TECHNICAL GUIDE

K69 Pond Systems for the Purification and Disposal of Domestic Wastewater from Small Communities: Use, Design, Operation and Maintenance

by

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NATIONAL INSTITUTE FOR WATER RESEARCH
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FOREWORD

The CSIR Special Report WAT 34 entitled *A Guide to the Use of Pond Systems in South Africa for the Purification of Raw and Partially Treated Sewage* by Meiring *et al.* appeared in 1968 and has since been in great demand. It was also reprinted for the Jerusalem International Conference on Water Quality and Pollution Research, June 1969, and further reprints were made by the Ann Arbor Science Publishers, Inc., P.O. Box 1425, Michigan 48106, USA.

Pond systems are ideally suited for use in small communities, and for schools, hospitals and other institutions since they are simple and economical to construct, operate and maintain. Numerous pond systems have been designed and commissioned in South Africa, particularly in developing areas. However, these systems have not always been constructed in accordance with the specified criteria and this, together with poor maintenance and operation, has largely been responsible for pond systems falling into disrepute. In recognising the numerous merits of pond systems, the NIWR is attempting to re-instate them as much-needed wastewater purification processes in the South African context. To this end, the *Guide* has been revised in the form of the present *Manual*.

The contents of the *Guide* have largely been rearranged and additional information has been included, for example on night-soil ponds, aerated pond systems and algae culture and harvesting pond systems. Measurements, diagrams and cost and other data have been metricated and updated. Findings obtained from monitoring existing pond systems have also been incorporated.

The author is to be commended on his initiative in summarizing the experience and evaluating the data collected over two decades. The *Manual* presents the collective expertise of the author and a number of his NIWR colleagues and should be seen as an up-to-date authoritative review of the use, design, operation, performance and maintenance of pond systems. It is hoped that it will provide much-needed information and guidance to a wide spectrum of scientists, engineers and entrepreneurs.

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1. INTRODUCTION

Pond systems provide a low cost means of handling the domestic wastewater from small communities. Their function relies on the natural self-purification process - basically photosynthetic oxidation - that occurs in a body of water and is dependent on natural factors such as sunshine, temperature and wind action. The longer the exposure of the water to such favourable conditions the better the purification is likely to be.

As provided for in the Water Act (no. 54 of 1956), General and Special quality standards were promulgated in 1962 and effluents have to comply with these before return to a water course. In terms of the Act it is in fact obligatory to return a purified effluent to a river for use by others entitled to that use. Other means of disposal may be authorized by the Minister of Environment Affairs and Fisheries, but are the exception rather than the rule.

Some of the effluents from the purification systems covered by this report may show marked seasonal variations in quality. No assurance can be given that the effluents would meet the requirements of promulgated standards from season to season. Effluents from pond systems usually contain high concentrations of algae in summer, whereas in winter high ammonia concentrations may be found. In recent years, however, many pond systems monitored have shown better performance than originally reported (Shaw *et al.*, 1962).

Any shortcomings of these systems should, of course, be seen against the background of their application. Over the past two decades the introduction of pond systems, particularly in rural areas and for smaller towns and institutions, has brought about a great improvement in environmental quality which, for practical and economic reasons, would not otherwise have been possible.

Because the quality of effluents discharged from stabilization pond systems does not always conform to that required in terms of the Water Act (South Africa, Republic, 1962), the use of these systems is subject to a permit from the Minister of Environment Affairs and Fisheries. The Department of Environment Affairs has also placed a limit on the size (or loading) of a stabilization pond system, namely that it may be employed for 5 000 persons (800 m^3/d flow) or less only. This stipulation may be waived by the Department by special permit if circumstances warrant this. For larger communities other, more elaborate treatment systems are expected to be used.

A pond system is simple and economical to construct, operate and maintain, and therefore is very often not regarded in the same light as a conventional wastewater purification works; i.e. as an engineering venture. It must be stressed that a pond system requires proper planning, design, construction and maintenance and a periodic review with regard to pond loading. A pond system also provides a better barrier against pollution than a conventional works, and laxity in pond management must therefore also be guarded against.

This manual applies *exclusively* to pond systems for the treatment of domestic wastes. If any such system is contemplated for the treatment of industrial wastes, specific investigations are necessary to establish the criteria for construction of a system which will produce an effluent of the desired quality. Separate treatment by evaporation must often be resorted to, in which case the nuisance and groundwater pollution aspects need careful consideration.

2. BIOLOGICAL BREAKDOWN OF ORGANIC MATTER

Breakdown cycles

In the biological hierarchy most organisms require oxygen and produce CO_2 and H_2O while others (like algae) metabolize CO_2 and produce oxygen by photosynthesis:

$$CO_2 + H_2O \underset{\text{bacteria}}{\overset{\text{energy algae}}{\rightleftarrows}} O_2 + \underset{\text{cell food}}{(CH_2O)_x}$$

This is considered the most fundamental biological process on earth, because it alone produces the complex organic substances which constitute the material basis of all living organisms. The formula below expresses the basic principle of all aerobic stabilization processes, namely:

Food + micro-organisms + oxygen → increased micro-organisms + nitrogenous waste products + carbon dioxide + water.

Anaerobic organisms function similarly, except that in their respiration processes other substances have to be used as an oxygen source; i.e. combined oxygen instead of dissolved oxygen, and the end products are usually organic acids and some hydrogen-rich substance other than water (such as H_2S and CH_4).

The breakdown reactions may be presented in a simplified form, as in Figure 1.

For their growth all organisms require food, which must contain compounds of C, H and O and the nutrient elements N, P and K. Some trace elements are also required. Should any of the main components be in short supply, algal as well as bacterial growth and reproduction will decline or cease completely.

Fortunately domestic wastewater contains sufficient nutrients in reasonably correct proportions to support a dense bacterial and algal population, and trace elements are usually present in sufficient concentrations. Industrial wastes, however, might not have such a good nutritional balance and the missing elements or elements in short supply may have to be supplemented for successful breakdown. Toxic wastes will, of course, be harmful to biological life.

Self-purifying biological action

The natural processes as applied in biological filters, activated sludge and pond systems all operate on the same fundamental biochemical principles differing essentially in the method of dissolved oxygen input.

