygen is pumped or mixed into the system, surface area does not limit design and depths up to 6 m can be used, thus reducing the surface area for any given volume. In fact it is advantageous to keep the surface area to a minimum to reduce heat loss from convection, evaporation, and radiation. Aerated lagoon depth should be at least 3 m for effective mixing.

![Mechanically Aerated Lagoon Diagram](image-url)
Aerated lagoons can be designed and operated in two ways. One is to accomplish complete aerobic waste treatment, normally prior to final discharge. The other is to partially aerate to provide odour control, but not to completely stabilize the waste. This would normally be done in waste treatment or storage facilities where waste is held for extended periods and odour problems arise.

Aerators perform two functions - oxygenation and mixing. The mixing is accomplished by pumping the liquid. Velocities of 0.3 m/s in the lagoon are necessary to keep solids in suspension and it is this function that requires the major energy input. Mixing usually requires about 7.5 kW per 1000 m³ for livestock lagoons for full treatment operation. When operating for odour control only, mixing and aeration should be confined to the upper third of the lagoon and power requirements reduced accordingly. Aerator configurations to accomplish various aeration patterns are commercially available and designers should use manufacturer's recommendations to select the appropriate equipment.

For complete stabilization with continuous aerator operation, the minimum oxygenation capacity of the aerator should be twice the total daily BOD loading. The oxygenation efficiency for most aerators is in excess of 1.5 kg O₂/kWh and with good design a dissolved oxygen level of 1 to 2 mg/l should be maintained in the aeration basin. For partial odour control, oxygenation capacity to supply one third to one half the BOD load has been recommended in the past, although recent research in Australia indicates that aeration for one-fourth the BOD load may be adequate (Ginnivan, 1980). This low rate of aeration reduces the release of volatile acids and the accompanying gases as well as allowing some oxidation to less odorous compounds. Generally, ammonia production is not stopped and the odour is still detectable, although usually low enough so as not to be a problem.
Aeration for this purpose has been done primarily on piggery lagoons and it is difficult to predict what problems might be encountered, if any, with lagoons receiving dairy wastes.

The shape of lagoons has an important effect on the ease with which they may be mixed and aerated. The greater the departure from a circular lagoon of depth about equal to its diameter, the more difficult it is to achieve good mixing and aeration using a single aerator. In any case, dead zones should be avoided.

Once the power requirements of oxygenation and mixing are determined, the planner must determine size and number of aerators to use. It is preferable to select several smaller units to provide aeration over the entire surface area than to select one or a few large units. This also reduces the risk of being unable to aerate due to equipment maintenance or breakdown.

Aerators should be operated continuously since aerobic conditions exist only when oxygen is freely available. When oxygen is not available, growth and reproduction of aerobic bacteria are inhibited and anaerobic conditions develop. If this condition persists, the whole system is upset and considerable time is required to return to the normal aerobic condition once the aerator is restarted.

Recommended detention time for an aerated lagoon is approximately 10 days so total daily waste volume (manure, washwater, etc) should be checked with planned lagoon volume to ensure that this detention time is provided.

Diffused Air Systems

Compressed air is released through diffuser plates at the bottom of the aeration tank. The rising bubbles allow oxygen uptake and, with suitable placement (Figure 6.8), induce mixing currents. The amount of air required varies with the degree of treatment desired, the size of bubbles, the effluent temperature, the depth of the basin and the extent of additional mixing. Table 6.2 gives approximate values for a 3 m deep tank and 90% B.O.D. removal.

---

**FIGURE 6.8: LAYOUT OF AIR DIFFUSERS IN AN ACTIVATED SLUDGE TREATMENT SYSTEM.**
TABLE 6-2 AIR REQUIREMENTS FOR DIFFUSED AIR AERATION SYSTEMS

<table>
<thead>
<tr>
<th>Bubble Size (mm)</th>
<th>O₂ Uptake Efficiency (% of air volume)</th>
<th>Air supply (m³/kg BOD removed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>fine (&lt; 1.5)</td>
<td>11</td>
<td>32</td>
</tr>
<tr>
<td>medium (1.5-3)</td>
<td>6.5</td>
<td>57</td>
</tr>
<tr>
<td>coarse (&gt; 3)</td>
<td>5.5</td>
<td>64</td>
</tr>
</tbody>
</table>

Note: Information derived from Melcer (1980).

In addition to the basic air requirement, additional capacity should be installed (up to 50%) to accommodate fluctuations in loading or other operational problems.

The system has problems with diffusers blocking with microbial growth, foaming, incomplete mixing, the need for large air compressors and the low utilization of available oxygen. Consequently it is more suited to large scale systems and has limited application in agriculture.

Oxidation Ditches

Oxidation ditches are generally constructed in a large oval or race track configuration (Figure 6.9). Cage rotors (Figure 6.10) are partially immersed in the liquor and provide aeration and pumping capacity to maintain the solids in suspension as they circulate around the ditch.

![Oxidation Ditch Diagram](image)

FIGURE 6.9: LAYOUT OF OXIDATION DITCH TREATMENT SYSTEM.
Ditches are operated as extended aeration systems. For municipal wastes F/M ratios of 0.05:1 and MLVSS levels of 2000 to 4000 mg/l are common. Livestock wastes have been satisfactorily treated by this method (Jones et al, 1971), with MLVSS as high as 30,000 mg/l. This yields a F/M ratio of 0.02:1 or less for normal loading rates or low temperatures. It does, however, require a greater total oxygen input due to the longer residence time and mass of biologically active material.

Loading rates for livestock waste range from 550 to 700 g BOD/m$^3$.d, approximately 5 times those used in municipal systems. This difference emphasises the dangers of equating design criteria for different types of waste and the adviser or designer must be cautious in the selection of design data. The rotor should be selected to provide an oxygenation capacity of twice the daily BOD load and pumping capacity to maintain a ditch velocity of 0.3 m/s. Rotor capacities are available from manufacturers. For example, the rotor could provide 2.0 kg O$_2$/hr.m of rotor and pump 0.3 m$^3$/s.m of rotor. The nett power requirements may be calculated using an oxygenation capacity of 0.8 to 1.0 kg O$_2$/kWh. To this must be added the losses in the drive trains. Ditch depth is limited to about 600 mm. Depths greater than this create difficulties in maintaining complete mixing and efficient pumping.

Based on the above criteria the ditch width and length can be calculated to meet an organic load. Long ditches require a number of rotors as there should be no more than 100 m between them. The corners should be baffled and the bottom filleted to avoid inefficient flow or quiescent regions allowing oxygen depletion and anaerobic decomposition of the settled sludge. The placement of ditches below slotted floors eliminates waste

FIGURE 6.10: A CAGED ROTOR AERATOR IN AN OXIDATION DITCH.
transport problems and, given adequate design, ensures an odourless treatment system. The operational requirements include maintenance on the rotor, solids removal and addition of make up water, if required. Ditches under "start-up" conditions or overload may have foaming problems. This can be solved by improved loading rates.

Despite their advantages, ditches have not been widely used because of their operating costs. For example, if the daily BOD load from the average pig is 100 g/day, the oxygenation requirement per pig is 0.20 kg O₂/day. Assuming an overall transfer efficiency of 0.8 kg O₂/kWh results in an input of 0.25 kWh/pig/d. At 8c/kWh, the annual electricity cost would be $7.30/pig/yr. This cost is sufficient to warrant consideration of other alternatives.

**Miscellaneous Aerators**

A number of different types of aerators are available using a combination of the principles given above or including air entrainment through a vortex. Detailed consideration of the devices is beyond the scope of this manual. However, care should be exercised before using an untried product.

**Worked Aerator Example**

Because of high energy costs, full treatment of livestock wastes by mechanical aeration cannot currently be justified. However, partial aeration for odour control may be warranted in some situations. The following example illustrates the planning of an aeration system for such a situation.

**EXAMPLE 6.2** Referring to the piggery example (Example 5.2) described in the anaerobic lagoon section, suppose that the proximity of nearby residences made even minor odour emissions from an anaerobic lagoon unacceptable. Mechanical aeration could be used to reduce odour emissions while the basic waste management system remained the same. For that example, a 7142 m³ anaerobic lagoon with 3 months waste storage was planned. Also, daily BOD load was estimated to be 180 kg. Using an aeration requirement of one-third the BOD load for partial odour control, the aeration capacity would need to be;

\[
180 \div 3 = 60 \text{ kg } O_2
\]

The aerator will be operated continuously, and will need to supply

\[
60 \div 24 = 2.5 \text{ kg } O_2 \text{ per hour}
\]

If an aerator is selected with an oxygenation efficiency of 2 kg O₂ per kWh, then the required aerator size would be

\[
2.5 \div 2 = 1.25 \text{ kW}
\]

Minimum aerator size then should be 1.5 kW (nearest standard motor size). The aerator can be operated in the anaerobic lagoon and should be of a configuration so that the upper layer of the lagoon is aerated and the bottom layers and sludge receive little mixing and aeration. With an assumed electricity cost of $0.08 per kWh, annual power cost can be calculated at

\[
1.5 \text{ kW} \times 24 \text{ hr} \times 365 \text{ days} \times 0.08 = $1051.20
\]
Composting is a process in which the volatile solids in livestock wastes or other types of organic wastes are digested by aerobic micro-organisms. The process differs from conventional aerobic waste treatment because it is achieved at a much lower water content. This allows the development of a loose matrix of material which can be aerated with less mixing than required by a liquid system. The biological activity in a good compost produces sufficient heat energy to drive the temperature into the thermophilic range (50 to 70°C) without external heat supplies. The aerobic, thermophilic conditions are inhibitory to most pathogenic organisms and because the process is aerobic, it is free of offensive odours. The product is a relatively stable material reduced in weight and volume from the original waste. It does not attract flies, and can be used as a soil amendment to improve structure, cation exchange capacity, fertility and other characteristics. Most weed seeds and insects are also killed by the high temperatures.

Composting can be used to treat poultry, cattle, and pig wastes. It probably adapts most readily to treating poultry manure due to its relatively low water and high nitrogen content. Most studies have found moisture content to be a critical factor affecting the composting process. In general, the best range is 50 to 65 per cent dry matter. The rule of thumb for compostability is: "damp but not wet". If too dry, the moisture is not adequate to support rapid bacterial growth. If too wet, movement of air and other gases is inhibited, which in turn causes anaerobic, rather than aerobic conditions to develop. Diffusion of air into manure is limited to a few inches and is almost nil at moisture levels greater than 50 percent. Poultry manure may be partially dried under cages to achieve the desirable moisture contents for composting.

Most wastes will compost well if the nitrogen content exceeds 2.5 percent on a dry weight basis. Livestock wastes have adequate nitrogen and can be mixed with other materials high in carbon. Carbon: nitrogen (C:N) ratios of 30:1 to 50:1 are regarded as optimum. When excess nitrogen is present, it is volatilized as ammonia, hence the ammonia smell from many compost areas. Adding carbonaceous material such as sawdust, wood shavings, corn cobs, or straw is often advantageous. These increase porosity of the waste mass, allowing better air movement. If added dry, they can help bring the moisture content of a wet material down to more acceptable levels. Finally, they bring the C:N ratio of a high nitrogen waste more into the desirable range.

The amount of material to add depends on moisture and C:N ratio of the waste as well as the material added. For example, poultry manure with a C:N ratio 5:5:1 and a dry matter content of 30 percent would benefit by the addition of an equal amount by mass of sawdust with a dry matter content of 90 percent. The composition of the two components and the resulting mixture is shown in Table 6.3.

The resulting mixture would have a dry matter content of 60 percent and a C:N ratio of 26:1, both reasonably good values for composting. Broiler litter with shavings or other bedding material already added will likely have a good C:N ratio, but may require moisture adjustment for satisfactory composting.
Interest in solids/liquid separation for piggery effluent has led to interest in composting of the separated solids. No reports of studies on the compostability of this material have been found. In general terms, the dry matter content of separated solids is usually in the 25 to 35 percent range, somewhat less than desirable, and the C:N ratio is also less than desirable. From this, it appears that for composting, separated piggery effluent solids would benefit from the addition of dry carbonaceous material at levels similar to those suggested for poultry manure.

Since moisture content is so critical, composting outdoors in areas of medium to high rainfall is difficult. This can be overcome by putting a roof or temporary cover over composting areas, but these are expensive measures.

Large scale composting is usually done either with forced aeration or with natural aeration and windrows which are periodically mixed. In windrow composting, wastes removed from production facilities are stacked in windrows 1 to 2 m high. The windrow is turned or mixed about once weekly to re-aerate, release ammonia and moisture, and redistribute remaining pathogens to achieve better kill. Nearly complete stabilization should be achieved in 3 to 4 weeks and the windrow should be turned at least 3 times during this period. Turning may be done by front-end loader, conveyor, commercial composter, or other means.

TABLE 6-3 DRY MATTER, CARBON AND NITROGEN CHARACTERISTICS OF POULTRY MANURE, SAWDUST AND EQUAL MASS MIXTURE.

<table>
<thead>
<tr>
<th></th>
<th>DM % mass, kg</th>
<th>H₂O % mass, kg</th>
<th>C % mass, kg</th>
<th>N % mass, kg</th>
<th>C:N ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM</td>
<td>30</td>
<td>30</td>
<td>70</td>
<td>70</td>
<td>37</td>
</tr>
<tr>
<td>SD</td>
<td>90</td>
<td>90</td>
<td>10</td>
<td>10</td>
<td>49</td>
</tr>
<tr>
<td>Mix</td>
<td>60</td>
<td>120</td>
<td>40</td>
<td>80</td>
<td>46</td>
</tr>
</tbody>
</table>

Forced aeration has been used to supply oxygen to composting waste. The main criteria is to supply adequate oxygen without causing excessive cooling or drying due to the air flow. Aeration requirements vary according to the specific waste and no general guidelines are available. Due to excessive energy and equipment costs, forced aeration systems do not appear to be economically attractive at the current time.

Nutrient loss during composting is not well defined. While phosphorus and potassium should be unaffected, Martin et al (1972) reported significant nitrogen losses. However, Loehr (1974) states that composting conserves most of the nitrogen. The different observations are apparently due to whether composting was done at an optimum C:N ratio or not.

Full details for procedures for composting can be found in the Inter-Departmental Committee on Utilization of Organic Wastes (1972).
REFERENCES CHAPTER 6


6-18
chapter 7

land application

ARTHUR R. GIFFNEY
Effluent from farm dairies, piggeries and poultry units is often spread on the land as a convenient means of disposal. Since manure can substitute for inorganic fertilisers this section of the manual takes the view that manure has value and should be utilised accordingly.

There are many management options available to the farmer. For example, consideration of nutrient losses indicates that spreading of fresh manure is more desirable than land application after storage. The storage option, however, allows application in the growing season and can avoid problems associated with manure spreading on wet soil.

There are also several different methods of application:

- Sprinklers are suitable for spreading effluent from water conveyance systems such as tipping bucket sluicing in piggeries. Suitable effluents usually have a total solids content of less than 5%.
  - Advantages: relative to the other methods of application, labour requirements are low and manure is readily applied in fresh condition. Can be used on sloping land.
  - Disadvantages: blockages of pumps, pipes and sprinklers can occur. Sprinklers require frequent shifting. Application in winter is limited to free-draining soils without groundwater contamination problems.

- Vacuum tankers are suitable for all forms of effluent from thick slurries (15% T.S.), to dilute wastes. They are generally used to empty lagoon or pit storage systems.
  - Advantages: flexible distribution operations, e.g. the manure can be readily carted to a neighbour's property. They are reliable machines capable of moving thick slurries.
  - Disadvantages: high labour content in applying manure. Machinery wheels cause soil compaction and traction problems on wet soils.

- Solids Spreaders: these machines are made to distribute stackable solids (20% T.S.).
  - Advantages: they are the only method of getting an even distribution of solid material.
  - Disadvantages: same as for tanker spreading described above.

- Border Dyke Irrigation: for large quantities of very dilute wastes (1-2% T.S.) border dyke or flood irrigation systems may be well suited.
  - Advantages: system can cope with large quantities of water.
  - Disadvantages: these systems are operated as an irrigation installation with high hydraulic loading. To prevent excessive nutrient application, waste water will often require controlled dilution. Requires flat land.

These methods of application are described in more detail in subsequent text. They all involve some form of machinery and the importance of a sound maintenance programme can not be over-emphasised. Machinery should be kept clean with moving parts lubricated. Manure is corrosive and abrasive, so clean equipment enables inspection for wear and preventive maintenance.
design principles

Utilisation of the manure as a fertiliser and avoidance of water pollution are the two aims addressed in the land application design procedure. Consequently both nutrient and hydraulic loading criteria are considered in selecting the land area required and the rate of the application.

NUTRIENT LOADING CRITERIA

Once a favourable nutrient status has been achieved, nutrient application should be matched to the net nutrient removal from the soil root zone. As a basis for deciding at what rate manure should be applied to various soils and crops, this manual proposes that the quantity of available nutrients applied be matched to the crop nutrient uptake - a similar concept to applying maintenance rates of inorganic fertilisers.

In the case of grazed pasture, plant nutrient uptake is partly returned to the soil as animal faeces and urine. Even for meadow hay and cereal crops, parts of the plants are reincorporated into the soil.

Another issue is nitrogen fixation by clover. In New Zealand, fertiliser application revolves around the practice of applying phosphate fertilizer to stimulate clover growth in order to get nitrogen fixation for grass growth, a situation arising from the difference in cost of nitrogen and phosphorus fertilisers. If there is a ready supply of nitrogen fertiliser then there is no need for clover, and in fact this is likely to happen naturally (see CLOVER SUPPRESSION). In addition, the quantity of effluent applied to grazed pasture is likely to be limited by stock health risk due to high potassium loading, before excessive nitrogen application poses serious pollution problems.

Although discussed in more detail later in this chapter, it is appropriate to mention that a portion of manure nutrients is not immediately available for plant uptake and is utilised only slowly over a period of several years. This is not taken into account in the design procedure and consequently the total quantity of nutrients applied would actually exceed that level indicated by plant uptake values.

The design criteria do not consider the seasonal nature of plant nutrient uptake. The utilisation of nutrients is much higher during periods of growth than in winter when plants are essentially dormant.

Table 7.1 lists typical figures for nitrogen utilisation which have been estimated from experimental work in the U.K.

<table>
<thead>
<tr>
<th>Time of Application</th>
<th>Percentage of available nitrogen effective for crop growth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autumn</td>
<td>0 - 20</td>
</tr>
<tr>
<td>Early winter</td>
<td>30 - 50</td>
</tr>
<tr>
<td>Late winter</td>
<td>60 - 90</td>
</tr>
<tr>
<td>Spring</td>
<td>90 - 100</td>
</tr>
<tr>
<td>Summer</td>
<td>variable, dependent on weather</td>
</tr>
</tbody>
</table>
It is conceded that it is a rough approximation to equate the average yearly nutrient uptake by plants with a 'yearly' load of manure nutrients which in some installations may come from only one effluent application, possibly during winter. To incorporate this supply and demand aspect into the design and management of all land application systems would disproportionately complicate this traditional method of effluent treatment. Storage of manure over winter would help reduce the supply and demand problem. If winter storage is not available the pollution potential is greater and there might be insufficient nutrients left to fully benefit spring growth.

HYDRAULIC LOADING CRITERIA

To describe the hydraulic loading criteria it is best to consider the classical 'column of soil' approach.

At field capacity, (Figure 7.1) there is very little downward movement of water through the soil profile. If more water is added (Figure 7.2), although the soil profile is still unsaturated, there will be some gravity drainage through the soil until equilibrium is reached at field capacity. In Figure 7.3 the soil is saturated and the whole soil moisture storage volume is full. If further water is applied, at a rate greater than the soil's infiltration capacity, there would be some surface runoff.