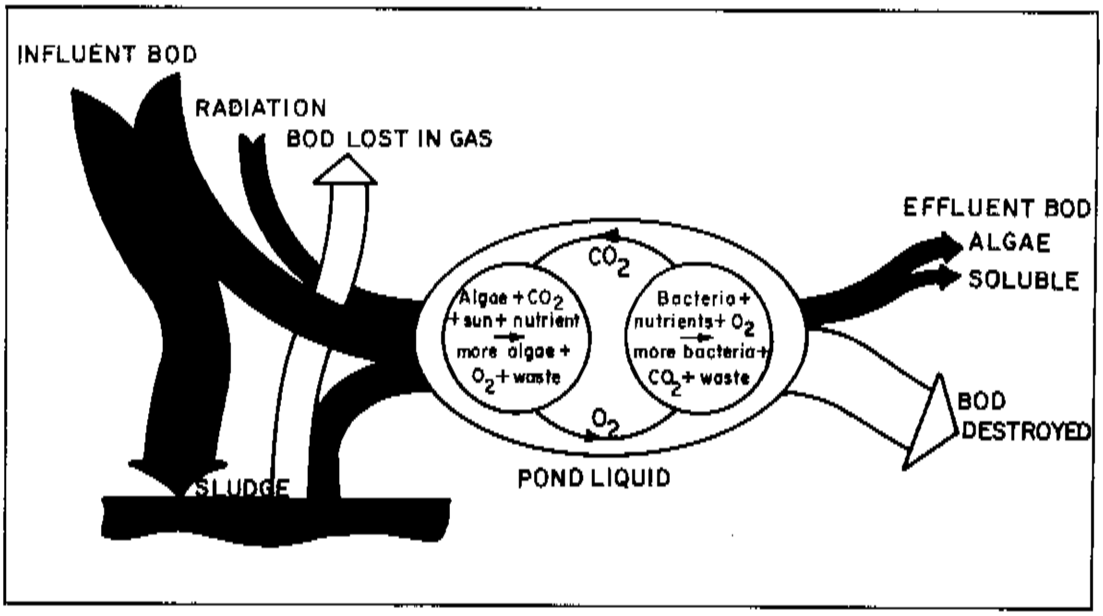


Figure 1. Energy flows in oxidation pond degradation processes.

In pond systems the purification process depends on the effective action of both anaerobic and aerobic bacteria (*Definitions*, p. 4) for the degradation of putrescible organic material and usually green algae for oxygenation. A mutual relationship exists between the algal and other organisms, such as bacteria, fungi, protozoa and higher animals, which are the primary workers and have the ability to effectively break down and utilize many complex organic waste materials. Algae, with the assistance of fungi, utilize the simpler degradation products.

As long as the algae can provide oxygen in excess of that required by the organisms a relatively aerobic environment will be maintained, at least in the upper layers of the pond. Under these conditions aerobic organisms can degrade the organic material. Part of the substrate will be used to make new cells, and the remainder will provide the energy required to further the degradation reactions.

If sufficient oxygen is not provided, as in the bottom layer of most ponds, anaerobic bacteria and facultative bacteria (i.e. bacteria which can function under both aerobic or anaerobic conditions) will obtain the required oxygen from complex chemical compounds and produce various breakdown products such as organic acids and alcohols. The anaerobic process is more complex than the aerobic process and will produce odoriferous conditions if the top layer of the pond liquid is not maintained in an aerobic state.

Most ponds develop into combination anaerobic-aerobic treatment units, and, in this respect, are very similar to rivers and lakes. Aerobic conditions are usually maintained near the surface and sometimes throughout most of the pond. However, because organic debris usually settles out, an anaerobic environment will persist at the bottom.

3. TYPES OF POND SYSTEMS AND APPLICATIONS

Definitions

Pond systems have been applied for the treatment and disposal of domestic wastewater and organic wastes in various ways. Unfortunately the terms used for pond systems are still used very haphazardly, although van Eck (1958) and Meiring *et al.* (1968) have tried to establish terminology to define these systems. The definitions given below will apply in the context of this *Manual*.

Pond system. Any system of ponds intended to fulfil a biological waste treatment requirement, which utilizes solar energy, bacteria and algae, together with a wide variety of aquatic biota.

Aerobic pond. A pond which is almost completely aerobic with no or only a thin anaerobic bottom layer.

Anaerobic pond. A (deep) pond with anaerobic conditions obtaining throughout.

Stabilization pond. A pond that is used for the stabilization of raw or partially treated domestic wastewater. When fully functional the pond has an effluent to be disposed of.

Facultative stabilization pond. Here aerobic conditions prevail at the water surface and below, and anaerobic conditions in the bottom sediments and lower water levels, especially in the primary pond of the system. In a minor modification of this system, water is recirculated from a secondary to a primary pond.

Anaerobic-aerobic stabilization system. In this system anaerobic ponds are followed by a facultative pond from which oxygenated water is recirculated to the raw waste feed entering the anaerobic ponds to counteract odours. These ponds together are considered the primary unit of a series of ponds.

Maturation pond. A pond used for the tertiary treatment (maturing) of effluents; e.g. secondary clarifier, humus tank or sand filtered effluents.

Night-soil oxidation pond. This is a facultative pond for the treatment and disposal of night-soil without nuisance and from which there is no effluent.

Conditions of application

As seen from the definitions, a pond system can be designed to treat raw, settled or conventionally treated domestic wastewater, septic tank effluent, night-soil or conservancy tank contents.

The design depends on the treatment objectives, but any one of these systems can be applied for locations where -

- climatic conditions are favourable;
- the population is too small to justify conventional purification;
- funds are limited;

- land is inexpensive;

- organic loadings fluctuate widely (e.g. at holiday resorts or schools); and

- the ultimate load does not exceed 5 000 PE's (population equivalents) or 800 kℓ/d stipulated by the Department of Environment Affairs).

Versatility of application

Pond systems have often been used to satisfy interim waste treatment requirements for the treatment of wastewater in small quantities and are particularly useful to bridge unsanitary conditions wherever they occur. They may be applied in the following instances:

- *Treatment of night-soil.* This specific pond type (Shaw, 1963; see *Design Criteria for Night-Soil Oxidation Ponds*, p. 19) can be used in many instances to relieve existing conventional wastewater purification works by treating night-soil and/or conservancy tank effluent separately rather than discharging these liquids to the sewer and thence to the purification works. If the ponds are sited adjacent to the existing wastewater treatment plant, humus tank effluent can be used profitably for topping up.