Effluent should not be applied at a higher rate than the infiltration capacity of the soil. This is based on the premise that surface runoff is entirely unacceptable but a little deep percolation is permissible.

Surface runoff into open drains and streams is avoided by restricting the application rate to less than the infiltration capacity. This allows for application in winter when most soils are continuously at field capacity or wetter. Although it is not promoted as part of spray system design, the hydraulic application rate could be increased in summer because soil infiltration capacities are generally higher on unsaturated soils.

In areas where drainage is impeded, due to a pan or a high water table, for example, then the designer must make a decision based on local experience as to whether or not land application is permissible. Often the problem can be overcome with provision for winter storage.

Design and management criteria which attempt to avoid deep percolation would be unnecessarily restrictive. Land application could only be carried out during times of soil moisture deficit, i.e. soil moisture levels less than field capacity. To design a system allowing winter application it would be necessary to model several years of soil moisture budget and then study statistical opportunity time for disposal of wastes to determine if waste could be applied, (and if so, how much). In addition it would be practically impossible to allow for the situation where 50 mm of rain falls on the day after manure application and takes the soil moisture level beyond field capacity anyway.
FIGURE 7.1  DIAGRAMMATIC REPRESENTATION OF A SOIL PROFILE AT FIELD CAPACITY.

FIGURE 7.2  SOIL PROFILE WITH MOISTURE CONTENT SLIGHTLY ABOVE FIELD CAPACITY.
One must keep the magnitude of the hydraulic loading in perspective:

Typical figures from a 100-sow piggery would be:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of pig equivalents</td>
<td>1080</td>
</tr>
<tr>
<td>Volume of raw manure</td>
<td>3.25 l/pig.day</td>
</tr>
<tr>
<td>Volume of flushing water</td>
<td>20 l/pig.day</td>
</tr>
</tbody>
</table>

Therefore the daily volume of waste water would be approximately 25 m$^3$. If this was distributed with a nozzle giving a 40 m diameter spray pattern then the average hydraulic load would be only 20 mm. However the nutrient loading would amount to nearly a whole year's crop requirement.

**Fertiliser properties of manure**

Ruminants utilise about one half of their ingested feed so the bulk of the excreted solid matter is composed of complex organic compounds similar to those found in their feed. Therefore, although most of the cellulose, starches, and sugars are utilised, hemicellulose and lignin are basically unchanged as are lignoprotein complexes similar to those found in soil humus. Monogastric animals (poultry and pigs) are even less able to digest the cellulose portion of their diet. In addition to undigested feed the waste contains sloughed stomach lining and a large number of micro-organisms.

When the fertiliser properties of manure are described in terms of nitrogen, phosphorus and potassium (N, P and K) it must be remembered that these nutrients are present in compounds of varying complexity and are continually being degraded by micro-organisms into simpler compounds and, eventually, to soluble chemicals suitable for plant uptake.
THE NITROGEN CYCLE

The nitrogen cycle (Figure 7.4) is particularly intricate and it is not intended to cover it fully here. However, there are some aspects which are relevant to design of land application systems.

Approximately 50% of manure nitrogen is excreted as urea and the remainder is contained in more complex organic molecules in the faeces.

The term "mineralization" covers a whole series of reactions involving both the plant and soil microbes. These organisms enable the enzymatic digestion of proteins and allied compounds in organic matter. The end products are ammonia and ammonium compounds.

\[
\text{Enzymatic Hydrolysis} \\
R\text{-NH}_2 + H_2O \rightarrow R\text{-OH} + NH_3 + \text{energy} \\
2\text{NH}_3 + H_2CO_3 \rightarrow (NH_4)_2 CO_3 \rightarrow 2NH_4^+ + CO_3^{2-}
\]

where "R" designates an organic alkyl group.

The ammoniacal nitrogen has four main destinations. Some is used directly by plants and soil micro-organisms. Another portion is fixed by clay minerals and the remainder goes to nitrification which involves two specialised bacterial transformations.

\[
\text{Enzymatic Oxidation} \\
2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 2H_2O + 4H^+ + \text{energy} \\
\text{(ammonium)} \quad \text{Nitrosomonas} \quad \text{(nitrite)}
\]

\[
\text{Enzymatic Oxidation} \\
2NO_2^- + O_2 \rightarrow 2NO_3^- + \text{energy} \\
\text{Nitrobacter} \quad \text{(nitrate)}
\]

The nitrate form of nitrogen is the soluble form most widely acceptable to plants. If soil microbes have a ready supply of carbonaceous (organic) material, they utilise the nitrate nitrogen more rapidly than plants. This 'immobilised' nitrogen may later become available to the plants when the supply of carbonaceous material has been exhausted or when microbial activity slows down.

In another important part of the mineralization process, urea, the major constituent of urine, breaks down rapidly by enzymatic hydrolysis to the ammonium form.

\[
\text{Urease} \\
CO(NH_2)_2 + 2H_2O \rightarrow (NH_4)_2 CO_3
\]

Many micro-organisms possess the enzyme urease and urea applied to the soil is very readily hydrolysed. The ammonium carbonate produced increases the pH if the cation exchange capacity is low, and above pH 7 considerable amounts of ammonia may volatilize (Gasser 1962). Thus urea nitrogen is nitrified and becomes available to the plants much more quickly than organic nitrogen.
FIGURE 7.4 THE NITROGEN CYCLE
NITROGEN LOSSES

Losses due to storage and pretreatment are covered in Chapter 2. Nitrogen losses following application of manures to the soil are mainly through leaching, denitrification, and ammonia volatilization. Nitrate ions and to a lesser extent ammonium ions are carried down the soil profile when rainfall or irrigation water causes soil moisture content to exceed field capacity. These losses may create nitrate groundwater pollution problems as discussed later in this chapter.

Denitrification occurs when facultative micro-organisms respire anaerobically drawing oxygen from nitrates and producing gaseous nitrogen and its oxides which are then lost to the atmosphere.

\[
\text{NO}_3^- \rightarrow \text{NO}_2^- \rightarrow \text{N}_2\text{O} \rightarrow \text{N}_2 \rightarrow 2\text{NO}
\]

This occurs in soils with poor aeration, or poor drainage, or both. This anaerobic condition can be brought on by excessive applications of manure with disastrous consequences. Apart from denitrification occurring the anaerobic bacteria may produce volatile organic acids resulting in problems with odour and phytotoxicity. Acetic and propionic are two acids which may be produced and which are toxic to plants. In addition "pasture burn" or "leaf scorch" may occur as ammonia is volatilized and salt concentration on the leaves causes plant dehydration.

THE PHOSPHORUS CYCLE

The diagrammatic P cycle of Figure 7.5 shows excreted phosphorus to be both mineralised by bacteria and available direct from phytin and nucleic acids. Phytin (the Ca-Mg salt of phytic acid) appears to be adsorbed directly by the plants while the nucleic acids are probably broken down by enzymes at the root surface and the phosphorus is then absorbed in either organic or inorganic form. (Brady, 1974).

Once mineralised, immobilisation of the phosphorous compounds is rapid. Insoluble iron and aluminium phosphates form in acidic conditions and calcium phosphates form in alkaline soils. Maximum solubility of these phosphates is in the soil pH range 6 to 7. Rapid decomposition of organic matter and consequent high microbial population results in the temporary immobilisation of inorganic phosphates in microbial tissue. In addition, some phosphorus is immobilised by direct fixation to clay particles. This immobilisation is less in sandy soils than in soils with a high clay content because of the lower absorption and reactive capacities of sandy soil.

At any one time approximately 80-90% of phosphorus is immobilised and while about 1% might be readily available in soluble form, the remainder is only slowly available in slightly soluble forms.

The capacity of a soil to adsorb phosphorus is not infinite. Each soil has a phosphorus adsorptive capacity which can be exceeded by prolonged application of large amounts of phosphorus. The phosphorus adsorptive capacity may not be exceeded for decades or centuries in soils having a high clay content. However high phosphorus levels in soils may lead to reduced availability of zinc, iron and copper, and therefore reduced plant uptake resulting in deficiencies of these trace elements. Excessive soil phosphorus can be stripped by successive cropping.
SOIL POTASSIUM

Most of the potassium excreted is found in the urine. It is not strongly bound and is immediately soluble in water. The remaining portion of potassium compounds require microbial intervention for its release. Carbonic, nitric, sulphuric and several organic acids produced by various bacteria are the major agents for releasing insoluble K in manures.

Soil potassium is considered to have three levels of availability:

- relatively unavailable potassium is held in primary minerals such as the feldspars and micas. Approximately 90% of soil K is contained in these weathering resistant minerals in young soils and consequently only a little K is released from this source during the growing season.

- slowly available K is fixed to clay minerals in either non-exchangeable or exchangeable sites.

- a small portion (1-2%) of soil potassium is readily available from exchange sites on soil colloids and from soil solution.

So about 1-10% of soil K is held in the equilibrium represented by:

Non-exchangeable K ⇄ exchangeable K ⇄ soil solution
(slowly available K) (readily available K, 1-2%)

The relative position of this equilibrium is determined by the nature of the soil colloids, moisture, presence of lime, and general weathering of clay minerals.
Because of its solubility and the equilibrium described above, soil K is subject to loss by leaching. In strong leaching conditions (permeable soils and high rainfall) the quantity of soil K lost may be similar to that lost by crop removal. Excess potassium may also result in luxury uptake by plants.

To avoid leaching and the possibility of luxury uptake it is widely appreciated that potassic fertilizers should be applied in light applications frequently (every year) rather than heavy applications less frequently. So with disposal areas receiving several applications of soluble K each year, animal manures can be useful sources of potassium.

**OTHER ELEMENTS**

Manures usually contain other elements such as calcium, magnesium, sulphur, and various micronutrients including iron, copper, molybdenum, manganese and zinc. A comparison of various information sources shows that quantities of micronutrients contained in wastes are variable over wide ranges, so there has been no attempt to include a table of 'typical' values in this manual. Although these quantities of micronutrients are probably sufficient in most circumstances, for situations where trace element deficiencies commonly occur, e.g. magnesium deficiency, and land application of manure is practised as the prime fertiliser source, then soil fertility should be supplemented with the appropriate micronutrients.

**NUTRIENT AVAILABILITY**

The previous sections give a simplified explanation of the fate of manure nutrients in the soil environment. The interaction of; microbial degradation and utilisation, clay fixation, leaching, and denitrification, are difficult to quantify. It is better to evaluate the usefulness of manure application by considering the plants' nutrient uptake.

In the U.K. recently revised values of nutrient availability have been given by MAFF (1978). The values in Table 7.2 have been determined by comparing dry matter and nutrient uptake responses to chemical fertiliser with responses to various rates of manure-applied nutrients. This gives a measure of the apparent fertiliser value.

**TABLE 7.2**

**NUTRIENT AVAILABILITY OF MANURES IN YEAR OF APPLICATION %**

(M.A.F.F. 1978)

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dairy cattle</td>
<td>50</td>
<td>50</td>
<td>90</td>
</tr>
<tr>
<td>Pig</td>
<td>65</td>
<td>50</td>
<td>90</td>
</tr>
<tr>
<td>Poultry (slurry)</td>
<td>65</td>
<td>50</td>
<td>90</td>
</tr>
<tr>
<td>Poultry (air-dried; deep or broiler litter)</td>
<td>65</td>
<td>60</td>
<td>75</td>
</tr>
</tbody>
</table>

**EXAMPLE 7.1** The farm dairy effluent from a 200-cow, factory-supply dairy herd would render available approximately 200 x 10.4 g/day of nitrogen (from Table 2.2), i.e. 601 kg for a 9.5 month lactation. This effluent is
applied to the land. From Table 7.2, 50% of the total nitrogen is available for plant uptake in the year of application.

i.e. the fertiliser value of the effluent is

\[
50\% \times 601 \text{ kg} = 300 \text{ kg of nitrogen.}
\]

The equivalent quantity of urea would be 650 kg. (See also Example 7.2).

The data in Table 7.2 was established for fresh manure. After treatment in an anaerobic storage lagoon, the liquor could be expected to have a higher proportion of soluble nitrogen (although total nitrogen content will be reduced by ammonia volatilization). It is suggested that the nitrogen availability be increased to 80% while retaining P and K values as in Table 7.2.

Although it need not be considered in assessing the fertiliser value, it should be remembered that there is a residual nutrient value after the year of application. This is due to the slow release of the organically bound nutrients, e.g. it is estimated that in year 2, the previous year’s application provides a further 15% of nitrogen and 25% of phosphorous (Berryman 1971).

SOIL HUMUS AND CATION EXCHANGE CAPACITY (C.E.C.)

The supply of nutrients is not the only benefit derived from applying animal waste to land.

Soil humus has for centuries been recognised as an important constituent of fertile soil and application of manure with its supply of bacteria and partly-digested plant material helps build the organic content in soil. The actual increase and resulting benefit is difficult to quantify however. Organic matter has several benefits:

- greater retention of soil moisture
- improved aeration and drainage properties
- improved tillage characteristics
- higher cation exchange capacity. This provides for better utilisation of applied fertiliser and animal manure, especially in soils of low clay content, by increased adsorption of nutrients and subsequent reduction in nutrient losses by leaching. Plants then have a greater store of available nutrients to draw on.

SOME MICRONUTRIENT PROBLEMS

- Zinc deficiency due to reduced uptake in the presence of excess phosphate. (Mentioned in the section on phosphorus).

- Toxic quantities of copper can occur in pig manure when pigs are fed copper additives to promote weight gain. There is little risk to grazing stock from uptake by the plant but direct ingestion of herbage coated with slurry may cause problems. Rain will wash the slurry off grass. The problem is avoided with lagoon treatment before land application, since about 85% of the copper is tied up with solid matter which settles to the bottom of lagoons.

- Large quantities of potassium fertiliser can suppress plant uptake of magnesium causing what is commonly known as "grass staggers" in grazing stock. High potassium levels are only likely to occur with excess application of manure. Cattle manure with a relatively high potassium content is more likely to cause problems than other manures.
Many N.Z. soils are known to be sulphur deficient. In applying superphosphate farmers are also applying 11% sulphur, while animal manure generally contains less than 0.5%. As with magnesium, where sulphur deficiencies are known to occur, manure application may require sulphur to balance the nutrient status. Soil testing will give some warning of this problem.

EXAMPLE 7.2  The potential dollar value of manure applied nutrients.
(Taking waste production figures from Example 2.2).

In order to minimise nutrient losses the effluent is applied fresh to pasture.

The number of 50 kg pig equivalents was estimated to be 1797. Using this figure the nutrient load is:

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>kg/50kg pig-day (meal feed)</th>
<th>Total/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>0.023</td>
<td>15,086 kg</td>
</tr>
<tr>
<td>P</td>
<td>0.0075</td>
<td>4,919</td>
</tr>
<tr>
<td>K</td>
<td>0.015</td>
<td>9,839</td>
</tr>
</tbody>
</table>

nutrients available in first year of application as fresh manure

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>% of total</th>
<th>Total/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>65%</td>
<td>9,806 kg</td>
</tr>
<tr>
<td>P</td>
<td>50%</td>
<td>2,460 kg</td>
</tr>
<tr>
<td>K</td>
<td>90%</td>
<td>8,855 kg</td>
</tr>
</tbody>
</table>

EQUIVALENT FERTILISER VALUE: (fertiliser prices July 1980)

Commercial fertilisers are given an N.P.K. rating. This refers to the percentage by weight of the various elemental components; i.e. nitrogen, phosphorus, and potassium.

For nitrogen in the form of urea the N.P.K. rating is 46-0-0. Therefore 9,806 kg N is equivalent to:

\[
\frac{9,806 \times 100}{46} \text{ kg of urea}
\]

i.e. 21,317 kg of urea

Urea cost $326.05/tonne gives N value = $6,950

Phosphorus: Superphosphate, N.P.K. 0-10-0, cost $95.40/tonne

\[
2460 \text{ kg P} = \frac{2460 \times 100}{10} \text{ kg superphosphate}
\]

cost $95.40/tonne gives P value $2,346

Potassium: Potassium Chloride, N.P.K. 0-0-50, cost $159.15/tonne

Equivalent fertiliser quantity:

\[
\frac{8,855 \times 100}{50} = 17,710
\]

K value $2,818

Equivalent Fertiliser Value $12,114

This analysis does not take into account that manure application continues throughout the year. Plant nutrient uptake however, is seasonal and therefore nutrient utilisation, particularly of nitrogen, may not be as efficient as timely applications of inorganic fertilisers. The analysis also assumes that an equivalent reduction in the application of inorganic fertilisers can be made. Where the farmer continues to apply his normal rate of inorganic fertilisers the manure may be considered to have little financial value, because there will be little crop response to the extra, manure-applied nutrients.
The initial step in designing a land application system is to determine the concentration of nutrients and the volume of waste discharged from the livestock operation. It is preferable to determine these parameters by direct measurement, i.e. to have a representative sample of effluent analysed for N, P, and K, and to measure hose discharge rates and flush volumes. If direct measurement isn't possible then the tables and procedures outlined in Chapter 2 should be used.

**NUTRIENT LOADING — LAND AREA REQUIRED**

As previously outlined in 'Design Principles' the quantity of available nutrients applied is matched to the crop's nutrient requirement. Typical plant uptake rates are shown in Table 7.3.

**TABLE 7.3 NUTRIENT UPTAKE KG/HA-YEAR**

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>P</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grass pasture</td>
<td>200</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>Grass pasture for hay</td>
<td>350</td>
<td>40</td>
<td>200</td>
</tr>
<tr>
<td>Cereals and maize (grain)</td>
<td>100</td>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>Maize (silage)</td>
<td>200</td>
<td>35</td>
<td>175</td>
</tr>
<tr>
<td>Choumoellier</td>
<td>360</td>
<td>60</td>
<td>400</td>
</tr>
<tr>
<td>Horticulture</td>
<td>170</td>
<td>40</td>
<td>50</td>
</tr>
</tbody>
</table>

This table is based on nutrient uptake of the plants and, where applicable, losses due to crop removal. The figures are obtained from a variety of references (MAF 1980, MAFF 1979, MAFF 1980) and personal communications with MAF advisers. They are broad generalisations and only intended for feasibility designs. Local M.A.F. advisers should be consulted for figures for use in detailed design.

Since the proportions of available nutrients in manure do not necessarily constitute a balanced fertiliser there are two methods of selecting the land area required.

- **Method I**
  Maximum utilisation of manure. Calculate the land needed to fully utilise the most abundant nutrient then supplement deficient nutrients with chemical fertilisers.

- **Method II**
  Total fertiliser needs. Select land area such that the most deficient component of manure is utilised fully and other nutrients are applied in excess.

As an upper limit to "excess nutrient application" it is suggested that up to twice the plants' requirements for nutrients can be applied without serious effects on plant growth and groundwater quality. (Based on figures from MAFF, 1980; Gould (1980); Hewgill and Le Grice, 1974; Massey University, 1977). Most of the nutrient excess would be adsorbed as luxury uptake by the plants; i.e. nutrient uptake without any corresponding increase in plant dry matter production. Stock health could be affected as discussed in "Some Micronutrient problems", so it is advisable to have soil and leaf nutrient analyses done annually. The M.A.F. provides such a service.
Procedure for Selection of Land Area:-

Step 1: select suitable nutrient rates (examples given in Table 7.3)
Step 2: calculate land area needed for each of nitrogen, phosphorous and potassium nutrients.
   i.e. \( \text{land area needed} = \frac{\text{available nutrient kg/yr}}{\text{nutrient requirement kg/ha-yr}} \) (hectares)
Step 3: for method I, select that nutrient giving the largest land area. Deficits of the other two macronutrients can be made up with chemical fertilisers. See example.
   for method II, select that nutrient giving the least land area. The other nutrients will then be supplied in excess. See example.

EXAMPLE 7.3 Selecting land area required on nutrient loading basis.
(Using figures from the previous piggery example, Example 7.2).

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>Total kg</th>
<th>Available kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>15,086</td>
<td>9,806</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>4,919</td>
<td>2,460</td>
</tr>
<tr>
<td>Potassium</td>
<td>9,839</td>
<td>8,855</td>
</tr>
</tbody>
</table>

Step 1: Pasture requirements
- Nitrogen: 200 kg/ha-yr
- Phosphorus: 30 kg/ha
- Potassium: 100 kg/ha

Step 2: Nitrogen: land area required \( \frac{9,806}{200} = 49 \) ha
   Phosphorus: land area required \( \frac{2,460}{30} = 82 \) ha
   Potassium: land area required \( \frac{8,855}{100} = 89 \) ha

Step 3:

- Method I
  The potassium application requires the largest land area. The manure would be spread over 89 hectares on a yearly basis, and nitrogen and phosphorus nutrients would be supplemented with inorganic fertilisers.

  Nitrogen deficit is \( (89 - 49) \times 200 = 8.0 \) tonnes/year
  Phosphorus deficit is \( (89 - 82) \times 30 = 0.2 \) tonnes/year

  The 9,806 kg of N applied over 89 ha would give an application rate of 110 kg/ha. This is double the rate recommended for established grass/clover pasture (Ball and Crush 1980), so the extra nitrogen would probably not need to be applied. The extra phosphorus requirement is so small that it could be neglected.

- Method II
  For this approach the nitrogen application is the deciding factor requiring 49 ha with phosphorus and potassium being applied in excess. The P and K application rates would be 50 kg/ha and 180 kg/ha respectively. As these rates are still less than twice the suggested rates no adverse effects on crops or groundwater would be anticipated. But there could be effects (grass staggers) on stock health.
HYDRAULIC LOADING

The suitability of a particular soil for manure application is largely dependent on its drainage characteristics. Problems normally associated with poor drainage would generally be aggravated by the additional hydraulic load of effluent disposal, especially during winter.

As outlined in "Design Principles" the hydraulic rate of manure application should be less than the soil infiltration capacity. Theoretically this will prevent surface runoff when applying effluent to saturated soils. However since there is a soil surface sealing effect due to the solids content of manure, it is advisable to reduce the clean water infiltration rate by 30% (Vanderholm and Beer, 1970).

In some cases the above recommendation will result in low application rates which cannot be achieved by the range of spray nozzles available. In these circumstances, winter application is not feasible. Alternatives should be considered; e.g. winter storage and spring - summer application from the storage pond.

The soil infiltration rate should be determined on site, using infiltrometer rings or the more sophisticated simulated rainfall method. If measurement is impractical then the infiltration rates from NZS 5103 may be used, as in Table 7.4.

The hydraulic application rate for a sprinkler is calculated simply as:

\[
\frac{(Q)}{(A)} = \frac{\text{effluent flow}}{\text{wetted area}}
\]

Generally uniformity of the spray pattern will not be a problem with properly operated sprinklers.

In situations where these design guidelines are used for land application of wastes from other than pig, poultry or farm dairies (e.g. processing wastes from dairy factories) the nutrient loading approach is still valid but dilute effluents could result in high hydraulic loading rates, (say greater than 50 mm/day). In order to avoid significant ground water contamination these systems should be designed using irrigation principles, i.e. waste water is applied to the land to compensate for soil moisture deficits and soil moisture budgeting would be an integral management tool.
TABLE 7:4 ESTIMATED MAXIMUM HYDRAULIC APPLICATION RATES FOR LAND APPLICATION OF MANURE (DATA BASED ON NZS 5103 1973)

<table>
<thead>
<tr>
<th>Soil groups based on texture and profile</th>
<th>Slopes* (0-8^\circ)</th>
<th>Slopes+ (9-12\ 1/2^\circ)</th>
<th>Slopes++ (over\ 12\ 1/2^\circ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(\text{mm/h})</td>
<td>(\text{mm/h})</td>
<td>(\text{mm/h})</td>
</tr>
<tr>
<td>Sands and light sandy loams uniform in texture to 1.82 m, pumice</td>
<td>22 (32)</td>
<td>18 (25)</td>
<td>14 (20)</td>
</tr>
<tr>
<td>Sandy loams to 0.61 m over-lying a heavier subsoil</td>
<td>14 (20)</td>
<td>12 (17)</td>
<td>9 (13)</td>
</tr>
<tr>
<td>Medium loams to sandy clays over a heavier subsoil</td>
<td>12 (17)</td>
<td>9 (13)</td>
<td>7 (10)</td>
</tr>
<tr>
<td>Clay loams over a clay subsoil</td>
<td>9 (13)</td>
<td>7 (10)</td>
<td>5 (7)</td>
</tr>
<tr>
<td>Silt loams and silt clays</td>
<td>7 (10)</td>
<td>6 (8)</td>
<td>4 (5)</td>
</tr>
<tr>
<td>Clays</td>
<td>5 (6)</td>
<td>4 (5)</td>
<td>3 (4)</td>
</tr>
<tr>
<td>Peat</td>
<td>12 (17)</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* \(0-8^\circ\) slope - level to undulating
\+ \(9^\circ-12\ 1/2^\circ\) slope - undulating to low hills
\++ over \(12\ 1/2^\circ\) slope - low to steep hills

NOTES

The above figures are intended for guidance only. Where detailed soil surveys and infiltration experiments have been carried out, or where reliable application rate data are available for a similar soil, the figures so established for application rates should be used.

Figures enclosed in brackets are the clean water application rates as set out in NZS 5103.
The type of equipment or system chosen for land application of wastes is dependent on:

- the wastes' physical characteristics
- the layout and terrain of the livestock facility
- to a large extent, personal preference of the farmer concerned.

The 'Introduction' to this chapter suggests the following combinations of equipment and total solids content:

- 1-2% solids: border dyke irrigation
- less than 5% solids: sprinklers
- less than 15% solids: tankers
- greater than 20% solids: spreaders

The designer must be wary of the type of waste. For instance, slurry from poultry units usually contains feathers which readily block spray nozzles. Garbage-feed piggeries and livestock buildings with bedding material give similarly difficult wastes which are usually only handled with tankers or solids spreading machines.

Siting and terrain are difficult topics to generalise on. Situations occur where the disposal site is several kilometres from the source so tankers are an obvious choice. No equipment is particularly suited to hilly or rolling terrain although where the livestock facility is considerably higher than the disposal area spray systems can use the gravitational drop efficiently.

The broad categories of manure spreading equipment are:

- single sprinkler spray equipment
- multiple sprinkler spray lines
- travelling irrigators
- border dyke irrigation
- slurry and solids spreaders
- injector tines for land incorporation

**SINGLE SPRINKLER SPRAY EQUIPMENT**

This system is used extensively throughout New Zealand. With only one sprinkler the area covered and quantity of waste discharged is limited. Typically it is used on small to moderate sized piggeries (up to 100 sows) and for farm dairies (up to 150 cows).

Two or three daily sprinkler shifts may be necessary to cope with effluent from larger units which may justify the use of travelling irrigators.

The components of the system are:

- collection and pumping sump
- pump
- mainline
- hydrant
- sprayline
- and sprinkler

Sumps and pumps are described in Chapter 3.
FIGURE 7.6 SECTIONED PLAN OF THRUST BLOCK SUPPORT FOR PIPE BENDS.

FIGURE 7.7 ALTERNATIVE THRUST BLOCK SUPPORT FOR PIPE BENDS.
The MAINLINE should be buried at least 0.6 m deep. Deeper lines are correspondingly more difficult to install. Shallower pipes are prone to damage from cultivation and machinery.

Polythene and P.V.C. pressure pipe are the most popular piping materials. A small section pipe with high flow velocities is required to sustain particulate matter in suspension while large section pipes reduce friction loss. The resulting compromise is often a 65 or 80 mm pipe for flow velocities of 1 m/sec. Pipe flow design is also covered in Chapter 3.

There are some basic aspects of pipe installation that farmers should be aware of. The bottom of the trench should be even with no large stones or other projections which cause stress in the pipe and may lead to failure, and no hollows where solids settle and initiate blockages. Deflection of fluid flow around a pipe bend causes stress in the pipe. The pipe will often fail if not supported with at least well-compacted soil, or preferably a treated wooden footing or a poured in situ concrete block to support the outside of the bend (Figures 7.6 and 7.7).

The HYDRANTS provide for connecting surface spray lines to the buried mainline. 'T' section joins are not suitable (Figure 7.8) as suspended solids settle in the dead section of the mainline causing blockages. Figures 7.9 and 7.10 illustrate two suitable hydrants. The 'humpback' version is the more conventional set up.

Rigid humpback hydrants can be made up from standard pipe fittings using either threaded connections or quick release couplings. The flexible hose type are more readily made with quick couplings. Accurate installation is important for both systems.

The SPRAYLINE allows the sprinkler to be shifted around the paddock. The main design features are dictated by the need for the spray line to be shifted, and so pipe diameter is generally not greater than 50 mm. This small pipe size results in large head losses, increasing the pump size required and also the running cost, consequently the length should be kept to a minimum. As a guide, sprayline length should probably not exceed 100 metres. For ease of handling, this total length would be broken into shorter sections and a convenient length is that equivalent to one diameter of the spray pattern. Shifting the sprinkler then involves removing or inserting one length of pipe, which shifts the spray pattern sufficiently to prevent overlap and saves the operator the chore of pacing the distance. P.V.C. pipes are not rugged enough for the handling involved. Polythene and aluminium are usually used.

The most satisfactory SPRINKLERS are the fully rotating variety. Some have adjustable sector stops allowing flexibility from the circular spray pattern. Typically the spray jet consists of a thick rubber diaphragm with a central hole of 10 to 15 mm diameter. The rubber diaphragm allows small stones and other potential blockages to be forced through the relatively small opening. Compared with irrigation spray nozzles, the choice of special purpose effluent nozzles is limited. The designer is advised to work with nozzles for which he has head versus discharge and wetted diameter characteristic curves. See manufacturer's specifications or N.Z.A.E.I. Test Report No. T/61.

Spray "Pots" have a good ability to cope with thick slurries (approximately 10% T.S.) containing long fibrous material and other solids. However they tend to have a small wetted diameter (around 10 metres) and a poor distribution pattern.
THESE HYDRANTS ARE NOT RECOMMENDED.

BLOCKAGES CAN OCCUR IN THE DEAD SECTION OF PIPE

FIGURE 7.8 “T” SECTION HYDRANT.

HYDRANTS CAN BE MADE UP FROM STANDARD PIPE BENDS AND QUICK RELEASE COUPLINGS

FLOW BYPASSES THIS HYDRANT
FLOW DELIVERED TO SPRAYLINE

FIGURE 7.9 RIGID “HUMP” HYDRANT.

FIGURE 7.9A PLAN VIEW OF MAINLINE BRANCHING WITH “HUMP” HYDRANTS.
FLEXIBLE HOSE AND QUICK RELEASE COUPLING

WOODEN BOARD TO SUPPORT COUPLING

FLOW BYPASSES THIS HYDRANT
FLOW DELIVERED TO SPRAYLINE

FIGURE 7.10 FLEXIBLE HOSE HYDRANT.

WOODEN BOARD TO SUPPORT BEND IN FLEXIBLE HOSE.

FIGURE 7.10A PLAN VIEW OF MAINLINE BRANCHING WITH FLEXIBLE HOSE HYDRANTS.
Overlap of sprinkler spray patterns is best avoided or excess nutrient loadings will occur. A suitable hydrant, sprayline and sprinkler layout is shown in Figure 7.11.

MULTIPLE SPRINKLER SPRAY LINES

Hand shift, side roll and other spray line irrigation equipment can be used for land application of effluent containing low quantities of suspended solids; e.g. effluent from the aerobic stage of a two-stage lagoon treatment system. Sprinkler blockages are likely with raw effluent or even liquid from a primary treatment lagoon. Hydraulic design, including consideration of the distribution pattern, is treated in the same manner as for irrigation installations. The nutrient loading is governed by the application rate and the spraying time at each position.

FIGURE 7.11 FARM PLAN SHOWING LAYOUT OF MAINLINE, HYDRANTS, SPRAYLINE AND SPRINKLER POSITIONS.
TRAVELLING IRRIGATION

Travelling irrigators are suitable for spraying large quantities of effluent without supervision. 'Big gun' irrigators can cover 2 hectares in a 400 m run with discharge rates ranging from 10 to 40 litres/sec. Nozzle pressures range from 40 to 60 metres head, so power requirement and running costs are high. Well-screened raw effluent can be sprayed through 'big gun' irrigators which typically have nozzle bores greater than 12 mm. Turbine drive units are in common use overseas; piston drive machines are not suitable for effluent application. In some irrigators the reaction force of a pair of opposing nozzles causes a rotating motion which with suitable gearing is transmitted to the unit's drive wheels or cable winch. The travel speed of the irrigator must be considered when determining the application depth and consequent nutrient loading.

i.e. depth of application = \( \frac{\text{effluent flow rate to irrigator}}{\text{land width} \times \text{speed of irrigator}} \)

BORDER-DYKE IRRIGATION

Large volumes of dilute effluent can be applied to the land through border dyke irrigation installations. Because of the high flow rates involved, storage lagoons often need to be incorporated into the design. When necessary, the lagoon enables dilution of the waste water. Dilution is sometimes required to prevent excess nutrient application.

For example: If the available nitrogen content of an anaerobic lagoon treating piggery waste is 575 mg/l, and the gross depth of application on the border dyked area is 80 mm, then undiluted effluent would result in a nitrogen loading of 460 kg/ha. If it was required to reduce this nutrient application to 200 kg/ha, the effluent would need to be diluted to 0.43 (200 / 460) of its original concentration.

SLURRY AND SOLIDS SPREADERS

For slurries and solid manure such as from poultry sheds, more labour-intensive systems of land disposal can be justified. Application rates are determined by considering nutrient loadings only, as the hydraulic loading is generally negligible. Solids loading rate might be important for grazed pastures.

Thick slurries (10-20\% solids) are readily spread with slurry tankers which typically have capacities in the range 2 to 6 m\(^3\). The basic type have a hole in the top for filling and a gate valve opening at the rear for discharging. The wetted path is about 3 m. More sophisticated spreaders have their own P.T.O. or motor driven pumps for filling and spreading. Conventional helical rotor and impeller pumps can form spray patterns 20-30 m wide. Most tankers have a facility for agitating the contents and one manufacturer promotes multi-purpose use, such as application of conventional liquid fertilisers and fire fighting.

P.T.O. or motor driven air pumps are used on some tankers. Vacuum pressure draws effluent into the tank and when it is full, the contents are agitated by bubbling air through it. Pressurising the tank allows discharge of the contents in spray form. Vacuum-loaded tankers avoid problems involved in pumping manure, while large suction hoses (75 to 150 mm) provide an easy passage for difficult solids.
The most popular solid manure spreaders use P.T.O. driven chain flails to distribute material to the side or behind the direction of motion. Fertiliser trucks with 'V' hoppers, chain feed, and spinning disc distributors have been used successfully. Trucks with tipping decks are not recommended because of the difficulty in controlling application rates.

The large tankers may require tandem axles and high flotation tyres to reduce compaction and disturbance of wet soils.

**INJECTOR TINES FOR LAND INCORPORATION**

Concern about odour following surface application of slurries has resulted in an increase in direct injection of liquid wastes into the soil with chisel type injector shanks. This conserves fertilizer nitrogen and significantly reduces odour following spreading. Injector systems may be mounted on the tanker or on tractor-mounted tool bars. Typically 2 injection chisels are used at a depth of 0.2 m. For a speed of 6.4 km/h the power requirement would be about 13 kW and the discharge rate approximately 900 l/min.

The tankers, muck spreaders and injection equipment described in the foregoing sections are in common use overseas. Their availability in New Zealand is somewhat limited, so it may be necessary to build or import a specific type if it is not available.

The benefits of land incorporation are also achieved by "ploughing in" or discing areas covered by a spray or tanker spreading system. The technique is recommended in odour-sensitive situations; e.g. manure spreading on market garden land adjacent to urban development.

**management**

For a land application system to be successful, the farmer must apply certain management aspects conscientiously.

**PASTURE PALATABILITY**

Effluent should only be sprayed on short pasture, i.e. immediately after grazing. Subsequent regrowth extends above the previously sprayed pasture, so new grass is not contaminated with effluent which would reduce pasture palatability. In addition the risk of grazing stock ingesting infectious organisms is reduced. Although palatability is adversely affected by the high applications of nutrients in urine and dung patches (Table 7.5), the lower rates recommended for land application avoid this problem.

**TABLE 7:5 TYPICAL NUTRIENT LOADING RATES FROM DAIRY COW DUNG AND URINE PATCHES**

*(Peterson et al, 1956) (kg/ha)*

<table>
<thead>
<tr>
<th></th>
<th>Faeces</th>
<th>Urine</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>852</td>
<td>448</td>
</tr>
<tr>
<td>P</td>
<td>171</td>
<td>7</td>
</tr>
<tr>
<td>K</td>
<td>411</td>
<td>392</td>
</tr>
</tbody>
</table>
APPLICATION FREQUENCY

There are three factors to consider in deciding the sprinkler shift frequency.

A rest period of 4 to 6 weeks between spraying and grazing should be practised. This reduces the health risk as pathogens die off in the adverse conditions of the soil environment and on the surface of the plants.

The nutrient loading is designed on a yearly basis and this quantity of nutrients must not be exceeded on any part of the total area. It is possible that a large piggery discharging waste through one sprinkler might apply the whole year's nutrient load to a specific area in one day. The situation would require daily sprinkler shifting. As another example, a dairy farmer might normally shift his sprinkler every 2 days and cover the total disposal area, 4 times a year. In spring he decides to close up a particular paddock for hay. He reduces the shift frequency to once every 8 days and applies the full yearly quota of nutrients in order to gain the greatest benefit in his hay paddock. Farmers must be aware of their daily nutrient application rate so that they can plan the shift routine.

The hydraulic load must also be considered. In winter more frequent shifts would spread the hydraulic load more thinly, lessening the likelihood of runoff pollution and anaerobic soil conditions which could kill grass and cause odour problems.

WEEDS

Weed seeds may remain fertile after passing through the digestive system. So it is possible that land application of manures will spread infestations on grazed pasture. Weeds can usually be controlled with management practices such as high stocking densities or break feeding.

CLOVER SUPPRESSION

Annual symbiotic fixation of nitrogen by clover may be as much as 500 kg/ha in new grass swards, declining to 150 - 250 kg/ha over several years (Ball and Crush, 1980). Additional nitrogen from other sources (e.g. from organic matter accumulated over several years) allows grass dominance with overcrowding and shading of clover plants. Clover tends to use this additional nitrogen as well and consequently less atmospheric N is fixed. As long as alternative nitrogen is applied annually, clover suppression is of no consequence. A typical M.A.F. recommendation for nitrogen application to mixed grass-clover swards would be 25-50 kg/ha.

TURF PULLING

It is plausible that readily available nutrients on the soil surface can lead to shallow rooting grass which is readily pulled out by grazing stock. However this condition is often associated with pugging. The shallow root system may be the result of impeded drainage or a high water table. The problem might be remedied with an appropriate drainage system and other measures to improve soil structure.
SALINITY

Soil salinity is not a common problem in New Zealand. Irrigated pasture in areas of low rainfall and high evapotranspiration are susceptible. A "soluble salts" or "conductivity" test result of 3 millimhos/cm and greater is an indication of salinity problems. The cure is to irrigate with clean water and attempt to leach the excess salts down into the soil profile.