- *Decentralized treatment facilities.* Where stabilization ponds are to be used in an interim scheme (or even otherwise), it may be economical to operate a number of small units on temporary sites close to the source of the effluent until it becomes justifiable to install a main collecting sewer (Stander and Meiring, 1963).

- *Treatment of septic tank effluent.* Facultative stabilization ponds may be employed for the disposal of pretreated effluent, such as that derived from septic tanks and aqua privies (Vincent *et al.*, 1962) or for the effluent from a primary anaerobic pond with recirculation, as described in the section on *Anaerobic-Aerobic Pond Systems*, p. 15).

- *Increased wastewater treatment capacity.* By introducing a quantity of settled wastewater with the nitrified effluent from a conventional works to the first of a series of maturation ponds, a marked reduction in the nitrate concentration may be achieved. (Bolitho, 1964; Gaillard and Crawford, 1964).

- *Advanced effluent treatment.* In South Africa, ponds are being used extensively for further treatment of secondary treated effluents, such as humus tank or sand filter effluent (Stander, 1955; Stander and Meiring, 1963; Cillié *et al.*, 1966). Primarily, these ponds are used to obtain an effluent of improved bacteriological quality. In addition, advanced biochemical purification is also achieved (which is frequently masked by prolific algal activity).

Range of application

A diagrammatic representation of different pond systems is given in Figure 2 and the relative pond areas required are roughly indicated. A range of three different stabilization pond systems is shown, where the variation is largely in the application of the primary pond (or system). Mechanically assisted stabilization ponds in which all or much of the oxygen requirements are supplied by mechanical aeration are not shown in the diagrams.

Maturation ponds as portrayed in Figure 2 normally follow conventional works. The well-stabilized effluents that can thus be further matured are clarifier effluent from an activated sludge plant, and humus tank or sand filter effluent from a biological filter plant.

As the effluent from a series of stabilization ponds is also well stabilized the final three ponds in such a series also perform the function of maturation ponds. Purification effected in these ponds is primarily with respect to bacteriological and virological quality, although some chemical improvement is also achieved.

In Figure 3 a possible night-soil oxidation pond is shown for an area of 1 ha, which is described further under the section on *Design Criteria for Night-soil Oxidation Ponds*, p. 19).

Cost of water-borne sanitation for small communities

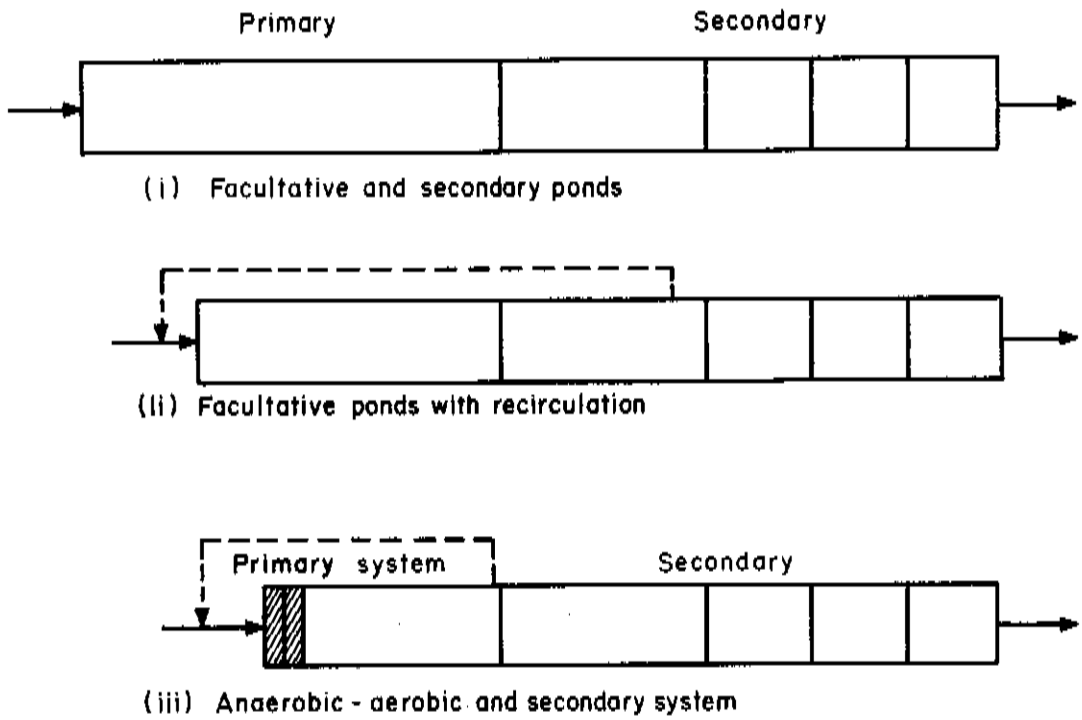
In Table 1 cost data based on information obtained from various existing installations (adjusted to 1983 costs) reveal an interesting comparison between the costs in the construction and running of conventional wastewater purification systems and facultative pond systems for similar sized communities. These data show that pond systems are highly economical for providing water-borne sanitation for small and isolated communities who cannot afford the construction of conventional treatment facilities.

TABLE 1. Relative costs of wastewater treatment facilities (1983)

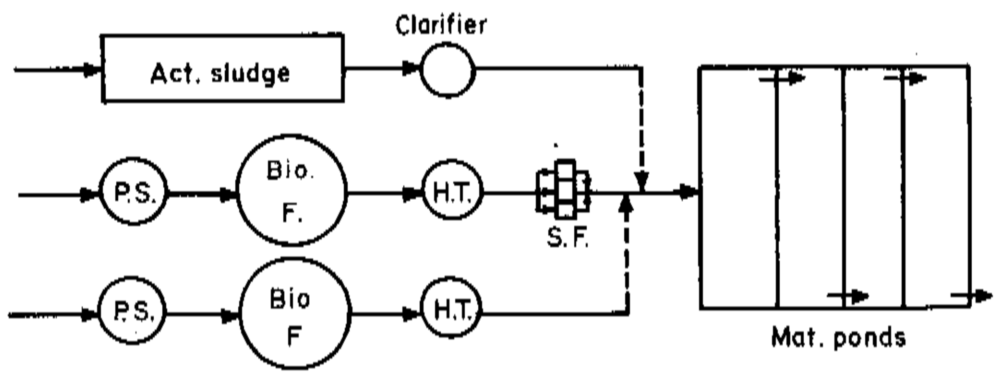
	Capital cost (rands/person)			Running costs (rands/person)	
Population	Conventional purification works	Facultative pond system: Without sealing of bottom*	Facultative pond system: With sealing of bottom**	Conventional purification works	Pond system
240	293	25	50	-	4,00
1 000	180	25	46	21	2,50
3 000	130	21	42	13	1,30
5 000	121	21	42	-	1,30

*Cost of construction estimated at R30 900/ha .