MAINTENANCE

Animal slurry is abrasive and corrosive. The importance of preventive maintenance cannot be over-emphasized. Farmers should be advised to keep moving parts (pumps, hose couplings and sprinklers) clean and well lubricated. With regular inspections for wear, the farmer may be able to anticipate failures and have replacement gear on hand.

If equipment is to be idle for any length of time (say more than a week) it is advisable to clean it with fresh water. Spray systems are readily flushed by pumping clean water from the sump.

environmental impact

There is no doubt that poorly executed land application of manure can cause serious environmental pollution. Both nutrient enrichment and bacterial contamination of surface and groundwater can occur while spray aerosols can also spread disease organisms.

Good management of manure spreading systems will avert most problems.

WATER POLLUTION

In the U.S.A. many states have put blanket bans on discharges to rivers. All waste water is applied to the land with the result that non-point-source pollution of streams is now the major concern. Long, slow-moving rivers accumulate nutrients as they flow to the coast and salt concentrations get so high that the water is unsuitable for irrigation.

The short, fast streams in New Zealand are unlikely to be affected to the extent of those in the U.S.A. but we should not be complacent about non-point-source pollution. A 1976 amendment to the Water and Soil Conservation Act specifically includes land application of effluent and consequent pollution of groundwater. Only a few Regional Water Boards would have sufficient data to differentiate between groundwater contamination from manure spreading operations and the normal background level of nutrients from soil weathering, erosion, grazing stock, inorganic fertilisers, septic tanks etc. It is expected that control of non-point-source pollution will be by regulating the quantity of nutrients applied and the responsibility for this lies heavily with the farmer concerned.

NITRATE LEVELS IN WATER

The World Health Organisation recommendations for standards of drinking water have been adopted by New Zealand. For nitrate nitrogen ($\text{NO}_3^-\text{N}$) the recommended maximum level is 10 mg/l $\text{NO}_3^-\text{N}$. 
It has been established that young infants (less than 6 months) receiving artificial feeds of milk diluted with water containing more than 10 – 20 mg/l of NO$_3$-N may develop methaemoglobinemia. This disease, which can be fatal, is characterised by the development of a greyish-blue or brownish-blue cyanosis which eventually covers the whole body. It is caused by the nitrates being reduced to nitrites which partially convert haemoglobin to methaemoglobin and this decreases the oxygen-carrying capacity of the blood. More recently, levels of NO$_3$-N above this recommended limit have been linked with an increase in the incidence of stomach cancer in adults, through the formation of carcinogenic nitrosamines. (Hill et al; 1973).

DISEASE ORGANISMS

Disease infection is a complex affair and results when the host and the organisms meet under conditions which favour disease.

Many pathogens must enter through a particular route called the "portal of entry". This differs for various organisms depending on their ability to attack certain organs or parts of the body. The alimentary tract is the portal of entry for organisms able to withstand the action of enzymes in saliva and other digestive juices, and survive the natural acidity of the stomach. Infection could occur with contaminated food or water, e.g. salmonella. Some micro-organisms have a special affinity for the respiratory tract and may set up infections in the bronchi and lungs. Aerosols from manure spraying would be an obvious transmission vector in this case. Still other organisms enter through abrasions or openings in the skin and set up local infections while a few enter through the skin and spread through the body in the circulatory system (e.g. leptospirosis).

Another condition for disease is that the host must be subjected to an "infective dose". The number of organisms in an infective dose varies with the species of host and the variety or strain of micro-organisms. When extremely virulent organisms enter a host via the proper portal, very few are required to establish infection while less virulent strains require greater numbers.

Many organisms can be transmitted from animals to man, (and some vice versa), e.g. viral infections • cow pox, orf
fungal infections • ringworm
bacterial infections • tuberculosis
• tetanus
• brucellosis
• leptospirosis
• salmonellosis
• streptococcus
and staphylococcus

Recent eradication schemes for tuberculosis and brucellosis have controlled these diseases in New Zealand.

These diseases are transmitted in many ways; e.g. handling afterbirth from a cow infected with Brucella abortus can result in serious illness in man. The main diseases transmitted through faecal contamination are various salmonella, streptococcus, and staphylococcus infections, while leptospirosis is spread through urine from infected animals.

Land application of manure can spread these organisms on to soil and herbage, increasing the incidence in grazing stock or infecting other
species. In particular farmers should be wary of spreading piggery waste on to pasture grazed by cows. The urine from carrier pigs can spread infections of *Leptospira pomona* causing fatal disease in young calves and abortions in cows. Some protection can be gained by vaccination (Edgar et al, 1972).

Pathogens are usually short-lived in the soil environment. Changes in temperature, pH, moisture, and the addition of sunlight restrict their activity outside the host. Hubbell et al (1973) found a 99% die-off of both coliforms and salmonella after about 2 weeks in a sandy soil. At the Wallaceville Animal Research Centre, Cooper (1974) investigated survival of salmonella and leptospira after spraying effluent on to pasture. Viable salmonellae could not be isolated from the top layer of soil, 6 weeks later. He concluded that transmission of salmonellosis and leptospirosis is unlikely to occur unless pasture is inundated with contaminated effluent and then grazed very closely.

The laboratory procedures for identifying pathogenic bacteria are difficult and involved. Usually their occurrence is estimated from a count of less serious indicator organisms such as coliform bacteria; i.e. a large count of coliform bacteria indicates faecal contamination and the possibility of pathogenic organisms being present.

Contamination of groundwater from controlled land application operations should be minor, since in the absence of soil fissures water percolation through soil is very effective in removing viruses and bacteria. McCoy (1969) reported 98% removal in only 350 mm depth of soil.

**AEROSOLS**

(This section is based on a report by Bidwell, 1980).

Transport of pathogens by spray irrigation aerosols will always be a moot point, especially between neighbours. The number of micro-organisms transported by aerosols is not a simple product of effluent strength and quantity of aerosols produced. The shock of aerosol generation has a species-selective effect on the mortality of organisms. In addition, during transport of aerosols in air, the micro-organisms suffer die-off from environmental effects such as solar radiation and dehydration. This process is also species-selective with viruses being more hardy, and therefore surviving longer than some of the indicator coliform bacteria. Again the only practical alleviative measures for both odour nuisance and health hazard is to lessen the risk with good management.

There are no absolute limits on how far aerosols will be carried. Contrary to popular belief spraying shouldn't be done on still days. The diluting and mixing effect of moderate breezes is preferable in minimizing odour and health risk. Spraying upwind of dwellings should be avoided, however. Aerosols behave like smoke particles and thus smoke plumes are a good indicator of atmospheric dispersion. In general, daytime conditions tend to favour lower aerosol concentrations than night time when stable air of low turbulence, high relative humidity, and zero solar radiation occur.

**BUFFER ZONES**

A major step in preventing water pollution and reducing health risk is to prevent direct contamination with sprayed effluent.
Table 7.6 suggests the minimum allowable distance between spray patterns and various features. Local bylaws and town planning ordinances may require different widths of buffer zones.

Designers are advised to check with their local city, or county, engineering office.

**TABLE 7:6 DISTANCES BETWEEN EFFLUENT SPRAY PATTERN AND VARIOUS FEATURES**

<table>
<thead>
<tr>
<th>Feature</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal open farm drain</td>
<td>10 metres</td>
</tr>
<tr>
<td>Major collection drains and rivers</td>
<td>20 metres</td>
</tr>
<tr>
<td>Boundary fences</td>
<td>20 metres</td>
</tr>
<tr>
<td>Buildings general</td>
<td>10 metres</td>
</tr>
<tr>
<td>Livestock</td>
<td>50 metres</td>
</tr>
<tr>
<td>Dwellings</td>
<td>100 metres</td>
</tr>
</tbody>
</table>

*Neighbours should be approached and informed in the planning stages of a land application system. Wind will distort sprinkler spray patterns. It is impractical to design for all possibilities so the farmer must be responsible for operating the system in a reasonable manner.

**REFERENCES CHAPTER 7**


7-29


waste
for re-use

ANDREW J. DAKERS
DAVID J. WARBURTON
introduction

The recycling and reuse of waste products from any process is a commendable ideal. However, before the concepts can be recommended the additional costs of recycling (capital, maintenance, labour), over and above the cost of a standard waste treatment facility, must be shown to be a profitable investment. The basis for assessing 'profitability' will vary with the individual; financial returns, independent source of feed and energy, or aesthetic acceptability may all contribute to justifying the required investment. Due to these variables and the site-specific differences in construction costs, details of the economics of recycling and reuse will not be presented.

The main areas where waste recycling has been studied are:

- Water recycle; to reduce the volume of potable water polluted through cleaning systems.
- Nutrient recycle; to reduce the amount of additional fertilizer that has to be purchased by supplementing nutrients and/or improving soil condition.
- Energy production; to provide alternative sources of heating and motive power.
- Feed production; to provide alternative sources of animal feed.

In addition, some investigations have looked at recycling which would require further processing, e.g., compressing of solids to form building blocks, but this level of development is beyond the scale of most agricultural enterprises with waste treatment problems and will not be addressed in this section.

water recycle

The most common use of water recycling is to provide flushing water. The liquid intake for recycle may occur at three sites depending on the design of the waste removal and treatment systems:

- Immediately after a solid/liquid separator
- From an anaerobic lagoon or single pond storage
- From an aerobic lagoon

Removing the liquid fraction immediately after a solid/liquid separator has the advantage of requiring minimum plumbing and power reticulation as the facility would be adjacent to the production unit. Furthermore the use of fresh wastewater after solids removal would ensure minimum odours as anaerobic biological activity would not be advanced in a flushed or routinely cleaned facility. The difficulty with this configuration is the matching of flows, and pipe sizes, to ensure an adequate volume of cleaning liquid under all conditions. The pump sump capacity at the separator would
FIGURE 8.1 CONCENTRATION OF SINGLE-SALT SOLUTIONS IN PERCENT AS RELATED TO ELECTRICAL CONDUCTIVITY.

(HAMILTON 1977)
be sized according to cleaning frequency, the percentage of cleaning water recycled and the method of cleaning, i.e., regular flushing or an infrequent manual operation. The potential disease risk from recycling fresh wastewater may be greater as there would be little time for the pathogens to die off. Therefore recycling from anaerobic or aerobic lagoons is more common. Anaerobic liquor has a greater odour potential and, unless the lagoon is lightly loaded or is designed for storage capacity, it is advised to recycle aerobic lagoon liquor. The cost of providing power to the lagoon site, pumping equipment and return plumbing may be considerable and must be offset against the advantages of hydraulic recycle, namely; reduced volume of waste to be discharged or applied to the land.

The main question in recycling of treated wastewater is: what percentage of the daily waste flow can be recycled liquid? The two controlling factors are odour and salt concentration. The odour restraint cannot easily be defined as its level will depend on where the wastewater is taken from (anaerobic or aerobic), the loading rates of the treatment system and the type of cleaning facilities, e.g. the type of flushing system. Care in overall management and design of the treatment facilities should minimise odour from a recycle cleaning system.

Salt concentrations are measured by electrical conductivity (millimhos/cm). (Conductance is the reciprocal of resistance and its units are mhos as opposed to ohms). The relationship between electrical conductivity (EC) and salt concentration is influenced by the salts in solution and the temperature (Hamilton, 1977; Georgacakis and Sievers, 1977). A general relationship at 25°C for conductivity and salt concentration is shown in Figure 8.1. Conversion of EC from other temperatures can be achieved through a conversion factor presented in Standard Methods (APHA, 1980).

The two areas influenced by salt levels are bacterial activity and soil/plant interactions. Georgacakis and Sievers (1977) investigated bacterial responses to salt levels in anaerobic lagoons. The data supported earlier work on municipal digesters (McCarty & McKinney, 1961) showing that low salt levels stimulated biological activity while high concentrations became toxic. These workers concluded that an EC of 4-8 mmmhos/cm was desirable for efficient biological activity but EC above 10 mmmhos/cm would start to show toxic effects. These salt levels are slightly higher than those recommended for irrigation water. (Electrical conductivities above 3 mmmhos/cm are normally considered to start causing problems). Applying liquid to land with this level of conductivity would require investigation into the salt tolerance of the crop, the total amount of salt to be applied and the amount of leaching that is available through precipitation or irrigation with low salt water. Design details are available in other manuals (EPA, 1981). The final problem with salt accumulation in a recycle system is precipitation within pumps and pipelines (Booram et al, 1975). One of the important salts was shown to be magnesium ammonium phosphate. Its removal is best achieved by circulating a 1:50 (volume basis) acetic acid solution. Comparison of plumbing materials suggested plastic pipes were less prone to salt precipitation and are recommended for recycle systems.
nutrient recycle

Land application of agricultural wastes may be selected purely on the basis of the system being the most suitable treatment process or on the grounds of recycling nutrients to allow improved crops. If wastewater treatment is the sole criterion, the system is designed to avoid pollution at minimum cost (maximum loading rates). However, should nutrient recovery be of prime importance additional care is required to minimise nutrient losses in the process (both in treatment and after being applied to land) and to ensure soil conditions are maintained to optimise plant growth.

Nutrient levels in agricultural wastes, losses in treatment systems and crop responses after land application are detailed in the appropriate sections of the manual. System design and economic analysis may be achieved for any operation from the available data.

energy production and use

The production of energy from agricultural waste may be achieved by anaerobic digestion and the release of methane, by incineration and the release of heat, or by pyrolysis and the production of hydrocarbons. The mechanisms for production of the different forms of energy have either been covered in the appropriate section (e.g. methane) or are beyond the scope of this manual (e.g. pyrolysis). Of greater interest here is the application of the energy produced and its integration with the overall operation.

INCINERATION

Incineration of waste may be used to provide heating. The calorific value of air-dry cattle manure has been measured at 11.6 MJ/kg (Fairbank 1974) which is approximately half that of coal. On a dry matter basis the calorific value is 15.6 MJ/kg, however, the gain in calorific value is not considered sufficient to justify the cost of drying.

The practical problems of incineration of wastes, namely controlling flue gas odours, ensuring an adequate supply of air dried waste and providing continuous, automatic stoking, generally result in the process being considered uneconomic or impractical. Furthermore, the only use for the energy is in heating and consequently the process must be matched to some production unit requiring a steady heat input (to avoid large stockpiles).

BIOGAS PRODUCTION

The production of biogas by the anaerobic digestion of livestock wastes is covered in Chapter 5 where the process of anaerobic digestion, the various methods adopted, the conditions necessary for suitable digestion and the degree of pollution control achieved, are all discussed in detail.

An end product of anaerobic digestion of organic wastes is a gas mixture known collectively as BIOGAS, which has energy value.
This section looks at energy production by anaerobic digestion of livestock wastes giving energy equations and outlining some of the practical implications of utilizing biogas.

**ENERGY PRODUCTION**

**Gross Energy**

Biogas contains a mixture of gases, predominantly methane (CH₄) and carbon dioxide (CO₂) but also smaller quantities of hydrogen sulphide, carbon monoxide, hydrogen and nitrogen. The relative proportion of methane and carbon dioxide depends on conditions of the digestion process. Under favourable conditions 65 to 70 percent by volume of the biogas is methane and the remaining proportion is predominantly carbon dioxide. Under less favourable conditions the carbon dioxide and hydrogen sulphide proportions usually increase. The energy value of biogas with 65% CH₄ is about 22 megajoules per cubic metre (MJ/m³). This is the lower calorific value.

The gross daily volume of biogas yield, G (m³/day) can be determined from the following equation:

\[
G = N \times C \times L \times Dm \times V
\]

where

- \( N \) = number of animals
- \( C \) = fraction of the total daily mass of fresh manure which is collected and eventually fed to digester
- \( L \) = fraction of organic matter remaining after losses by biodegradation during handling, storage or composting or some form of pretreatment prior to being fed to the digester
- \( Dm \) = Daily, dry matter or total solids production per animal (Table 2.1) (kg/animal.day).
- \( V \) = Volume of biogas yielded daily per kg of dry matter (m³/kg.day) (Table 8.2).

Gross energy yield, \( E_g \), can be determined from:

\[
E_g = CV \times G \text{ (MJ/day)}
\]

\( CV \) is the calorific value of biogas in MJ/m³ (approx. 22 MJ/m³)

The calorific values of other common fuels are given in Table 8.1.

**TABLE 8.1 CALORIFIC VALUES FOR SOME FUELS.**

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Calorific Value (lower)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>33 MJ/m³</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>43 MJ/m³</td>
</tr>
<tr>
<td>Propane</td>
<td>92 MJ/m³</td>
</tr>
<tr>
<td>Butane</td>
<td>120 MJ/m</td>
</tr>
<tr>
<td>Petrol (96 Octane)</td>
<td>33 MJ/L</td>
</tr>
<tr>
<td>Diesel</td>
<td>36 MJ/L</td>
</tr>
<tr>
<td>Coal</td>
<td>20-34 MJ/kg</td>
</tr>
<tr>
<td>Wood</td>
<td>13 MJ/kg (approx)</td>
</tr>
<tr>
<td>Electricity</td>
<td>1 kWh = 3.6 MJ</td>
</tr>
</tbody>
</table>
ENERGY DEMAND

The system requires energy to operate. The greatest demand is that energy required to maintain the digester contents at the operating temperature. This section outlines a method for estimating this demand so that the net or profit energy can be determined.

The net energy required to maintain temperature, \( e_n \), is;
\[
e_n = e_i + e_L
\]

where;
\( e_i \) is the energy required to raise influent temperature
\( e_L \) is the energy required to replace heat losses from the digester

The total energy requirement \( E_D \) then will be:
\[
E_D = e_n / z
\]

where \( z \) is the overall efficiency of the gas burner and heat exchanger.

Therefore the net or profit energy \( (E_N) \) is simply:
\[
E_N = E_g - E_D
\]

Both \( e_i \) and \( e_L \) can be determined. If the heat capacity of the influent is 4.19 MJ/m\(^2\) C, \( Q_i \) is influent volume fed daily into the digester (m\(^3\) /day) and \( \Delta T \) is the required average temperature rise in °C then
\[
e_i = 4.19 Q_i \times \Delta T \text{ MJ/day}
\]

To estimate \( e_L \) is a bit more involved. (See approximate method using C below). The heat loss from the digester is mainly due to conduction of heat through walls, floor and roof of the digester. This loss will be greater in colder climates. In colder countries, and certainly in N.Z., digesters must be well insulated to minimize this loss. Kroeker et al (1975) demonstrated that the rational conductive heat transfer theory accurately predicted heat loss from an insulated digester tank. The general equation for heat transfer is:
\[
H = U \times A \times (T_1 - T_2)
\]

where
\( H \) is the rate of heat loss in MJ/hr
\( U \) is the overall coefficient of thermal conductivity in MJ/hr.m\(^2\).C
\( A \) is the area normal to the direction of heat flow in m\(^2\)
\( T_2 \) is the air temperature outside the digester in °C
\( T_1 \) is the required temperature of the digester liquid in °C

The overall thermal conductivity is obtained from the following equations.