**A rate of ca. R3,00 per m^2 has been assumed for sealing of pond bottoms, both primary and secondaries.



Stabilization pond systems



Maturation ponds after conventional works

Figure 2. Pond systems - range of application (pond areas approximately proportional).

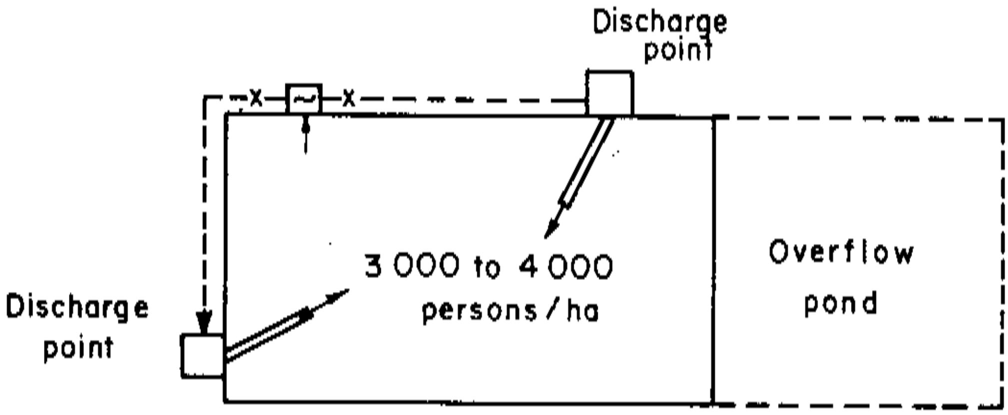


Figure 3. Night-soil oxidation pond system.

4. POND LOADING AND SIZING

Conditions for loading of a stabilization pond system

The pond loading is the quantity of polluted water that will flow into the system per day and determines the size of the system so as -

- not to create a nuisance; and
- to produce an effluent (if any) of acceptable quality.

A *nuisance-free* pond is one that does not produce undesirable odours, favour mosquito and fly breeding and has a generally pleasing appearance. Anaerobic conditions in ponds result from overloading, which causes the oxygen demand to exceed the reoxygenation capacity. Thus overloaded conditions, absence of dissolved oxygen and odour production go hand-in-hand. It was realized that odour-free operation would govern the size of the primary pond of a stabilization pond system.

The meaning of 'acceptable quality' is somewhat controversial. Compliance of effluent quality with the South African General Standard would, of course, be the ideal. It is, however, suggested that primary consideration should be given to the provision of a practical nuisance-free system at reasonable cost which produces an effluent that does not degrade the environment significantly. (Water reuse hardly needs consideration in these instances due to the relatively small volume of effluent.) Effluent quality requirements would naturally govern the size and arrangement of secondary ponds.

Estimation of available load for a stabilization pond system

Before sizing a pond system correctly, it is necessary to estimate the hydraulic and organic load and the projected load expected in 10, 15 or more years. Figures and data for expected flows and organic loads carried in various domestic wastes are given in *Flow and Load Criteria for Wastewater*, an Information Sheet (I Wat 6) published by the National Institute for Water Research in August 1978. In this *Manual* only domestic wastes are considered and industrial wastes are excluded.

Sources of wastewater

Domestic wastewater may comprise the following components:

- Domestic wastewater from residential areas, offices and factory toilets and showers

- Groundwater infiltration into sewers

- Stormwater penetration at manholes and gullies.

The flow of domestic wastewater may fluctuate widely according to source and season. The average flow depends on the availability and cost of usage water, whether water is metered or not, and on the lifestyle of the inhabitants. Care should therefore be taken when making estimates of flow and load that all possible sources are considered, as well as the living standard of the contributors and whether they work in areas away from the reticulation catchment. An allowance must then be made in the load estimation.

If population figures or waste flow measurements are not available, water consumption records might be of some help in the wastewater flow estimation. The type of sanitation supplied to a housing area will affect the criteria that can be applied for hydraulic and organic load estimations (see Table 2).

In each case the fraction of a day that a system is not used (people working in factories in other catchment areas) must be taken into account and the load reduced accordingly.

Design criteria for stabilization pond systems

Facultative pond systems

The design of this type of system treating raw or primary treated domestic wastes has been fully covered by Shaw *et al.* (1962), from which the essential points are given below:

- *General.* The first consideration affecting the size and arrangement of a facultative pond system is that nuisance-free operation depends on adequate sizing of the *primary* pond.

  The second consideration is that effluent quality is influenced by the size and arrangement of the *subsequent* ponds.

- *Loading of primary pond.* Anaerobic conditions in the surface layers, usually in the primary pond of a system, result from overloading, which causes the oxygen demand to exceed the reoxygenation capacity. Overloaded conditions can therefore be inferred from the absence of dissolved oxygen or the production of odours, or both.

For domestic wastewater, as well as for stronger and weaker effluents, such as those from aqua privies, septic tanks and primary sedimentation tanks (see next section, p. 11), the following procedure is suggested for estimating the minimum detention time in the *primary* pond:

TABLE 2. Load estimation criteria for load arriving at pond system

Type of area	Hydraulic load* (ℓ/d)	Organic load* (g BOD/d)	Organic load* (g PV†/d)	Organic load* (g COD/d)
Sophisticated residential area, fully sewered	135-200	54-60	12-13,5	115-130
Residential area with denser housing >20 houses/ha, fully sewered	80-150	50-56	11-12,5	105-120
Conservancy tank contents carted to ponds or wastewater treatment works, with bathrooms, basins and kitchen sinks connected	80-150	45-54	10-12	96-115
Conservancy tanks (or septic tanks) with *no* bathwater, basins and kitchen sinks connected	50-60	35-40	8-9	75-85
Township with water supply standpipes and externally collected water-borne wastewater	50-60	35-45	8-10	75-96
Load for night-soil pond system	-	36	8	76

*Per capita.
†PV refers to the British method.