(i) for roof and walls above liquid level
\[
\frac{1}{U_a} = \frac{1}{h_i} + \frac{1}{k_a} + \frac{x_1}{k_1} + \frac{x_2}{k_2} + .... + \frac{1}{h_o}
\]

8-6
(ii) for walls below water level and floor (inside surface conductance ignored)

\[
\frac{1}{U_b} = \frac{x_1}{k_1} + \frac{x_2}{k_2} + \ldots + \frac{1}{h_0}
\]

where

- subscripts denote different material types
- \( x \) = material thickness (mm)
- \( k \) = material coefficient of thermal conductivity \( \text{MJ.mm/hr.m}^2\cdot\degree\text{C} \)
- \( h \) = inside and outside unit - surface conductances
- \( h_0 = 0.033 \text{ MJ/hr.m}^2\cdot\degree\text{C} \)
- \( h' = 0.10 \text{ MJ/hr.m}^2\cdot\degree\text{C} \)
- \( k^0 \) = coefficient of conductivity of air and gas \( (0.023 \text{ MJ/hr.m}^2\cdot\degree\text{C}) \)

**NOTE** - If floor is on a dry soil base then the floor heat losses will be small

Total energy loss \( (e_1) \) from the digester is the sum of all losses from roof, wall and floors of the digester.

The losses from those surfaces above water level \( (H_a) \) is

\[
H_a = U_a x A_a x (T_1 - T_2) \text{ MJ/hr}
\]

where 'a' denotes above water level

The losses from those surfaces below water level \( (H_b) \) is

\[
H_b = U_b x A_b x (T_1 - T_2) \text{ MJ/hr}
\]

where 'b' denotes below water level

Thus total heat loss \( H_T \) is

\[
H_T = H_a + H_b
\]

The daily energy required to replace heat losses is:

\[
e_L = 24 (U_a A_a + U_b A_b) \Delta T
\]

\( \Delta T \) is the average temperature difference in \( ^\circ\text{C} \) over the 24 hr period.

As an approximation, if the digester is completely insulated the daily energy losses will be;

\[
e_L (\text{approx}) = A_t x \Delta T \text{ MJ/day}
\]

where \( C = 16.7 \) if fully insulated with 50 mm polystyrene or the equivalent \( C = 25 \) if fully insulated with 75 mm polystyrene or the equivalent \( A_t \) is the total conducting area in m².

If the biogas is being used to provide this energy, the efficiency of a gas burner and heat exchanger must be allowed for. Also, in some cases dilution of digester feed is carried out by direct use of digester liquid thus reducing \( e_1 \). Other requirements include energy for mixing and agitation of digester contents and energy for any pumping that is necessary. These energy requirements are small (5 to 10%) in comparison to \( E_T \).
PROCESSING

Biogas, as produced by a digester, will contain hydrogen sulphide which is highly corrosive and in nearly all situations should be removed. Its concentration will depend on the feedstock and can vary from 0.06% to 5%. The simplest method of removal is to pass the gas through a drum containing iron turnings. Periodically these need to be exposed to air to regenerate. Larger units sometimes use wood shavings soaked in iron sulphate, bubbling the gas through copper sulphate solution or spent oxide.

High moisture levels in the gas can be a problem. Removal of moisture is achieved by cooling the gas then removing the condensate through a trap.

For some applications, especially as a vehicle fuel replacement, it is essential that the CO₂ is removed or at least reduced. CO₂ is non-combustible and by its removal, the energy density of biogas will be improved considerably. Also if the methane/CO₂ ratio for the biogas is not constant, this will affect vehicle performance. The simplest methods of removing CO₂ (called scrubbing) are:

- A counter-current water spray tower
- Dissolving CO₂ in water under pressure;
- Bubbling biogas through caustic chemicals (e.g. lime water).

STORAGE

Unless gas demand exactly matches gas production, some form of gas storage is required. Low pressure storage systems are the most common, but if the gas is also used as a vehicle fuel, some storage can be provided at high pressures.

At low pressures (100 to 150 mm of water gauge is common), gasometers and butyl rubber bags can be used. However, to store significant quantities of energy, enormous volumes are needed. To contain the same energy as a 200 litre drum of petrol, a low pressure storage system will need a volume of about 300 cubic metres (equivalent to an average sized house).

High pressure systems use a three or four-stage compressor to compress the gas to pressures of approximately 25 MPa and contain the gas in high-pressure cylinders. Even at these high pressures methane still has only one sixth of the energy density of liquid fuels.

Because of these difficulties with both low and high pressure storage, it is vitally important to match the production and demand for gas as closely as possible. Methane production from the digester can be varied according to demand simply by altering the feedstock loading rate into the digester.

Response time is generally several days. Unfortunately, any reduction in utilising the digester's full production capabilities, will decrease the returns from it and thus increase the cost per cubic metre of biogas.

Demand for the gas will depend on use. Uses such as crop drying, glasshouse heating and tractors often have high seasonal or high daily requirements and are difficult to match with supply from the digester. Thus every effort should be made to use biogas in applications where demand is relatively constant to keep storage to a minimum.
FIGURE 8.2: SCHEMATIC ILLUSTRATION OF THE PRODUCTION AND USE OF BIOGAS IN VEHICLES. (FROM MARTIN AND STEWART, 1980)
UTILIZATION

Heating

Biogas can be used as a heating fuel for a variety of purposes in exactly the same manner as natural gas, L.P.G. or coal gas. Burners for biogas have to be specifically designed or other gas burners converted. It is important that the correct gas/air ratio and mixture velocity is obtained. For complete burning of methane, the gas/air volume ratio should be about 1:9.6. Mixture velocity depends on the size of the jet and the pressure of the gas.

Biogas can be used domestically for hot water heating, home cooking and heating similar to other gas. Consumption per household for these functions is approximately 1 000 m$^3$ methane annually.

Biogas could replace any of the fuels presently utilised for crop drying. Because this use is often seasonal and the gas consumption relatively high, the effect this will have on storage volumes required must be considered. Fortunately, many crops do not need to be dried immediately after harvest, and this property can be used to lengthen the drying process.

Similar problems of seasonal use exist in glasshouse heating. Biogas use, however, besides providing heating, can also offer CO$_2$ enrichment. Piggeries, poultry houses or other animal houses could use biogas as a source of heating.

Vehicle fuel

Methane is a good spark ignition fuel (Fig. 8.2). Conversion kits are available in New Zealand to convert petrol engines for C.N.G. and these can also be used for methane. Diesel engines are not so easily converted but conversion equipment has recently become available. The major disadvantage of methane as a vehicle fuel is the limited range possible without increasing the weight of the vehicle excessively.

For use in vehicles, the methane is compressed in either a three or four-stage compressor to 25 MPa and stored in a high-pressure gas storage cascade. This cascade is necessary to facilitate quick refuelling of the vehicle's storage cylinders. The number of cylinders in the cascade will depend on the size of digester and the number of cylinders fitted to each vehicle. For a 45 m$^3$ digester, at least three or four 9.2 m$^3$ cylinders would be necessary. Similarly, the hourly capacity of the compressor must exceed the hourly methane production from the digester if vehicle use is the principal gas use.

Stationary internal combustion engines

The use of biogas for stationary engines has the advantage of not necessarily requiring compressed storage of the gas or the removal of CO$_2$. Also the waste heat from a stationary engine can be recovered for digester heating thereby increasing overall efficiency.

Stationary diesel engines driving a constant load at constant speed can be easily converted to run on up to 90% biogas. Some diesel is still required for ignition however. These dual-fuel (diesel/biogas) engines are often used by sewage treatment works for pumping and electricity generation.
TABLE 8.2 BIOGAS YIELDS FOR DIFFERENT FEED MATERIALS (MESOPHILIC CONTINUOUS DIGESTION).

<table>
<thead>
<tr>
<th>Feed Type</th>
<th>Detention Time</th>
<th>(a) % Total Solids</th>
<th>(b) V m$^3$/kg DM</th>
<th>(c) Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poultry</td>
<td>15</td>
<td>6</td>
<td>0.352</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>6</td>
<td>0.380</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>4</td>
<td>0.480</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>10</td>
<td>0.320</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>14</td>
<td>0.291</td>
<td>4</td>
</tr>
<tr>
<td>Pig</td>
<td>10</td>
<td>5</td>
<td>0.300</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>5.3</td>
<td>0.526</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>3.3</td>
<td>0.297</td>
<td>4</td>
</tr>
<tr>
<td>Cow</td>
<td>20</td>
<td>6</td>
<td>0.195</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>6</td>
<td>0.215</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>10</td>
<td>0.270</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>7.8</td>
<td>0.203</td>
<td>1</td>
</tr>
<tr>
<td>Grass</td>
<td>20</td>
<td>7.5</td>
<td>0.283</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>7</td>
<td>0.300</td>
<td>5</td>
</tr>
</tbody>
</table>

(a) Total solid content of digester feed
(b) V - m$^3$ biogas per kg total dry solid input
(c) (1) Bousfield et al (1979)
(2) Hobson et al (1977)
(3) Fischer et al (1975)
(4) Hobson (1976)
(5) Stewart et al (1979)

Possible uses for stationary engines are: Electricity generation, pumping, driving fans, etc. Electricity generating plants powered by biogas are available in New Zealand.

**Economics of Biogas Production**

The viability of using methane is very dependent on scale. Table 8.3 compares the return that may be achieved for a small and a large piggery. The savings are only an indication since they do not take into account the energy for mixing or the additional capital investment required to 'save' the equivalent amount of electricity. The fivefold difference in return does not require a fivefold difference in capital investment. For example, flame traps, control valves, sensors, etc, are similar irrespective of the size of plant.

In conclusion, the use of waste to produce energy may be economically justifiable in large scale operations with careful design and operation of the plant.

(The preceding sections on Processing, Storage and Utilization have been extracted from Martin and Stewart, 1980).
TABLE 8.3 ENERGY AND ECONOMIC RETURNS FROM A DIGESTER RECEIVING PIGGERY WASTE; EFFECT OF SCALE.

<table>
<thead>
<tr>
<th>Option</th>
<th>40 Sow Unit</th>
<th>200 Sow Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Production</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of pigs</td>
<td>400</td>
<td>2000</td>
</tr>
<tr>
<td>Methane (cu m/d)</td>
<td>31</td>
<td>156</td>
</tr>
<tr>
<td>Gross Energy (MJ/d)</td>
<td>1040</td>
<td>5200</td>
</tr>
<tr>
<td><strong>Direct Heating</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy provided as</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hot Water (MJ/d)</td>
<td>499</td>
<td>2496</td>
</tr>
<tr>
<td>Energy Saved (kWh/d)</td>
<td>139</td>
<td>693</td>
</tr>
<tr>
<td>Savings on Electricity ($) (2)</td>
<td>5.50</td>
<td>27.70</td>
</tr>
<tr>
<td><strong>Stationary Engine and Heating</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy Provided as</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity (MJ/d) (3)</td>
<td>156</td>
<td>780</td>
</tr>
<tr>
<td>Energy Saved (kWh/d)</td>
<td>43</td>
<td>217</td>
</tr>
<tr>
<td>Savings on Electricity ($) (4)</td>
<td>3.90</td>
<td>19.5</td>
</tr>
<tr>
<td>Thermal Heat Recovery available for other uses (MJ/d)</td>
<td>260</td>
<td>1300</td>
</tr>
<tr>
<td>Energy Saved (kWh/d)</td>
<td>72</td>
<td>361</td>
</tr>
<tr>
<td>Savings on Electricity ($) (2)</td>
<td>2.89</td>
<td>14.4</td>
</tr>
<tr>
<td>Total Savings Using</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engine and heat recovery ($) (5)</td>
<td>6.79</td>
<td>33.9</td>
</tr>
</tbody>
</table>

**Notes**

(1) Assumes 80% of gross energy available to heat water and 60% of this is effective in heating water.

(2) Assumes electricity for water heating costs 4c/kWh.

(3) Assumes all gas consumed in the engine and that the engine and generator unit are 15% efficient.

(4) Assumes uncontrolled electricity charges are 9c/kWh.

(5) Assumes 50% of the thermal energy in the fuel can be recovered and half of this is available for other uses, i.e., not heating the digester.
feed supplements

The production of protein and feed supplements for livestock or human consumption is a major challenge. The direct application of agricultural wastes to provide this raw material is particularly appealing as the net efficiency of protein production may be raised and a pollution control problem solved.

The application of agricultural waste to land is part of the refeeding cycle since it assists in production of various crops, cereals, pasture, vegetables etc. However, other alternatives are available to the livestock operator.

DIRECT REFEEDING

Some animals, e.g. rabbits, eat their own faeces as a normal part of their diet. Being monogastric herbivores they rely on the bacterial decomposition of the feed in the large intestine and colon to convert the feed into a more readily digested form. Other animals eat faeces as a behavioural routine but not primarily for the feed value. It has been observed, and encouraged by some operators, that livestock, e.g. pigs, will feed on excreta and the normal ration may be reduced because of this supplement. Collection of the solid fraction, either directly from animal pens or via a solid/liquid separator for incorporation into the animal ration has been researched and used in some commercial operations (Overhults et al, 1978, Byrnes, 1978). Since approximately 20% of a finishing pig's intake is excreted, a practical limit on waste in a finishing ration would be 15-18%. Under such conditions of total recycle, the fresh feed requirement was shown to decrease by about 15%, the average liveweight gain was reduced by an average of 19% and the total dry matter intake suppressed by 10% when compared to the control. The overall feed conversion efficiency (based on total D.M. intake) was 10-14% poorer with manure. However, based purely on the new feed intake the manure-fed animals showed a 5-6% improvement on feed conversion efficiency. No disease problems were reported. The economics of this type of operation may be marginal due to greater occupancy times and costs of feed recycle. Rations to gestating sows of up to 95% recycled feed (waste from the whole piggery recycled to sows) have been successful in commercial ventures with suggestions that the recycled feed not only reduced feed costs but also improves the antibody levels in sows, resulting in less scouring in the farrowing buildings.

Direct recycling with minimum to zero processing is open to criticism as it may force animals to feed on unacceptable diets, increase the level of disease transmission and be unacceptable to the consumer, presenting a poor image on the quality of the final product. Changes in producer and consumer attitude, and the availability of more information may make this practice more acceptable in the future.

REFEEDING AFTER PROCESSING

Processing of animal wastes prior to refeeding them their own excreta has been aimed at: decreasing the disease risk, improving the nutritive status of the recycled material, increasing the flexibility of the feeding programme (i.e. better integration with waste treatment, feed mixing and storage and feed distribution) and reducing natural prejudice of refeeding animal wastes. The processing has been done in four main ways;
• Drying the waste prior to incorporating with the ration.
• Ensiling or anaerobic treatment of the waste prior to distribution.
• Aerobic treatment prior to incorporation with the ration.
• Chemical treatment of the waste to change its nature and improve its nutritive value.

**Drying Waste**

Dehydration of waste reduces the viable microbial population and allows the material to be stored and handled with less difficulty. Most drying studies have been on poultry waste which are voided at a lower moisture content (approx. 70-80% DM) than the faeces and urine from livestock. (Solid/liquid separation of livestock waste may produce a solid fraction of similar moisture levels to poultry waste but much of the nutritive value remains in the liquid fraction, making the two incomparable). The driers are typically rotary drum units (Woods, 1975) though other systems have been investigated. The effectiveness of different drying conditions have been investigated by various authors (Chang et al. 1975, Fontenot et al. 1971). A dry heat (150°C) and reducing the moisture level below 10% appears the most effective in giving the desired bacterial kill. The difficulties with drying are; the capital cost of the drier, the operating costs (fuel and labour) and the potential for atmospheric pollution from the drying waste. The pollution can be controlled by venting the gases through a burner or gas scrubbers before release to the atmosphere.

**TABLE 8.4 CHEMICAL COMPOSITION OF FRESH AND DRIED BROILER LITTER.**

<table>
<thead>
<tr>
<th></th>
<th>As Excreted</th>
<th>Dried</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry matter, percent</td>
<td>80.48 ± 0.847</td>
<td>99.82 ± 0.000</td>
</tr>
<tr>
<td>Crude protein, percent</td>
<td>29.98 ± 2.572</td>
<td>25.95 ± 2.325</td>
</tr>
<tr>
<td>Ether extract, percent</td>
<td>3.08 ± 0.588</td>
<td>2.48 ± 0.472</td>
</tr>
<tr>
<td>Crude fiber, percent</td>
<td>18.28 ± 1.224</td>
<td>17.80 ± 1.307</td>
</tr>
<tr>
<td>Ash percent</td>
<td>30.67 ± 5.272</td>
<td>28.79 ± 5.126</td>
</tr>
<tr>
<td>NFE, percent</td>
<td>17.88 ± 2.269</td>
<td>24.98 ± 2.006</td>
</tr>
<tr>
<td>Calcium, percent</td>
<td>1.64 ± 0.217</td>
<td>1.82 ± 0.222</td>
</tr>
<tr>
<td>Phosphorus, percent</td>
<td>1.46 ± 0.180</td>
<td>1.20 ± 0.149</td>
</tr>
<tr>
<td>Magnesium, percent</td>
<td>0.31 ± 0.021</td>
<td>0.33 ± 0.024</td>
</tr>
<tr>
<td>Gross energy, kcal per g</td>
<td>3.25 ± 0.284</td>
<td>3.35 ± 0.275</td>
</tr>
<tr>
<td>Protein N, percent</td>
<td>2.87 ± 0.209</td>
<td>2.53 ± 0.272</td>
</tr>
<tr>
<td>Protein N, percent of total N</td>
<td>62.09 ± 3.633</td>
<td>61.23 ± 3.633</td>
</tr>
<tr>
<td>Nonprotein N, percent</td>
<td>1.92 ± 0.257</td>
<td>1.62 ± 0.209</td>
</tr>
<tr>
<td>Nonprotein N, percent of total N</td>
<td>37.91 ± 3.633</td>
<td>38.77 ± 3.633</td>
</tr>
<tr>
<td>Ammonia N, percent</td>
<td>1.02 ± 0.066</td>
<td>0.39 ± 0.030</td>
</tr>
<tr>
<td>Ammonia N, percent of total N</td>
<td>22.20 ± 1.318</td>
<td>9.63 ± 0.419</td>
</tr>
<tr>
<td>DOT and metabolites, ppm</td>
<td>0.095 ± 0.011</td>
<td>-</td>
</tr>
</tbody>
</table>

Reference: Miner and Smith (1975)
The change in composition of poultry waste during drying and its nutritive value as a feed are shown in Tables 8.4 and 8.5. (Similar values may be obtained from the literature for other wastes). The percentage of a total ration formulated from dried poultry waste (DPW) has ranged from 0 to 50% (Fontenot et al 1971, Flegal and Zindel 1971, Woods 1975, Hodgets 1971). In practice a ration of 30% DPW recycled back to the birds would almost eliminate all the waste handling and give total recycle (Woods 1975). (The exact levels will vary depending on the initial and final moisture levels of the waste). As a general rule, rations with over 25 to 30% DPW started to cause a reduction in egg production although egg quality was unaffected. Trials using 10-20% DPW suggest that there is no adverse effects on egg production or feed conversion efficiency in layers. However, even this level of DPW in the feed of growing chicks did suppress their 4-week body weight and feed conversion efficiency (Flegal and Zindel, 1971 and Flegal, et al, 1975). No problems with pesticide residues or salt accumulation have been reported in these studies.

The use of dried poultry waste for other livestock has yielded similar results to those presented for refeeding to birds (Fontenot et al 1971, Bucholtz et al 1971). Intake and performance tended to drop with more than 25% DPW in the feed. It was also considered necessary to have a crude protein level of approximately 25% (dry weight basis) in the DPW before recycling the feed was economically justifiable.

ANAEROBIC PROCESSING

Ensiling, or anaerobic fermentation, of livestock waste has been shown to reduce disease risk (Ciordia and Anthony, 1969, McCaskey & Anthony 1975) and improve the nutritive status of the feed by converting non-protein nitrogen into protein nitrogen (Miner & Smith, 1975).

Combining cattle feedlot waste into a maize/grain ration, to achieve 40% manure in the final feed and ensiling for 20 days has proved a viable operation in commercial cattle feedlots. Estimates of a 15% increase in overall profitability through recycling have been claimed. Anthony (1966) used up to 60% manure in silage mixtures and reported no difficulties with intake and animals performed better with silage from a manure/hay mixture than straight hay. Similar studies on the ensiling of broiler litter (Fontenot et al, 1975) showed good digestibility and improved palatability with the inclusion of manure in the ensiled mixture. However, although the system is proven, its application in New Zealand with few feedlot fattening units and minimum controlled feeding operations may be limited.
Fermentation of piggery waste for 7 days prior to refeeding showed improved feed conversion efficiencies in relation to untreated recycled waste. The processing also increased the ether extract (fat level) but decreased the total nitrogen level. (Overhults et al, 1978). The nutritive value of anaerobic digester effluent has not been well defined but it may be possible to recycle part of the digester effluent in the feed.

AEROBIC PROCESSING

Aeration of the waste may include composting, mechanical aeration, or biological aeration depending on the desired end product. Composting of the waste prior to inclusion in a cattle ration reduces the digestibility of the manure and would not seem to be justified from a nutritional standpoint (Albin and Sherrod, 1975). Harmon and Day (1975) reported on the use of oxidation ditch mixed liquor (ODML) as a substitute for drinking water and protein. Pigs on a 12% protein diet showed improved growth with ODML as opposed to the control. However, good management is required to ensure over-aeration (producing toxic nitrates - up to 5,000 mg/l NO₃-N have been measured) or under-aeration (anaerobic liquor reduced liveweight gains and produced odours in the building) do not occur. Under conditions of ODML recycle no effluent leaves a building and make-up water would be required to maintain ditch volume. A review of other work by Miner and Smith (1975) shows similar results but not the extent of improved liveweight gains with aerated liquor as part of the feed.

Algal harvesting from stabilization ponds has been achieved by Hill and Lincoln (1979) with over 90% algal recovery. Present studies on the nutritive value of the algae suggest it can be incorporated into the diet with few problems. Calculations on production levels suggest that efficient algal production is limited to 35° either side of the equator limiting much of New Zealand for this type of feed production. A comprehensive study in Oregon (Boersma et al, 1978) may be more relevant to New Zealand conditions. It also indicated that very high daily rates of solar radiation (say, greater than 17 MJ/m² day) were required for year-round operation of algal basins, rates not exceeded in New Zealand. The use of duckweed has also been shown to have potential (Hillman and Culley, 1978). Plant growth rates are at least twice those of fast-growing higher plants, e.g. maize. Furthermore, there is no woody material suggesting improved nutritive value as the whole plant is essentially a leaf (37% crude protein). In reviewing the potential of duckweed, Hillman and Culley (1978) indicate that it can be grown satisfactorily on ponds receiving livestock waste.

CHEMICAL PROCESSING

Chemical processing is aimed at improving the availability of nutrients bound in the organic fraction of the waste. Simple chemical treatment by adding sodium hydroxide, sodium peroxide or similar chemicals to break down the fibre fraction in dairy waste has been investigated with limited success (Smith et al, 1971). Davies et al (1975) reported on more intensive chemical processing using urea and formaldehyde. The process improved the nitrogen status of the feed but, as with the simpler chemical treatment, it is doubtful if the returns would justify the outlay.
PRODUCING OTHER FEED SUPPLEMENTS

Novel concepts of using livestock wastes as a feed source have been suggested. Calvert et al (1971) grew housefly larvae on chicken manure, feeding adult flies to the chickens. Ettinger and Wade (1971) showed the feasibility of growing maggots on cattle waste and presented a proposed system. However, these concepts have not been widely applied, and the reader is referred to the references for details.

resources for other industries

The potential for intensive fish production from aerobic treatment ponds seems extremely good. Schroeder (1977) reported fish yields of 30 kg/ha·day which was twice the national (Israel) average of fish production. While this potential is good, care is required to ensure excessive organic loading does not deplete oxygen reserves in the pond. Carp, cat-fish and other species have been tried in experimental and commercial operations with some success.

The use of the fibrous component from livestock waste for use in the building or pulp and paper industries has been raised by some (Fairbank et al, 1975). The difficulties involve quality control of the raw material, sufficient scale to justify a processing facility and the overall economics of such a venture. The possibilities of using the fibres to grow mushrooms (to supplement the hay/straw mulch) or production of earthworms (done commercially overseas for the fishing fraternity, but could be used as a protein source) may warrant investigation as the number of solid/liquid separators and size of production facilities increase.
REFERENCES CHAPTER 8


chapter 9

odour and atmospheric pollution

DAVID J. WARBURTON
introduction

Air pollution from agriculture may be divided into several classes depending on the nature of the contamination. Gases (noxious, toxic and malodorous), suspended solids (dust or smoke) and nutrients (ammonia) form the main categories, with malodorous gases presenting the greatest single problem. The increasing scale and intensification of livestock production facilities, in conjunction with urban sprawl and the proliferation of small farms has resulted in a greater level of odours and of complaints from affected residents.

Producers have been served with closure notices and expansion of facilities has been delayed due to concern over increased odours. Planned new operations have not received 'specified rights of departure' from County Authorities because of objections by neighbours. Dakers (1978), reporting on a national survey of livestock waste management problems, showed that approximately 60% of the counties had odour-related problems, compared to only 25% with water pollution problems.

The following sections deal with the source and extent of these problem odours, the livestock producers' legal standing and the methods to alleviate what is generally regarded as the primary problem confronting waste management.

compounds causing atmospheric pollution

There are two main sources of odour in a livestock operation. The first is that from the animals and from feed such as silage. These odours always exist irrespective of the management system and are not generally the cause of major problems. The second, and of greater importance, is the odour from the anaerobic decomposition of wastes (animal excreta, spilled feed).

A list of compounds identified as volatiles from cattle, poultry and piggery wastes is given in Table 9.1. Identification of these compounds is most commonly done with gas-liquid chromatography. However, as the level of analytical resolution is up to 1,000 times less sensitive than that of the human nose, the compounds need to be concentrated by various procedures before analysis.

Table 9.2 summarises 'odour threshold' values reported in the literature. The table shows the concentration at which the odour is just detectable and the nature of the odour for each of the major compounds identified around livestock facilities. The experiments to identify these concentrations are closely controlled and the evaluations are done on pure (as opposed to mixed), vapours. In practice, odour levels are significantly influenced by the relative 'mix' of the different odorants in the gases emitted from a particular system (Hill & Barth, 1976). Consequently, the prediction of odour intensity by chemical analysis is only of academic interest and should not be used as the criteria to establish odour levels.
TABLE 9.1 CHEMICALS IDENTIFIED AS VOLATILES FROM CATTLE, POULTRY, AND PIG WASTES.

<table>
<thead>
<tr>
<th>CHEMICAL</th>
<th>CHEMICAL</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ALCOHOLS</strong></td>
<td><strong>NITROGEN-CONTAINING</strong></td>
</tr>
<tr>
<td>Methanol*</td>
<td>Methylamine*</td>
</tr>
<tr>
<td>Ethanol*</td>
<td>Dimethylamine*</td>
</tr>
<tr>
<td>Hexanol</td>
<td>Trimethylamine*</td>
</tr>
<tr>
<td>n-Propanol</td>
<td>Ethylamine*</td>
</tr>
<tr>
<td>Isopropanol*</td>
<td>Triethylamine*</td>
</tr>
<tr>
<td>n-Butanol</td>
<td>n-Propylamine</td>
</tr>
<tr>
<td>Isopentanol</td>
<td>n-Butylamine*</td>
</tr>
<tr>
<td>2-Butanol</td>
<td>n-Amylamine</td>
</tr>
<tr>
<td>Sec-Butanol</td>
<td>3-Aminopyridine*</td>
</tr>
<tr>
<td>Phenol</td>
<td>Ammonia*</td>
</tr>
<tr>
<td>Et-phenol</td>
<td></td>
</tr>
<tr>
<td>p-cresol*</td>
<td>Indole</td>
</tr>
<tr>
<td>2-ethoxy-1-propanol</td>
<td>Skatole</td>
</tr>
<tr>
<td><strong>CARBONYL-CONTAINING</strong></td>
<td><strong>SULPHUR-CONTAINING</strong></td>
</tr>
<tr>
<td>Acetic Acid*</td>
<td>Hydrogen Sulphide*</td>
</tr>
<tr>
<td>Benzoic Acid</td>
<td>Carbonyl Sulphide</td>
</tr>
<tr>
<td>Propionic Acid</td>
<td>Dimethyl Sulphide</td>
</tr>
<tr>
<td>n-Butyric Acid</td>
<td>Carbon disulphide</td>
</tr>
<tr>
<td>Isobutyric Acid</td>
<td>Dimethyl disulphide</td>
</tr>
<tr>
<td>n-Valeric Acid</td>
<td>Methanethiol*</td>
</tr>
<tr>
<td>Isovaleric Acid</td>
<td>Ethanethiol* * mercaptan</td>
</tr>
<tr>
<td>Anthanic Acid</td>
<td>Propanethiol*</td>
</tr>
<tr>
<td>Caproic Acid</td>
<td>Dimethyl trisulfide</td>
</tr>
<tr>
<td>Benzaldehyde</td>
<td></td>
</tr>
<tr>
<td>Acetaldehyde*</td>
<td>Ketones</td>
</tr>
<tr>
<td>Propionaldehyde</td>
<td>Acetophenone</td>
</tr>
<tr>
<td>n-Butyraldehyde</td>
<td>2-Octanone</td>
</tr>
<tr>
<td>Isobutyraldehyde</td>
<td>Aromatic Organics</td>
</tr>
<tr>
<td>n-Valeraldehyde</td>
<td>Toluene*</td>
</tr>
<tr>
<td>n-Hexaldehyde</td>
<td>Xylene*</td>
</tr>
<tr>
<td>n-Octaldehyde</td>
<td>Aklyl benzene</td>
</tr>
<tr>
<td>n-Decaldehyde</td>
<td>Indane</td>
</tr>
<tr>
<td>Ethylformate*</td>
<td>Ringed Organics</td>
</tr>
<tr>
<td>Methylacetate*</td>
<td>Me-naphthalene</td>
</tr>
<tr>
<td>Isopropylacetate*</td>
<td>Simple Organics</td>
</tr>
<tr>
<td>Isopropylpropionate</td>
<td>CO₂*</td>
</tr>
<tr>
<td>Isobutylacetate*</td>
<td>Methane</td>
</tr>
<tr>
<td>Acetone*</td>
<td></td>
</tr>
<tr>
<td>2-Butanone*</td>
<td></td>
</tr>
<tr>
<td>3-Pentanone*</td>
<td></td>
</tr>
<tr>
<td>2,3-butanedione</td>
<td></td>
</tr>
<tr>
<td>3-Hydroxy-2-Butanone</td>
<td></td>
</tr>
</tbody>
</table>

* Listed for limitation in working Environment by Occupational Safety and Health Standards.

Source: Kreis, 1978
TABLE 9.2 ODOUR THRESHOLD, THRESHOLD LIMIT VALUES AND QUALITY DESCRIPTION OF CHEMICALS CONSIDERED TO BE IMPORTANT TO ORGANIC WASTE ODOURS.

<table>
<thead>
<tr>
<th>CHEMICAL</th>
<th>Odour Threshold(1) ppm</th>
<th>Threshold Limit Values(2) ppm</th>
<th>Odour Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbonyl-containing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>0.21</td>
<td>100</td>
<td>Green sweet</td>
</tr>
<tr>
<td>Propionaldehyde</td>
<td>0.0095</td>
<td>*</td>
<td>Butter-like</td>
</tr>
<tr>
<td>3-Hydroxy-2-butanone</td>
<td>1.0</td>
<td>10</td>
<td>Vinegar-like</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>20.8</td>
<td>*</td>
<td>Pickle-like</td>
</tr>
<tr>
<td>Propionic acid</td>
<td>8.1</td>
<td>*</td>
<td>Sweet-like</td>
</tr>
<tr>
<td>2-Methylproponic acid</td>
<td>0.301</td>
<td>*</td>
<td>Sour, Rancid</td>
</tr>
<tr>
<td>Nitrogen-containing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methylamine</td>
<td>0.021</td>
<td>10</td>
<td>Ammoniacal</td>
</tr>
<tr>
<td>Dimethylamine</td>
<td>0.047</td>
<td>10</td>
<td>Fishy</td>
</tr>
<tr>
<td>Trimethylamine</td>
<td>0.00021</td>
<td>*</td>
<td>Fishy</td>
</tr>
<tr>
<td>Ethylamine</td>
<td>*</td>
<td>10</td>
<td>*</td>
</tr>
<tr>
<td>Skatole</td>
<td>0.019</td>
<td>*</td>
<td>Ammoniacal</td>
</tr>
<tr>
<td>Ammonia</td>
<td>46.8</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>Sulphur-containing</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Methanethiol</td>
<td>0.0021</td>
<td>0.5</td>
<td>Skunk, Foul</td>
</tr>
<tr>
<td>Ethaneothiol</td>
<td>0.001</td>
<td>0.5</td>
<td>Onion-like</td>
</tr>
<tr>
<td>Propanethiol</td>
<td>0.00074</td>
<td>*</td>
<td>Onion-like</td>
</tr>
<tr>
<td>1-Butylthiol</td>
<td>0.00009</td>
<td>0.5</td>
<td>*</td>
</tr>
<tr>
<td>Dimethyl sulphide</td>
<td>0.001</td>
<td>*</td>
<td>Rotten cabbage</td>
</tr>
<tr>
<td>Diethyl sulphide</td>
<td>0.0005</td>
<td>*</td>
<td>Rotten cabbage</td>
</tr>
<tr>
<td>Hydrogen sulphide</td>
<td>0.00072</td>
<td>10</td>
<td>Eggy Sulphide</td>
</tr>
</tbody>
</table>

NOTES: (1) Odour concentration for detection by most people. (2) Maximum recommended concentration that nearly all workers may be exposed to for a normal 40 hour week. (3) Asterisks indicate that no data was available.


odour evaluation

Odour evaluation using an individual's sense of smell is an extremely subjective measurement. Perception of odour by the human nose is greatly influenced by fatigue, masking, the inability of some people to identify specific odours and the wide variations in individual sensitivity to an odour. Warburton et al (1979) reviewed the range of odour measuring techniques that have been developed to accommodate these sources of variation.

The Barneby-Cheney Scentometer for obtaining the threshold dilution of odorous air in the field is shown in Figure 9.1. Odour-free air is obtained by drawing air in through the activated charcoal filters. Malodorous air is inhaled directly from the various inlets and the ratio of air flows is selected where the odour can just be detected. This ratio provides the basis for calculating the dilution threshold. Although this unit is convenient to use, and has been adopted as the basis for some odour control legislation overseas, the values obtained are still dependent on the sensitivity of the operator's nose. Furthermore, it does not provide any value for the acceptability of the odours.
Dust levels have been closely associated with odour (Muehling 1969, Hammond et al. 1977), possibly because of an odour-concentrating effect in nasal passages. The suspended solids in the air may also create unpleasant working conditions and cause problems with the respiratory system.

The presence of dust is easily detected by the eye and may be quantitatively measured by drawing a known volume of air through a pre-weighed filter. Selection of the filter pore size and the volume of air will vary depending on the conditions, but most researchers aim to remove particles greater than 0.5 micrometres. Commercial instruments using the principle of light scattering are available (Miner and Smith, 1975) and may be calibrated to measure dust levels from particles of 1 micrometre or less.
concentration of atmospheric pollutants resulting from livestock operations

The concentration of ammonia and sulphides commonly measured around livestock facilities is given in Table 9.3. The range of ammonia concentration under normal operation in a piggery has been reported as 6 to 35 ppm (Miner and Hazen, 1969). Hydrogen sulphide usually occurs in piggeries below 2 ppm (Curtis, 1975) with values of 0.09 ppm being measured under typical operating conditions (Muehling, 1969). It may be seen from these values that there is little to no risk of direct health hazard from atmospheric pollution around livestock facilities. Comparison of Tables 9.2 and 9.3 shows that gas levels measured around livestock facilities are often below threshold concentrations indicating that much of the detected odour is due to synergistic reactions (Miner, 1979).

Dust levels in livestock buildings range from 2 to 7 mg/m$^3$ but values as high as 41 mg/m$^3$ have been measured (Miner and Smith 1975). The dust concentration and particle size depends on the type of feed, the extent of grinding, the method of feed distribution and the design and operation of the livestock facility. Atmospheric pollution by suspended solids from other sources, e.g. spray drift, is covered in the appropriate sections.

Nutrient transfer, particularly nitrogen through volatilisation, has caused concern. Studies on ammonia losses (Koellicher and Miner 1973, Miner 1979) suggest that the main problem would be ammonia desorption from piggery lagoons. Values of 16,000 kgNH$_3$/ha-yr have been reported but it is unlikely to reach these levels in New Zealand due to cooler, wetter summers.

health and atmospheric pollution levels

Specific human and animal health hazards associated with gases which evolve from agricultural wastes are limited to isolated situations where people or livestock encounter large concentrations of such gases. Threshold limit values for various gases associated with animal wastes are presented in Table 9.2. The threshold limit is the concentration at which nearly all workers may be repeatedly exposed during a working day without adverse effect. Odorant concentrations which influence the performance of livestock are not widely agreed on. Curtis et al (1978) showed that ammonia levels above 75 ppm adversely affected liveweight gains. Concentrations of 50 ppm of NH$_3$, 8.5 ppm of H$_2$S and up to 300 mg/m$^3$ of dust had no significant effect on growth rates when applied in isolation (Curtis et al 1975). However, combining ammonia and dust levels reduced the liveweight gain of young pigs. Muehling (1969), in reviewing the literature, showed that 50 to 100 ppm of NH$_3$ and over 20 ppm H$_2$S started to influence animal performance.

Hydrogen sulphide, one of the worst offenders, can give eye and respiratory tract irritation at 20 ppm and damage to the nervous system with exposure of 500 ppm for 30 minutes. Several instances have been reported of pig deaths due to toxic gases released from agitated waste within poorly ventilated livestock buildings where volumetric concentrations of 800 to 1000 ppm have been reported (Anon., 1979). However, it must be emphasised that under normal conditions in a well-designed, adequately ventilated production unit there is no evidence that any noxious gases reach lethal or harmful concentrations (Muehling, 1969).
In addition to proven or suspected health hazards, attention must be paid to the annoyance reaction produced by air pollution. From the medical point of view, the term "annoyance" implies an effect which is not demonstrably pathogenic but involves a negative effect on the individual comfort and well-being. Although no direct tie has been established between odour and disease it may affect an individual's well-being, induce a feeling of nausea or be associated with poor hygiene and disease.

Dust levels from livestock facilities are not controlled by specific legislation but should remain within the N.Z. Health Department guideline for nuisance dusts of 10 mg/m$^3$ with less than 1% of this dust containing quartz material (DOH, 1982). Curtis (1975), summarising results of dust in piggery environments, shows that bacterial levels in the area are closely correlated to dust concentrations and that dust particles less than 5 micrometres in diameter cause the greatest problem. Larger particles tend to be filtered out in the nasal passages and do not result in any damage or infection to lung tissue. Transmission of aerosols has been cited as a potential source of health risk because of the bacterial levels associated with the aerosol drifts. However, no established cases of infection from this source of contamination have been reported.

In summary, the main problem with atmospheric pollution in the livestock industry is that of odour nuisance and its policing and control are covered in the following sections.

### TABLE 9.3 CONCENTRATIONS OF ODOROUS COMPOUNDS MEASURED IN THE VICINITY OF LIVESTOCK PRODUCTION FACILITIES UNDER NORMAL OPERATING CONDITIONS.