The average concentration of BOD_5 in the raw wastewater influent to the first pond (if it cannot be measured directly) is given by -

$$P_o = (\frac{b}{q}) \; 10^3$$

where P_o = BOD concentration in the influent to the pond (mg/ℓ)
b = BOD contribution per person per day (g)
q = effluent flow per person per day (ℓ).

The minimum detention time in the primary pond -

$$R = (\frac{P_o}{P} - 1) \times \frac{1}{C}$$

where R = the detention period (days)
C = constant dependent on temperature (refer Table 3)
P = maximum concentration of BOD in the pond consistent with aerobic conditions.

As an acceptable value of P, the following empirical formula is given:

$$P = \frac{600}{1{,}97d + 8}$$

where d = the depth of the pond (m).

As a general guide a loading of approximately 135 kg BOD/ha.d, (i.e. 2 500 persons/ha.d) can be adopted for domestic raw wastewater in a primary pond with a depth of 1,2 to 1,5 m .

TABLE 3. *C* values for different climatic regions

Average temperature in coldest month	<7 °C	7 - 10 °C	>10 °C
GEOGRAPHIC REGION	Most of Drakensberg range, south of the Transvaal and adjoining areas	Southern and western Free State, Highveld, Transvaal and central Karoo	All coastal regions, northern Natal, Transvaal north of the Highveld, northern and western Cape
C VALUE	0,14	0,17	0,20

In Table 4 some retention times (in days) for the primary pond as given for different values of incoming BOD concentrations, at different depths and different average winter temperature ranges are given.

- *Sizing and arrangement of subsequent ponds.* Sizing of the subsequent ponds is based principally on detention time. A vital feature for efficient reduction, of faecal bacteria especially, is that the ponds should be arranged in series, as will be demonstrated in the section on *Design Criteria for Maturation Ponds*, p 17. It is also known that, owing to algal activity during daylight, the pH increases, resulting in ammonia losses, and that nitrogen removals generally improve with increased overall detention times. In the past a total of at least 25 days detention time, based on flow into the primary pond, had been recommended and it has been found by subsequent investigation of existing systems that detention times of 25 to 35 days for the secondary system were apparently ideal, as best results were obtained from systems with an overall detention time of more than 45 days (Drews, 1982).

  It must also be mentioned that oversizing of these ponds would result in excessive evaporation and a small outflow, which will lead not only to increased salt concentrations in the effluent but even to higher COD values than expected. The latter will not necessarily be due to algal growth alone but to a build-up of the non-degradable organic matter, which will show up as high COD and therefore an apparent low reduction of COD through the pond system.

TABLE 4. Some worked examples for primary pond retention times (days)

Average temperature, coldest month: <7 °C (C = 0,14)					
(BOD (mg/ℓ; P_o)		200	250	300	350
Depth (d):	1 m	16,6	22,5	28,5	34,4
	1,2 m	17,5	23,7	29,9	36,0
	1,5 m	18,9	25,5	32,0	38,5
	2,0 m	21,3	28,4	35,5	42,6
Average temperature, coldest month: 7-10 °C (C = 0,17)					
*BOD (mg/ℓ; P_o)		200	250	300	350
Depth (d):	1 m	13,7	18,6	23,4	28,3
	1,2 m	14,4	19,5	24,6	29,7
	1,5 m	15,6	21,0	26,3	31,7
	2,0 m	17,5	23,4	29,2	35,1
Average temperature, coldest month: >10 °C (C = 0,20)					
*BOD (mg/ℓ; P_o)		200	250	300	350
Depth (d):	1,0 m	11,6	15,8	19,9	20,9
	1,2 m	12,3	16,6	20,9	25,2
	1,5 m	13,3	17,8	22,4	26,9
	2,0 m	14,9	19,9	24,9	29,8

*For convenience BOD may be taken as 0,5 COD. This should preferably be verified for each situation.

Depending on the rate of seepage from the system and the effluent flow the build-up is slowed down, but it is a matter to be kept in mind when designing pond systems (see also the sections on *Evaporation Losses from Ponds*, p. 29 and *Seepage Losses*, p. 29).

The first of the secondary ponds should have a minimum of 10 days detention, while subsequent ponds in series (third, fourth and fifth) should have 5 days detention each at a depth of 1,2 m . Further subdivision of the fifth pond should have an additional beneficial effect on the bacteriological quality of the final effluent (see section on *Design Criteria for Maturation Ponds*, p. 17).

(For screens, detritus channels, flow measuring and other pretreatment, as well as pond appurtenances see Chapter 5.)

Facultative pond systems with recirculation (Fig. 2)

These ponds constitute an application somewhere in between facultative ponds without recirculation (*Facultative Pond Systems*, p. 9) and facultative ponds preceded by an anaerobic pond system (*Anaerobic-Aerobic Pond Systems*, p. 15).

The performance of a facultative pond is considered satisfactory as long as the upper layer of the liquid in the pond remains aerobic for the greater part of the day. Thus photosynthetic activity in the upper layers must not be overwhelmed by anaerobic conditions proceeding upward from the bottom, where active anaerobic fermentation is taking place in the sludge layer. It is therefore of importance that, if effluent from a secondary pond is recirculated and admixed with the raw wastewater influent to the primary pond, the loading as calculated on the overall area of the recirculation pond system can be increased considerably without creating anaerobic conditions (Abbott, 1963).

Loading

According to Abbott (1963) the BOD load applied to the recirculation pond system (i.e. primary and recirculation pond) can be as high as 280 kg/ha.d without a nuisance being caused by anaerobic conditions. Considerable overloads can even be withstood by this system for short periods. A maximum loading of the primary-cum-recirculation pond of 225 kg/ha.d is recommended.

Recirculation from a secondary pond could also be used as a relief measure during periods of overloading of a normal facultative stabilization pond.

Recirculation rate

At the above loading, the minimum recirculation rate for satisfactory performance seems to be 1:1. Provision should, however, be made for higher recirculation rates up to 2:1 when required.

Detention time

Although the detention period will depend on the strength of the wastewater and the maximum load criterion, a detention period of 18 days was recommended by Abbott for a recirculation pond system (primary and secondary pond combined) treating domestic wastewater of average strength.

The recommended sizing of the pond system would be as follows:

Recirculation Pond System	(Primary pond detention) ((based on incoming flow))	: 8 days
	(Secondary pond detention)	: 10 days
Subsequent Ponds	(Third pond detention)	: 5 days
	(Fourth pond detention)	: 5 days
	(Fifth pond detention)	: 5 days

(For pond depths, pretreatment units and pond appurtenances see Chapter 5, and the section on *Sludge Accumulation and Removal Methods*, p. 31).