<table>
<thead>
<tr>
<th>Sample Source</th>
<th>Constituents</th>
<th>NH$_3$ (mg/m$^3$)</th>
<th>total sulphides (mg/m$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broiler production room litter system</td>
<td></td>
<td>2.38</td>
<td>-</td>
</tr>
<tr>
<td>Texas high plain beef feedlot</td>
<td></td>
<td>0.12</td>
<td>0.005 and 0.027</td>
</tr>
<tr>
<td>Pig confinement building</td>
<td></td>
<td>4 to 24</td>
<td>-</td>
</tr>
<tr>
<td>Poultry house</td>
<td></td>
<td>0.45 to 2.6</td>
<td>1.54 to 22.9</td>
</tr>
<tr>
<td>Pig confinement building</td>
<td></td>
<td>7.4</td>
<td>0.10</td>
</tr>
</tbody>
</table>

Source: Miner, 1979

Note: To convert from ppm (by volume) to a concentration in mg/m$^3$ the density of the particular compound must be known.

\[
\text{NH}_3 \text{ density} = 0.770 \text{ kg/m}^3 \quad (\text{Muehling, 1969})
\]

\[
\text{H}_2\text{S} \text{ density} = 1.540 \text{ kg/m}^3 \quad (\text{Muehling, 1969})
\]

E.g. 3.1 ppm of NH$_3$ (3.1 ml/m$^3$) is a mass concentration of $3.1 \times 0.770 = 2.38 \text{ mg/m}^3$. 

9-6
Air quality control is the jurisdiction of the Department of Health and is primarily governed by the Health Act, the Clean Air Act and the Town and Country Planning Act. Detailed discussion of these acts in conjunction with the Water and Soil Conservation Act is presented in a separate chapter. This section summarises some aspects relating solely to air quality control.

The Clean Air Act is aimed at controlling atmospheric pollution from large industry (chimney exhausts, boilers, processing plants). Although agricultural production is legally defined as an industrial or trade practice it would appear that, from a practical standpoint, livestock production facilities are only influenced by three sections. Firstly, the release of specific gases such as hydrogen sulphide. However, as concentrations from most operations are very low, this is of little consequence. Secondly, the act encompasses 'Clean Air Zones' which could impose severe limitations on an existing operation, if invoked for a given locality, or restrict new enterprises in designated areas. Thirdly, the release of dust or suspended solids may be limited by the act, but it is doubtful if the levels would be of significance. Odour, as such, receives virtually no comment in the Clean Air Act.

The Health Act is of greater importance because it addresses the problem of 'nuisance'. The Act defines 'nuisance' to cover a wide variety of areas including the keeping or rearing of animals; "in a manner considered to be objectionable or possibly injurious to health". Failure to meet the requirements of the Health Inspector (or County Engineer) may result in closure of the premises and prosecution in a District Court. The difficulty is in defining what is 'objectionable' and interpreting the extent of 'possibly injurious to health'. Opinions on these matters vary widely and each case would be judged on its merits.

Although the ultimate interpretation of this legislation is a matter for the courts the following guidelines are suggested to assist in developing a rational and factual definition of an air pollution problem which should ultimately assist in selecting the most appropriate method for control. The guidelines are given in relation to clarifying odour problems but the same principles would apply for other areas of atmospheric pollution.

(i) Odour evaluations should be made by a group of people some of whom have no vested interest in which way the decision goes. This precaution avoids the very significant bias that may result from the subjective nature of the measurements.

(ii) Evaluations should be made of odour intensity and quality. Both aspects are related but they should be assessed separately to ensure the problem is clearly defined.

(iii) The duration, frequency and timing of the odour problem should be established. The duration defines how long the problem persists at any one time; 1 hour or all day. The frequency measures the return period, i.e., is it a seasonal, weekly or daily occurrence? The timing indicates when the problem is most noticeable during the day. A bad odour in the evening during tea is often more objectionable than during the day, even though its strength has not altered. Defining these three points helps to provide a complete picture of the nature of the problem.
Finally, the source of the odour should be investigated. The nature of the odour may assist with this, but it is important, before advising on remedies, to ensure that the problem is being treated, not the most immediate (visual) potential source.

**control procedures**

Because of the various sources of odour from a livestock operation, the sensitivity of the human nose, the influence of climatic factors and the variable likes and dislikes of the public, it is impossible to lay down guidelines which will guarantee the elimination of odours. Outlined below are suggestions that have proved useful in various situations and any combination of them may be appropriate in solving a specific problem.

**ATTITUDE** Although often ignored, the producer's attitude towards the complainant is critical in solving an odour problem to the satisfaction of both parties. A willingness to investigate, to ask for suggestions and to co-operate will at worst give some time to study the problem and initiate controls before legal action imposes restraints on the operator.

**APPEARANCE** Since attitudes to odour are subjective there is a tendency to associate bad odours with unsightly areas. Hence, the quickest way to have a property associated with malodours is for it to appear neglected. Clearing up and landscaping the site may not influence the odour level, but will improve the public image of the facility. In addition, it provides congenial working conditions and the forced maintenance will improve the life of buildings and equipment.

**SITE SELECTION** Added to the many aspects to be considered when selecting a site, an investigation of the prevailing winds which would carry any odours to neighbours is important. A pear-shaped buffer zone around a facility has been suggested. (Figure 9.2). The size of the buffer zone may be influenced by the size of the operation, its management, the nature of surrounding facilities (farm, school, hospital etc.) and climatic conditions. The prevailing winds should be studied during warm, damp conditions when the odour is at its worst. Suggestions as to the dimensions of the buffer zone vary considerably but typically quoted values range from 1 to 6 km. (Kreis, 1978).

It may be appropriate for these buffer zones to limit urban sprawl to the same extent as they would control the establishment of a new livestock facility.

**FACILITY DESIGN** Good building design is essential for efficient operation. Care should be taken to ensure there are no inaccessible areas in pens or effluent channels that may be difficult to clean and could accumulate decomposing waste. Odorous gases from this waste or the livestock are exhausted by the ventilation fans and are often the source of complaints. Reduction of ventilation fan odour may be achieved in a number of ways:-

- **Good Housekeeping**: Keeping the facility clean will minimise the amount of decomposing material releasing malodorous gases into the ventilation exhausts. If the wastes are to be disposed of hydraulically then they should be removed from the facility at least daily. Should the material be left in the buildings, and handled in a dry form, to encourage composting, the operator must ensure there are no water spills which will result in anaerobic areas in the waste material.
• **Dust Control:** Dust reduction may be achieved by avoiding unnecessarily fine grinding of the feed or long feed drops into bins or onto floors. In addition where farmers mill and mix their own feeds, additives such as tallow may be used to control dust. Wet and dry scrubbers to remove dust from exhaust air have been studied with satisfactory results (Eby and Willson 1969, Licht & Miner 1978). However, care should be taken when installing scrubbers to ensure that they are accessible for routine maintenance and cleaning and that the increased headloss in the system does not reduce the air flows to unacceptable levels. These restrictions on the application of scrubbers, and their high cost, has resulted in very few if any units being installed in commercial facilities. Electrostatic precipitators and recirculatory filters can also be used.

• **Exhaust Air Control:** Most odour control work for ventilation systems has been associated with dust removal. Other alternatives that have been tried include chemical oxidation of the odorous gases through combustion or biochemical oxidation by exhausting the air flow into the bottom of a trickling filter. Unless gas flare-off equipment is available, e.g., if methane was being produced on the property, combustion would not be an economic control method as the exhaust gases cannot maintain the combustion process. Trickling filters have been used successfully at municipal waste treatment stations (Hutchinson, 1974) but their application to livestock situations has not been so successful. Air flows and loading rates will have to be better defined before this system can be recommended for general use.
Plantings around a facility not only improve its appearance but are generally believed to decrease odours from a livestock production unit by acting as a rough filter and windbreak. If ventilation exhausts were sited at ground level, plantings would improve vegetative screening and filtering and aid in odour reduction prior to dilution and dispersion of the gases.

WASTE TREATMENT SYSTEMS

IN-HOUSE TREATMENT

Because of odour control problems with ventilation systems it is generally recommended that fresh waste be removed from the building as soon as practical, preferably before the commencement of anaerobic decomposition. The exceptions to this would be deep litter, dry waste or below-floor oxidation ditches. These systems rely on aerobic treatment and produce no major malodours. Below floor anaerobic pits are not recommended as New Zealand's climate allows the waste to be handled outside the livestock buildings all year.

ANAEROBIC TREATMENT

High-rate, anaerobic treatment of waste in a digester for the production of methane, produces little or no odour problems when the gases are collected and burnt because sulphur and nitrogen compounds are released in an oxidized form. The by-products from combustion may cause some odour but are unlikely to cause major problems.

Properly designed, operated and carefully sited anaerobic lagoons should not cause major problems. Overloading, intermittent loading and poor start-up procedures have contributed to odour problems. If the lagoon is undersized or sited in a sensitive area where even seasonal odours, (e.g. during the spring turn-over) must be avoided, a number of alternatives may be considered. Incineration has been used if the pond is sealed with a rubber cover so that gases can be released through a single vent. The anaerobic process releases methane as well as the foul-smelling gases and the combustion may be self-sustained. Once the gases are contained they could be vented into a trickling filter or dispersed in an aerobic lagoon if combustion was not suitable.

The advantages of "crusting over" of a lagoon surface are debated but it is generally agreed that a surface crust reduces gas losses and therefore improves odour control. This principle is supported by results from municipal waste treatment where covering the surface of the tanks with inert floating balls reduced the odour levels (Hutchinson 1974).

Farm dairy wastes often form a natural surface crust on anaerobic lagoons which acts as a filter removing some of the malodorous gases. Piggery wastes do not usually form a crust on the surface, due mainly to the lack of fibrous material in the effluent. Attempts to induce a surface crust by spreading straw or wood chips on lagoons has achieved some success. The long term effectiveness of this system is not known but may be improved with the use of mesh or flotation material to prevent water-logging.
LAND APPLICATION

Direct land application of fresh diluted waste does not usually have major odour problems. However, if wastewater is to be removed from anaerobic ponds greater care is required. Some general guidelines for land application for minimising odour are outlined below:

• Avoid spraying where the system (wagon or sprayline) is easily visible from neighbour's properties or the road.

• Select an application method that minimises aerosols. The use of low splash plates or gated pipes are an alternative to spraying. Vacuum tankers may not be as advisable as pumped filling because throughout the filling time the pump degasses the waste and exhausts the malodours into the atmosphere. Complete emptying of pressurised tankers should likewise be avoided.

• Carefully control application rates so that surface sealing and ponding of the soil does not occur. Excessive application can result in surface anaerobic conditions and further odours. If heavy applications must be used they should be "ploughed in" or applied sub-surface.

• Select the application timing. Apply the waste only if there is a suitable breeze to disperse any odour away from neighbours. Studies on the timing of complaints (Kreis, 1978) suggest avoiding applications on weekends, when more residents tend to be about their homes, and, also, the application of waste in the morning rather than later in the day. As the air warms, it rises and dissipates the odours into the upper air. Furthermore, morning applications allow the waste to dry out stopping additional gas production. It should be noted that this procedure may increase the nitrogen losses from the applied waste and the best management practice will vary with each situation.

ODOUR CONTROL BY AERATION

Mechanically-aerated lagoons or partial aeration of sump contents for odour control are described in Chapter 6.

CHEMICAL ODOUR CONTROL

The concept of applying a chemical to alleviate all odour problems is attractive and a large range of chemicals have been investigated by many researchers. The chemicals may be divided into 7 main categories.

Oxidants: These chemicals oxidise the reduced compounds in the anaerobic waste converting them into non-odorous components.

Deodorants: Specific chemicals react with the odorous compounds to either inhibit their release as a gas or neutralise their unpleasant odour.

Masking Agents: Compounds with a strong, but acceptable, odour are added to the manure to overpower its natural odours.

Digestive: Mainly sold as proprietary compounds, these products contain bacterial cultures or enzymes which are aimed at biologically controlling the production and/or release of unpleasant odours. The manufacturers often claim that these products also improve the solids breakdown in the waste.
Adsorbants: Products with a large surface area e.g., charcoal, are used to adsorb the odorous chemicals prior to their release into the atmosphere.

Feed Additives: Chemicals for addition to the animals' ration, to improve production and reduce effluent odours, are marketed in some areas.

Miscellaneous: A variety of other chemicals such as bactericides or proprietary compounds that are not easily classified in the above listing.

The use of a number of major chemicals, proprietary compounds and feed additives has been reviewed and studied by Warburton et al (1979). Based on their investigations the following guidelines for the use of odour control chemicals are suggested.

- For short-term odour control, such as treatment prior to land application, chemical application (particularly oxidizing agents) may have some value.

- Oxidants such as potassium permanganate and hydrogen peroxide, while effective against sulphides, are not recommended for controlling ammonia. Ammonia may be controlled by free chlorine or formaldehyde through chemical reaction, or with bentonite and zeolites through surface binding.

- Bactericidal compounds tend to show the best long-term odour control from anaerobic processes. However, the long-term effect of this type of chemical in the waste, if stored in lagoons or applied to land is not known.

- The cost of chemicals to effectively control odour might be equivalent to that of aeration and might not be as reliable. Hence, caution should be exercised before recommending their use. (See Smith et al, 1980).

- The mechanism by which some of the reported odour control chemicals function is yet to be confirmed. Until some of these processes are better understood (many claims are contrary to present knowledge) it is recommended that more conventional odour control techniques be used.
REFERENCES CHAPTER 9


Kreis, R.D. (1978) Control of animal production odours; the state of the art. EPA 600/2-78-083, U.S. Environmental Protection Agency.


chapter 10

legislation

ANDREW J. DAKERS
introduction

To write a comprehensive essay on all legislation that might relate to the management of farm waste is beyond the scope of this manual. For a detailed account, the reader is referred to "A Guide to Environmental Law in New Zealand", Commission for the Environment, 1976.

In this section are outlined some of the more important statutory laws which apply directly to agricultural waste management. It would seem that statutory law is more applicable in this field than common law which can be used as a legal tool. However very few cases, if any, have directly concerned agricultural wastes. For this reason common law is not discussed in this section.

The existing statutory legislation relates to the following three areas:

- landuse and siting
- pollution
- nuisances

landuse and siting

The most relevant legislation is the TOWN AND COUNTRY PLANNING ACT 1977 (T.C.P.A.) and the 1978 Regulations. This Act covers "the preparation, implementation and administration of regional and district planning". It also makes provision for maritime planning. The responsibility of the Act ultimately lies with united or regional councils and will be implemented, at the local level, by local government authorities. Every county, borough and city council is required to prepare a district planning scheme. This is basically a policy document on the existing and future land use and development in the district. The policy is based on a common-sense appraisal of the overall welfare and needs of the community and the individual member within it. Following the drafting of the scheme, it is made public and is then open to submissions and/or objections from any group or member of the public who might be affected by it (ss 44 and 45). These submissions and/or objections are considered by the Council and any decisions made are subject to appeal to the Planning Tribunal (s. 49). This Tribunal has the power and authority of a Court and is chaired by a judge. Once operative, the district scheme can be varied by following specified procedures (s. 47). It is also required that the scheme be reviewed every 5 years (s. 59).

Under the district scheme it is likely that certain types of farming activities may or may not be permitted in designated areas within the district. The scheme will classify the various land uses and the developments into three types (s. 36(4)):

(a) Those which are permitted as of right provided that they comply in all respects with all controls, restrictions, prohibitions and conditions specified in the scheme:

(b) Those which are appropriate to the area but which may not be appropriate on every site or may require special conditions and which require approval as conditional uses under section 72 of this Act:
(c) Those which are permitted subject to such powers and discretions specified in the scheme as are necessary or desirable to achieve the general purposes of the scheme and to give effect to the policies and objectives contained in the scheme relating to –

(i) Landscaping;
(ii) The design and external appearance of buildings; and
(iii) Such other matters as may be specified in that behalf by any regulations in force under this Act.

Under the previous T and C.P. Act (1953) the use classified in (a) was known as "predominant use" while (b) was called "conditional use".

If a particular type of farming is considered 'as of right', then no planning consent is required, although certain conditions may have to be met. If it is considered a 'conditional use' as in (b), then a planning consent is required. In a number of regions, larger pig farming enterprises are classified conditional use. A planning consent requires public notification and is subject to objections and subsequent hearings by the Council (ss 65, 66). The Council's decision is open to appeal through the Planning Tribunal. Thus, considerable time can elapse between application for a consent and final approval, if given. The consent may contain any number of conditions relating to the proposed land use. For example, these conditions can specify the total number of animals held on the property, location of proposed buildings with regard to boundaries, existing buildings and dwellings, type and location of waste treatment system, and so on.

From the farmer's point of view, there are likely to be fewer problems and less time delay if the proposed land use comes under classifications (a) and possibly (c), than the conditional use in (b). Finally, if the farmer wishes to establish a land use that is an exception to any provision of the operative district scheme, he must apply for a specified departure (s. 74). This can also take considerable time to be processed as it must go through the public notification and objection stages.

The TCPA (1977) is a very complex legislative document and can have wide-ranging implications on the establishing of the larger and more intensive forms of animal farming, such as piggeries and poultry units. This is primarily as a result of past environmental problems due to poor housing, poor management, inadequate waste management and an increasing awareness of the environment.

One other smaller legislative document that influences siting of waste treatment systems is the Milk Production and Supply Regulations 1973 which is relevant to dairy farms only. This Act requires that waste treatment or disposal sites be at least 45 m from the farm dairy or its water supply (s. 10).
pollution

Under the general heading of pollution a number of statutory acts may be relevant. For example the Clean Air Act 1972, relates to air pollution, while noise pollution is covered by several acts (see section on nuisances) and water pollution is covered in such acts as the Health Act 1956, Counties Act 1956, Marine Pollution Act 1967, Fisheries Act 1980 and the list goes on. However most aspects of water pollution are covered in the Water and Soil Conservation Act 1967 and this Act is now virtually solely implemented for control of water pollution. The design and management of waste treatment systems is very dependent on and sensitive to water pollution control criteria, and for this reason this section will discuss in some detail the WATER AND SOIL CONSERVATION ACT 1967.

This Act provides for the regulation of the "conservation, allocation, use, and quality of natural waters", where "natural waters" means virtually all forms of water (groundwater, river water, rain water, snow, ice and sea water) but does not include water in a reservoir which is owned by a public authority or water in pipes or tanks. The Act constitutes the National Water and Soil Conservation Authority (NWSCA) and Regional Water Boards (RWB).

As a means of control over the many uses made of natural waters, it is a requirement under this Act that a WATER RIGHT be obtained from the local regional water board for the following, (with certain exceptions) (s. 21):

- to dam any river,
- to divert or take natural water,
- to discharge natural water or waste into natural water,
- to discharge natural water containing waste on to land if, as a result, natural water is likely to be contaminated,
- to use natural water.

Most relevant to waste management is the requirement for a water right to discharge waste waters into natural waters or onto land. Application for and processing of such a water right will generally consist of the following stages (s. 24):

- The farmer, or his representative, applies in writing to the local RWB for a water right. There is a cost to the applicant which varies between the different boards.
- The RWB then publicly notifies receipt and the nature of the application (normally in the local newspaper).
- Objections to the application can be lodged, in writing, from any party within 28 days of notification. On receiving an objection, the RWB is required to notify the applicant of the objection.
- The applicant can request a hearing with a special tribunal, provided this request is made within 14 days of notification of an objection. Otherwise the RWB will either consider the application or call for a special tribunal to consider the application.
- The Board's or Tribunal's decision is made, the applicants and objectors are informed and the decision is publicly notified.
- The above decision is subject to appeal (s. 25) by either objectors or applicants, and this appeal must be taken to the Planning Tribunal, as constituted in the TCPA (1977), within 28 days of the decision notification. The Planning Tribunal's decision is final and binding.
When a water right to discharge is issued it will nearly always be subject to certain conditions. The purposes of these conditions (s. 71 (3A)) is basically to ensure that the discharge, and its cumulative effect with any other legal discharges into the same body of water, does not cause the quality of the receiving water to fall below a certain standard, as specified by its classification. If, on receiving a water right, the farmer objects to any part of the right, including the conditions, he can appeal to the Planning Tribunal. This can involve considerable time and expense.

For an existing right, a farmer can apply for a variation of any provision, restriction or condition of that right (s. 24B). This need may be brought about by extensions to the enterprise or changing of waste removal or treatment methods. Water rights are transferable (s. 24A), subject to their conditions, which may be necessary upon the sale of a farm. However the RWB must be notified of the transfer by the transferor.

A water right is generally issued for a period (say 5 years) which will be specified in the conditions. At the end of this period the right will expire and will have to be reapplied for if required.

The RWB can, in some situations, issue a general authorisation for use, etc of natural waters (s. 22). For example in a number of regions there is a general authorisation for the spray irrigation of farm dairy wastes onto land. This means that a farmer in that region does not have to obtain a water right to irrigate his farm dairy wastes.

So far this section has dealt, at some length, with the water right and what it involves, particularly from the viewpoint of the farmer. However the Act covers other important features relating to the control of water pollution. Worthy of brief mention is the classification of natural waters. There are a number of stages in the process of classifying waters. The final classification "shall be a declaration of the minimum standards of quality at which the natural water so classified shall be maintained in order to promote, in the public interest, the conservation and best use of the water" (s. 26H). The water standards are measured in terms of such parameters as temperature variation, acidity and alkalinity, colour, oxygen content and bacterial counts (s.26C). The sort of use that may apply to different classifications for fresh water are:

Class A - human water supply, controlled catchment
Class B - human water supply, uncontrolled catchment
Class C - bathing and fishing
Class D - general agriculture

The RWBs are responsible for the classification of natural water.

It should be noted that at the time of writing this manual, the Water and Soil Conservation Act 1967 is being considered by Government for review. It is unlikely that it will be a complete review and any amendments will mainly apply to administration. However it is proposed that the Act be amended to enable regional water boards to manage water resources through water management statements, water allocation plans and water quality classifications and that the public will be fully involved in their formulation.
nuisances

A nuisance problem can be covered by two acts.

The HEALTH ACT 1956 defines nuisance in section 29 and can virtually mean anything that may be offensive or is likely to be injurious to health. Such things as odours, spray drift, noise, can be considered as a nuisance. The Act sets out local authority responsibilities and powers with respect to various public health services and the abatement of nuisances. If satisfied that a nuisance does in fact exist, the authority is empowered to secure the abatement of the nuisance or removal of the condition (ss 23(C), 34).

Under the TCPA (1977) there is authorized control of "objectionable elements" where an objectionable element means "noise, smoke, smell, effluent, vibration dust or other noxiousness or danger or detraction from amenities ..." (s. 77).

If such exists the council may issue a notice requiring the causal landuse to cease, or remove it or reduce it to an acceptable level. Such a notice is subject to appeal through the Planning Tribunal provided the appeal is lodged within 1 month of being notified.

summary

There are a number of laws and bylaws that relate to the management of agricultural wastes. In regard to siting of waste treatment facilities, the local council should be consulted. In regard to discharging wastes into natural waters or onto ground, the local regional water board must be consulted. If nuisances are created as a result of an operating waste management system legal action can be taken, usually through the local council.
glossary

ABSORPTION: Transfer of a substance into the cell contents of an organism.

ACTIVATED SLUDGE: A flocculent microbial mass produced when organic wastewater is continuously aerated.

ADSORPTION: (1) The adherence of dissolved, colloidal, or finely divided solids to the surfaces of solid bodies with which they are brought into contact. (2) Action causing a change in concentration of gas or solute at the interface of a two-phase system.

AEROBIC BACTERIA: Bacteria that require free elemental oxygen for growth. Oxygen in chemical combination will not support aerobic organisms.

AEROBIC DECOMPOSITION: Breakdown of organic matter in the presence of free or dissolved oxygen by aerobic microorganisms.

AEROBIC LAGOON: See LAGOON.

AERATION: (1) The bringing about of intimate contact between air and a liquid by one or more of the following methods: (a) spraying the liquid in the air. (b) bubbling air through the liquid. (c) agitating the liquid or promote surface absorption of air. (2) The supplying of air to confined spaces under nappes, downstream from gates in conduits, etc. to relieve low pressures and to replenish air entrained and removed from such confined spaces by flowing water.

AERATION TANK: A tank in which a mixture of sludge and wastewater, or other liquid, is aerated.

AEROSOL: A system of colloidal particles dispersed in a gas, smoke or fog.

AGITATION: The turbulent remixing of liquid and settled solids.

ALGAE: Primitive plants, one or many-celled, usually aquatic and capable of synthesizing cell material by photosynthesis.

ALKALINITY: The capacity of water to neutralize acids, a property imparted by the water's content of carbonates, bicarbonates, hydroxides, and occasionally, borates, silicates, and phosphates. It is expressed in milligrams per litre of equivalent calcium carbonate.

ANAEROBIC BACTERIA: Bacteria not requiring the presence of free or dissolved oxygen for metabolism. Strict anaerobes are hindered or completely blocked by the presence of dissolved oxygen and sometimes by the presence of highly oxidized substances, such as nitrates, nitrites, and perhaps, sulfates.

ANAEROBIC DECOMPOSITION: Breakdown of organic matter caused by micro-organisms in an anaerobic environment.

ANAEROBIC LAGOON: See LAGOON.
BACTERIA: A group of universally distributed, rigid, essentially unicellular, microscopic organisms lacking chlorophyll. Bacteria usually appear as spheroid, rod-like or curved entities, but occasionally appear as sheets, chains, or branched filaments. Bacteria usually are regarded as plants.

BIOCHEMICAL OXYGEN DEMAND (BOD): The quantity of oxygen used by microorganisms in the biological oxidation of organic matter in a specified time, at a specified temperature, and under specified conditions. A standard test used in assessing wastewater strength. Unless otherwise specified, BOD in this publication refers to the demand after 5 days and at 20°C i.e. the 5 day B.O.D., often shown as B.O.D.5 in other publications.

BIODEGRADATION (BIODEGRADABILITY): The destruction or mineralization of either natural or synthetic organic materials by the microorganisms populating soils, natural bodies of water, or wastewater-treatment system.

BIOLOGICAL OXIDATION: The process whereby living organisms in the presence of oxygen convert the organic matter contained in wastewater into a more stable or a mineral form.

BIOLOGICAL STABILIZATION: Breakdown of organic matter as a result of the metabolic activity of organisms.

BIOLOGICAL WASTEWATER TREATMENT: Forms of wastewater treatment in which bacterial or biochemical action is intensified to stabilize, oxidize, and nitrify the unstable organic matter present. Lagoons, trickling filters, and activated sludge processes are examples.

CARBON-NITROGEN RATIO (C:N): The weight ratio of carbon to nitrogen in a waste material.

CHEMICAL OXIDATION: Oxidation of organic substances without benefit of living organisms. Examples are by thermal combustion or by oxidizing agents such as chlorine.

CHEMICAL OXIDATION DEMAND (COD): A measure of the oxygen-consuming capacity of inorganic and organic matter present in water or wastewater. It is expressed as the amount of oxygen consumed from a chemical oxidant in a specified test. It does not differentiate between stable and unstable organic matter and thus does not necessarily correlate with biochemical oxygen demand. Also known as OC and DOC, oxygen consumed and dichromate oxygen consumed, respectively.

CHLORINATION: The application of chlorine to water, sewage or industrial wastes, generally for the purpose of disinfection, but occasionally for accomplishing other biological or chemical results.

CLARIFIER: A device for the reduction of solids by coagulation, sedimentation or filtration.

COAGULATION: In water and wastewater treatment, the destabilization and initial aggregation of colloidal and finely divided suspended matter by the addition of a floc-forming chemical or by biological processes.
COLIFORM BACTERIA: A group of bacteria used as indicators. They predominantly inhabit the intestines of man or animals, but are also present in soil and vegetation. They are gram-negative, aerobic and facultatively anaerobic, nonspore-forming bacilli that ferment lactose with production of gas. Also included are all bacteria that produce a dark, purplish-green colony with metallic sheen by the membrane-filter technique used for coliform identification. The two groups are not always identical, but they are generally of equal sanitary significance. Tests are available to assess total coliforms or faecal coliforms. See ESCHERICHIA COLI.

COLLOIDAL MATTER: Finely divided solids that will not settle but may be removed by coagulation or biochemical action or membrane filtration.

COMPOSTING: Present-day composting is the aerobic, thermophilic decomposition of organic wastes to a relatively stable humus. The resulting humus may contain up to 25% dead or living organisms and is subject to further, slower decay, but should be sufficiently stable not to reheat or cause odour of fly problems. In composting, mixing and aeration are provided to maintain aerobic conditions and permit adequate heat development. The decomposition is done by aerobic organisms, primarily bacteria, actinomycetes, and fungi.

DEHYDRATION: The chemical or physical process whereby water in chemical or physical combination with other matter is removed.

DENITRIFICATION: The reduction of nitrates (by microbial or other means), with nitrogen gas evolved as an end product.

DETENTION POND: An earthen basin constructed to store runoff or waste water until such time as the fluids may be recycled onto land.

DEOXYGENATION: The depletion of the dissolved oxygen in a liquid under natural conditions associated with the biochemical oxidation of organic matter present.

DIGESTION: Although aerobic digestion is being used, the term digestion commonly refers to the anaerobic breakdown or organic matter in water solution or suspension into simpler or more biologically stable compounds, or both. Organic matter may be decomposed to soluble organic acids or alcohols and subsequently converted to such gases as methane and carbon dioxide. Complete destruction of organic solid materials by bacterial action alone is never accomplished.

DISINFECTION: The art of killing the larger portion of microorganisms in or on a substance with the probability that all pathogenic bacteria are killed by the agent used.

DISSOLVED OXYGEN (DO): Free oxygen dissolved in water, wastewater, or other liquid, usually expressed in milligrams per liter, parts per million, or percentage of saturation.

ESCHERICHIA COLI (E. COLI): One of the species of bacteria in the coliform group. Its presence is considered indicative of fresh faecal contamination.

EVAPORATION RATE (of water): The loss of water, expressed in terms of depth, evaporated from a given surface per unit of time. It is usually expressed in mm per day, month or year.
FOOD TO MICROORGANISMS RATIO (F:M): The ratio of organic food (BOD) to microorganisms (volatile suspended solids, or sometimes, suspended solids).

FACULTATIVE BACTERIA: Bacteria that can grow in the presence, as well as in the absence, of oxygen.

FACULTATIVE DECOMPOSITION: Reduction of the net energy level of organic matter by facultative microorganisms.

FERTILIZER VALUE: The potential worth of the plant nutrients contained in the wastes and that could become available to plants when applied onto the soil. A monetary value assigned to a quantity of organic wastes represents the cost of obtaining the same plant nutrients in their commercial form and in the amounts found in the waste. The worth of the waste as a fertilizer can be estimated only for given soil conditions and other pertinent factors such as land availability, time, and handling.

FILTRATION: The process of passing a liquid through a filtering medium (which may consist of granular material, such as sand, magnetite, or diatomaceous earth, finely woven cloth, unglazed, porcelain, or specially prepared paper) for the removal of suspended or colloidal matter.

GASIFICATION: The transformation of soluble and suspended organic materials into gas during waste decomposition.

HOLDING POND: A storage pond usually with an earth embankment, where lot runoff, lagoon effluent, and other dilute wastes are stored before final disposal. It is not designed for treatment.

HUMUS: The dark or black carboniferous residue in the soil resulting from the decomposition of vegetable tissues of plants originally growing therein. Residues similar in appearance and behaviour are found in composted manure and well-digested sludges.

INCINERATION: The rapid oxidation of volatile solids within a specially designed combustion chamber.

INCUBATION: Maintenance of viable organisms in or on a nutrient substrate at a constant temperature suitable for growth and reproduction.

INFILTRATION: The process whereby water enters the soil through the immediate surface.

INFILTRATION RATE: (1) The rate at which water enters the soil or other porous material under a given condition. (2) The rate at which infiltration takes place, expressed as depth of water per unit time, usually in millimeters per hour.

INFLUENT: Water, wastewater, or other liquid flowing into a reservoir, basin, or treatment plant, or any unit thereof.

INOCULM: Living organisms, or an amount of material containing living organisms (such as bacteria or other microorganisms), added to initiate or accelerate a biological process (e.g. biological seeding).
LAGOON: An all-inclusive term commonly given to a water impoundment in which organic wastes are stored or stabilized, or both. Lagoons may be described by the predominant biological characteristics (aerobic, anaerobic, or facultative), by location (indoor, outdoor), by position in a series (first stage, second stage, etc) and by the organic material accepted (sewage, sludge, manure or other). In this publication, refers to impoundment where treatment is the primary function. See POND.

LEACHING: (1) The removal of soluble constituents from soils or other material by water. (2) The removal of salts and alkali from soils by abundant irrigation combined with drainage. (3) The disposal of a liquid through a non-water-tight artificial structure, conduit, or porous material by downward or lateral drainage, or both, into the surrounding permeable soil.

LIQUEFACTION: (1) Act or process of liquefying or of rendering or becoming liquid. (2) Act or process of converting a solid or a gas to a liquid state by changes in temperature or pressure. (3) The changing of the organic matter in wastewater from a solid to a soluble state.

LIQUID MANURE: A suspension of livestock manure in water, in which the concentration of manure solids is low enough so that the flow characteristics of the mixture are more like those of Newtonian fluids than of plastic fluids.

MANURE: The faecal and urinary defecations of livestock and poultry. Manure does not include spilled feed, bedding, or additional water or runoff.

MESOPHILIC BACTERIA: Bacteria that grow best in the moderate temperature range of 25°C to 40°C.

MIXED LIQUOR: A mixture of activated sludge and organic matter under-going activated-sludge treatment in the aeration tank.

ODOUR THRESHOLD: The point at which, after successive dilutions with an odourless medium, the odour of the sample can just be detected. The threshold odour is expressed quantitatively by the number of times the sample is diluted.

ORGANIC MATTER: Chemical substances of animal or vegetable origin, or more correctly, of basically carbon structures, comprising compounds consisting of hydrocarbons and their derivatives.

OXIDATION DITCH: A modified form of the activated-sludge process. An aeration rotor supplies oxygen and circulates the liquid in an oval, racetrack-shaped, open-channel ditch.

pH: The negative of the logarithm of the hydrogen-ion concentration. The concentration is the weight of hydrogen-ions, in grams per litre of solution. Neutral water, for example, has a pH value of 7 and a hydrogen-ion concentration of $10^{-7}$.

PERCOLATION: The flow or trickling of a liquid downward through a contact filtering medium. The liquid may or may not fill the pores of the medium.

PERCOLATION RATE: The rate of movement of water under hydrostatic pressure through the interstices of a contact filtering medium.
PERMEABILITY: The property of a material that permits significant movement of water through it when saturated and actuated by hydrostatic pressure of the magnitude normally encountered in natural subsurface water.

POLLUTION: The presence in a body of water (or soil or air) of material in such quantities that it impairs the water's usefulness or renders it offensive to the senses of sight, taste, or smell. Contamination may accompany pollution. In general a public hazard is created but in some instances only economy or aesthetics are involved, as when waste salt brines contaminate surface waters or when foul odours pollute the air.

POND: Often used interchangeably with the term lagoon. In this publication, refers to impoundments where storage is the primary function and treatment is incidental.

POPULATION EQUIVALENT (PE): A means of expressing the strength of organic material in wastewater. Equivalence can be estimated on the basis of a number of parameters, most commonly flow, BOD or suspended solids. For example, domestic wastewater consumes, on average, 0.08 kg of oxygen per capita per day as measured by the standard BOD test. This figure has been used to measure the strength of organic industrial waste in terms of an equivalent number of persons. If an industry discharges 480 kg of BOD per day, its waste is equivalent to the domestic wastewater from 6 000 persons (480/0.08 = 6 000). Caution must be exercised when using population equivalents because of the difficulty in comparing agricultural wastes directly with municipal wastes.

PUTREFACTION: Biological decomposition of organic matter with the production of ill-smelling products associated with anaerobic conditions.

SEDIMENT: (1) Any material that is carried in suspension by water and will ultimately settle to the bottom after the water loses velocity. (2) Fine water-borne matter deposited or accumulated in beds.

SEDIMENTATION TANK: A basin or tank in which water or wastewater containing settleable solids is retained to remove by gravity a part of the suspended matter. Also called sedimentation basin, settling basin, settling tank.

SEPTIC TANK: A settling tank in which settled solid matter is in immediate contact with the wastewater flowing through the tank and the organic solids are decomposed by anaerobic bacterial action.

SETTLEABLE SOLIDS: (1) That matter in wastewater that will not stay in suspension during a preselected settling period, such as 1 hr, but either settles to the bottom or floats to the top. (2) In the Imhoff cone test, the volume of matter that settles to the bottom of the cone in 1 hr.

SETTLING TANK: See SEDIMENTATION TANK.

SEWAGE: The spent water of a community. Term now being replaced in technical usage by preferable term, wastewater.

SILT: Soil particles that constitute the physical fraction of a soil between 0.002 mm and 0.05 mm in diameter.

SLUDGE: (1) The accumulated solids separated from liquid, such as water or wastewater during processing, or deposits on bottoms of streams or other bodies of water. (2) The precipitate resulting from chemical treatment, coagulation, or sedimentation of water or wastewater.
SOLIDS CONTENT: The residue remaining when the water is evaporated away from a sample of water, sewage, other liquids, or semisolid masses of material and the residue is then dried at a specified temperature, usually 103-105°C. Referred to as total residue in Standard Methods for the Examination of Water and Wastewater. See total solids.

SUPERNATANT: The liquid standing above a sediment or precipitate.

SUSPENDED SOLIDS: (1) Solids that either float on the surface of, or are in suspension in, water, wastewater, or other liquids, and that are largely removable by laboratory filtering. (2) The quantity of material removed from wastewater in a laboratory test, as prescribed in Standard Methods for the Examination of Water and Wastewater and referred to as nonfiltrable residue.

THEOMOPHILIC BACTERIA: Bacteria that grow best within the temperature range of 40°C to 55°C.

TOTAL SOLIDS: The sum of filtrable and nonfiltrable solids in water or wastewater, usually stated in milligrams per litre.

TRICKLING FILTER: An artificial bed of coarse material, such as broken stone, clinker, slate, slats, brush, or plastic materials, over which wastewater is distributed or applied in drips, films, or spray from troughs, drippers, moving distributors, or fixed nozzles, and through which it trickles to the underdrains, giving opportunity for the formation of slimes that clarify and oxidize the wastewater. Also called a biological filter, fixed-growth reactor or fixed media biological reactor.

VOLATILE ACIDS: Fatty acids, containing six or less carbon atoms, that are soluble in water and that can be stream-distilled at atmospheric pressure. Volatile acids are commonly reported as acetic acid equivalent.

VOLATILE SOLIDS (VS): The quantity of solids in water, wastewater, or other liquids lost in ignition of the dry solids at 550 ± 50°C. VS are an indication of organic matter present.

VOLATILE SUSPENDED SOLIDS (VSS): That portion of the suspended solids residue driven off as volatile (combustible) gases at a specified temperature and time, usually 550 ± 50°C for at least 1 hr.
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