Mechanically aerated pond systems

Advantages of mechanical aeration

In facultative stabilization ponds, the desirable aerobic conditions in the surface layers are largely brought about by the photosynthetic activity of green algae. If, however, the biochemical dissolved oxygen uptake, such as in an overloaded pond, exceeds the photosynthetic reoxygenation capacity, the critical balance is upset and the whole pond becomes anaerobic, ousting the algae.

An apparent balance between the biochemical dissolved oxygen requirement and photosynthetic reoxygenation capacity of the water in a pond may, however, be upset for reasons other than an increase in pond loading. A drop in temperature or a large and sudden reduction of the algae concentration brought about by an extremely rapid increase in numbers of predator organisms such as *Daphnia* and *Moina* spp., could well be the cause of such a drop in pond performance.

Contributing further to the inefficiency of algae as an oxygen producer is the lack of uniformity of the oxygen concentration through all the water layers.

To make a primary pond less reliant on the photosynthetic reoxygenation activity of algae, mechanical aeration of the pond contents could be resorted to. In the U.S.A. it has, for instance, been shown (Olson, 1966) that at loadings of 448 kg BOD.ha.d, an overall efficiency of about 90% BOD reduction could be achieved even while the ponds were covered with ice. Apparently loadings up to 600 kg BOD.ha.d would be possible in warmer climates in aerated ponds of 2 m depth, but retention time should not be less than 5 days.

Odour problems may, in some instances, be the most urgent reason for conversion to a mechanically aerated pond. However, the following factors also favour an aerated pond over an ordinary facultative pond:

- Better land utilization through higher possible loadings in terms of persons per hectare.
- Improved sustained quality of the effluent during winter and spring months.
- Less cost of sealing of ponds in porous soil because of less surface area.

Depth of pond

In the case of a straightforward facultative stabilization pond without aeration, the surface area exposed to solar radiation is the critical parameter and treatment capacity cannot be substantially increased by merely deepening the pond. This does not apply to mechanically aerated ponds, in which case depths of 3 m have been successfully employed (Olson, 1966), since the additional depth facilitates the introduction of certain aerator mechanisms which would otherwise not have been possible.

A mechanically aerated pond differs from an aerobic pond in that the algae growth which provides the oxygenation for the latter is replaced by mechanical aerators (usually) or diffusers, and the pond can be 2 to 4 m deep. Although the mixing caused by aeration keeps most of the pond contents in suspension, some solids usually do settle out to undergo anaerobic decomposition. These deposits are limited in size by turbulence in the basin and rarely cause difficulties.

Aeration requirements and facilities

Oxygen requirements of 1,0 to 1,5 g O_2/g BOD_5 should be sufficient. Placing of the aerators (whether floating or fixed) or diffusers should be accomplished in such a way that the sludge layer is disturbed as little as possible. A slab of concrete below turbine aerators is desirable to prevent vortex erosion. If a diffuser system is used the diffusers should be mounted clear of the sludge deposit (say 1 m) to avoid total mixing.

The aeration facilities should be easily dismantled to facilitate overhaul or sludge removal, should this become necessary after a few years' operation.

To minimize turbulence and obtain optimum efficiency, coarse bubble aeration should be avoided if possible.

Power requirements

The control of bubble size, rise rate and laminar flow conditions will result in efficient utilization of power: The air supplied is then employed for oxygenation of wastes rather than for rapid turnover of water to keep sludge in suspension. The power requirement for aerating mechanically has been estimated at less than 0,0045 kWh per person. At 4,5c per kWh the operating cost would be R1,8 per person per year.

Secondary ponds

Because of turbulence in the aerated pond (which is really activated sludge without sludge recycling), a considerable amount of solid matter will come over into the first secondary pond. An anaerobic sludge layer, which may have to be removed at intervals, will build up. Until more information is at hand secondary ponds following a mechanically aerated primary pond should be designed in the normal way.

(For further details on pond systems in general see Chapters 5, 6 and 7 and the section on *Sludge Accumulation and Removal Methods*, p. 31).

Anaerobic-aerobic pond systems

When anaerobic ponds are followed by a facultative pond from which oxygenated water is recirculated to the raw wastewater entering the anaerobic ponds, the system is referred to as an anaerobic-aerobic stabilization pond system (An-Ae system; van Eck and Simpson, 1966). This system is considered as a primary unit in a series of ponds.

It would be advisable, for aesthetic reasons, to discharge only screened, detritus-free wastewater into these ponds.

A diagrammatic layout of an An-Ae system is given in Figure 4. The system consists of 3 anaerobic ponds A, B_1 and B_2 and one large facultative pond, C, with aerobic surface layers. A pump circulates water from pond C into the raw wastewater entering pond A at a recirculation rate of 25% of the raw wastewater flow.

As in the case of the single facultative primary pond (p. 9) the An-Ae system is followed by aerobic ponds (usually four) in series in order to obtain a final effluent of high quality.

Pond A should operate as an anaerobic digester in which active fermentation is established in the sludge layer. As a result of the waste stabilization processes, methane, carbon dioxide and sometimes nitrogen gases are produced. Ponds B_1 and B_2, which are operated alternately in series with Pond A, remove suspended solids carried over by Pond A effluent, thus obviating unnecessary loading on Pond C. Only two anaerobic ponds are operated at any one time.

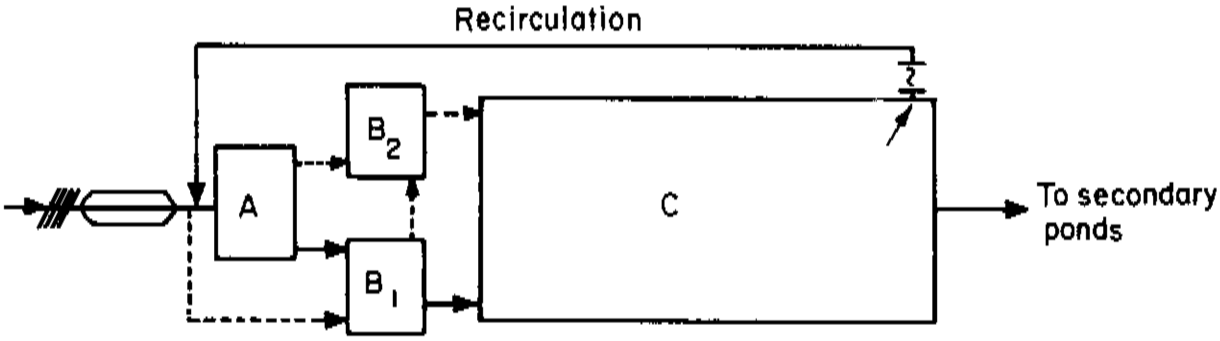


Figure 4. Flow diagram of An-Ae system.

Pond design and loading of the An-Ae system

It should be noted that these design criteria are tentative and may be altered in the light of further experience. Ponds A, B_1 and B_2 should be of equal areas and 2,5 to 4 m deep. Pond C, which is much larger than the anaerobic ponds, should be 1,2 to 2 m deep.

The daily BOD load of the raw wastewater will determine the pond sizes of the An-Ae system. The volume of Pond A should be calculated on a maximum loading of 0,4 kg BOD/m^3.d or a minimum detention of 12 h, whichever is applicable. Ponds B_1 and B_2 should be the same size as Pond A.

In designing the size of Pond C, it can be assumed that the anaerobic section of the An-Ae system will remove on an average 60% of the BOD load of the raw wastewater.

The size of Pond C is based on an area loading. Pond C should not receive a loading greater than 135 kg BOD/ha.d (see section on *Loading of Primary Pond*, p. 9).

Sludge accumulation

From an anaerobic pond, sludge may have to be removed once every year. For this reason triplicate anaerobic ponds are recommended, so that the effluent may all be diverted to the one set of ponds while sludge is being removed from the third one. The ponds may be operated according to the following system:

Run 1. For 6 months, raw wastewater to A → B_1 → C.

Run 2. Succeeding 6 months, raw wastewater to A → B_2 → C. Pond B_1 to be desludged in the interim.

Run 3. Following 6 months, raw wastewater to A → B_1 → C. Runs 1, 2 and 3 to be repeated until it becomes necessary to desludge Pond A (usually 2 to 4 years).

Run 4. Raw wastewater to B_1 → B_2 → C, while Pond A is desludged.

Fly breeding

Anaerobic ponds are usually covered by a layer of scum in summer, which may be a suitable breeding habitat for flies. Fly traps containing poison placed at very frequent intervals around the perimeter of these ponds would only partly remedy the situation. For this reason, anaerobic ponds should be placed at least 1 km away from the nearest habitation.

Future application

Although this system is of great technical interest, it is, at this stage, not recommended for general use in South Africa until more knowledge is available.

Models for stabilization pond design

The design methods and formulae discussed in this *Manual* are largely derived by empirical or semi-empirical techniques (Herman and Gloyna, 1958; Marais and Shaw, 1961), which limits their application to certain climatic conditions. Designers who would like to use design equations based on more scientific principles are referred to recent papers in which authors have used various design approaches and have suggested mathematical models for pond system design. A number of these publications is listed in the Appendix.

Design criteria for maturation ponds

Maturation ponds as such are not intended to cater for underdesigned conventional wastewater purification facilities to obviate the extension of an overloaded works or to save on costs of operation and supervision. Maturation ponds are biological units in which a well-oxidized clarifier, humus tank or sand filter effluent is purified to give a water of high bacteriological quality (Stander 1955; Marais, 1963a; Stander and Meiring, 1963; Malherbe and Coetzee, 1965; Drews, 1966). Thus retention time and the configuration of a series of such ponds are determined primarily by the measure of bacterial purification required. Unless the effluent to be treated has received only limited stabilization, a maturation pond cannot readily be overloaded to become anaerobic and only practical considerations would therefore dictate the size of such ponds.

Sizing and arrangement

The die-off of faecal bacteria in aerobic ponds follows a first-order reaction rate, provided good mixing is assured; i.e. the rate of die-off is more or less inversely proportional to the bacterial concentration (Marais and Shaw, 1961). This die-off is reflected in the following equation, which gives the relationship, expressed as a percentage, between the concentration (N) of bacteria in a single pond to the influent concentration (N_o) for varying detention times:

$$\left(\frac{N}{N_o}\right) = \frac{100}{(KR + 1)}$$

where R = detention time in pond (days)
K = velocity constant (value of 2 assumed).

The value of K has been established empirically and has been shown to vary considerably with the extent to which short-circuiting and seasonal effects (such as hours of sunshine) influence pond performance.

However, the value of K has never been observed to be less than 2,2, and until more data are available showing to what extent improved prevention of short-circuiting, for instance, would enable the designer to use an increased value for K, a K value of 2 is recommended for design purposes.

The advantage of having a series of small ponds instead of one big pond of the same overall size is illustrated by doubling the detention time in the above equation. The relationship then becomes -

$$\left(\frac{N}{N_o}\right) = \frac{100}{(K2R_1 + 1)}$$

However if, instead, a second pond of equal size is added in series, the relationship between the quality of the effluent from the second pond and the primary pond influent would become -

$$\left(\frac{N}{N_o}\right) = 100 \left(\frac{1}{KR_1 + 1}\right) \left(\frac{1}{KR_1 + 1}\right)$$

$$= \frac{100}{(KR_1 + 1)^2}$$

By inserting any figure for R, the superior performance of a series of ponds would become evident.

According to the above equation, four properly operated ponds in series, each having 4,5 days retention, should give a 99,99% reduction in faecal bacteria. Five ponds in series, each having 3 days retention, would perform even better.

Effluent quality requirements

Bacteriological

The faecal coliform concentration in maturation pond effluent should be nil in terms of the General Standard, which means that chlorination would have to be applied. However, the following should be considered as an argument for keeping ponds a reasonable size.

It has been established that the faecal coliforms present in the effluent from any particular pond have a logarithmic normal distribution, with a logarithmic standard deviation (S) not exceeding 0,45 (Marais, 1963b). From this information it is therefore possible not only to set a quality requirement for a pond effluent, but also to stipulate an upper confidence limit on a rational basis. Since a biological system is being dealt with, a confidence limit is considered an essential feature of any quality requirement.

For design purposes it should be accepted that an effluent bacteriological count of 1 000 faecal coliforms per 100 mℓ should be considered the upper limit of the 95% confidence range (exceeded only by 2,5%) of effluent quality. In most cases such effluent should be acceptable for -

- flood irrigation of crops for human consumption that are not likely to be eaten raw;

- flood irrigation of fruit and trellised vines;

- irrigation of pastures for grazing but not for milk producing animals;
- irrigation of golf courses, parks and sports fields during the development stage only; and
- discharge into streams after chlorination.

It can be shown that if the requirement stipulates that faecal coliform concentration in the effluent must not exceed 1 000/100 mℓ with 97,5% confidence, then assuming a logarithmic standard deviation (S) = 0,45, the pond must be designed to give a mean effluent concentration of 132 faecal coliforms per 100 mℓ .

Referring to the suggested sizing of ponds (p. 17), it is interesting to note that if a humus tank effluent with 1,32 x 10^6/100 mℓ faecal coliforms is treated in a well-designed system of 4 ponds in series, each with 4,5 days detention, an effluent of the desired quality should be produced since this system should be sufficient to bring about a 99,99% reduction. For treating more highly polluted effluents to the desired bacteriological standard, the bacterial reduction in such a system would be insufficient.

Chemical

The chemical quality of the effluent is affected by influent quality. A general survey (Drews, 1966) has indicated that 4 ponds in series, 1,2 m deep, with 2,5 days retention each, would produce an effluent with an OA of less than 10 mg/ℓ and a COD of less than 100 mg/ℓ on a *filtered* pond effluent sample, provided the OA of the unfiltered humus tank effluent does not exceed 20 mg/ℓ, and the COD, 175 mg/ℓ .

Design criteria for night-soil oxidation ponds

Loading

In the past, smaller local authorities have experienced difficulties with the disposal of night-soil and conservancy tank contents, because the usual methods of trenching, spreading or composting caused nuisances and pollution and were generally unhygienic and even expensive. The treatment of night-soil in oxidation ponds proved promising and effective. Subsequent researchers (Shaw, 1963) found that a night-soil oxidation pond could be loaded at the same rate as a primary stabilization pond; i.e. ≯135 kg/ha.d in a Highveld climate. Since night-soil does not include kitchen, bathroom and washing wastes, this is equivalent to a load of 3 000 to 4 000 persons.ha.d .

The low water content of night-soil would not compensate for loss by seepage and evaporation, and the pond would become extremely unsightly and odorous and would dry out. It is therefore an essential feature of a pond treating night-soil that make-up water must be available to keep the pond filled at all times, but also that, irrespective of waste to be treated, the pond should never be overloaded.

A seepage and evaporation loss of 10 mm/d is equivalent to 100 m^3/ha.d and may be considered in design.

No effluent is to flow from the pond and as a result the dissolved solids concentration may gradually increase. Where the waste treated is such (especially when conservancy tank effluent is also included) that an effluent will result, an overflow pond should be constructed alongside.

Irrespective of the surface loading criteria, the pond should have a minimum depth of 1,2 m (1,5 to 2,0 m preferably). If night-soil ponds are to be used for a larger community, it may be better, because of mixing difficulties, to have a number of separate ponds rather than a single large one.

Introduction of night-soil and desludging

No hard and fast construction details can be given for night-soil introduction into the pond, but the following points may serve as a guide:

- The design of flushing points will depend on vehicles and equipment.
- Concrete ramps, aprons and chutes should be such that all residual night-soil can be washed or drained into the pond and sufficiently dispersed so that sludge banks are not formed.
- Night-soil should be introduced to the pond in a diluted form for which a circulating pump taking water from the pond into a mixing sump may be used.
- Make-up water for the pond may be used for washing down aprons and chutes and for breaking up lumps in the flushing tank.
- For large ponds, more than one point of introduction should be provided, and the number of points spread around the pond should be increased according to size of the pond.
- A number of smaller ponds would facilitate mixing and desludging. Before drying (or pumping) out the pond, it should be kept full of water without feeding for at least one month so that the sludge is given time to digest.

5. SITING AND LAYOUT OF POND SYSTEMS

Siting and land requirements

When planning the siting of a pond system the following factors have to be considered:

- Cost of land.

- Elevation of land in relation to the town (or wastewater treatment works) i.e. gravity flow versus pumping is to be considered.

- Topography (whether steeply sloping or flat) and whether valleys or depressions could be made use of to reduce costs.

- All land between the wastewater purification plant - whether it be stabilization ponds or a conventional wastewater purification plant - and the nearest water course should be acquired and owned by the owners of the system. For a facultative stabilization pond system an area of about 2 ha is required for a flow of 450 m^3/d . Extra area must be allowed for embankments, dividing walls and roads. The above requirements of 2 ha pond area will differ for other types of ponds. If irrigation of the effluent is to be practised, about 20 to 35 ha per 1 000 m^3 water are required, depending on the soil.

- Type of soil (rocky, clayey or sandy soil), which influences the costs of excavation.

- Groundwater pollution potential; i.e. the distance from water sources, boreholes and wells.

- Prevailing winds. Good winds are desirable for pond mixing but ponds should preferably be down wind of the residential area. If correctly loaded and well operated, and keeping mosquito breeding in check, facultative ponds need not be further than 300 m away from the nearest habitation.

- Odours and fly breeding are not always easily controlled on anaerobic ponds and they should thus be placed at least 1 km away from the nearest habitation.

- For night-soil ponds transport costs must also be considered and these ponds should therefore not be too distant.

Layout

The layout of a pond system depends largely on the topography of the land area. The perimeter of each pond should be uniform and coves, islands and peninsulas should be avoided.

Ponds on flat ground may have any practicable shape and water would usually be contained at the same level for all ponds in a system. Overflows from pond to pond could consist of sufficiently large connecting pipes, at least 20 cm below the water level.

On steeper ground, the ponds would become long and narrow along the contours and special overflows have to be designed.

The least amount of earthmoving for the construction of ponds is usually required on gently sloping land. However, it should also be noted that this type of site is not necessarily the most suitable for the construction of a wastewater purification works of conventional design which may later replace the stabilization pond system as a treatment facility.

Pretreatment and flow measurement

Screens and grit channels

Every pond system should have a pleasing appearance and therefore bar-screens and detritus channels (Fig. 5), correctly sized and designed, should be installed for every system. Bar-screens, in particular, should be obligatory (especially for facultative primary, aerated primary and the anaerobic ponds) since primary ponds with no well-operated inlet works can be most unpleasing to the eye. Whether detritus channels are included or whether a depression is provided in the primary pond below and around the inlet to hold 5 to 10 years' detritus, will depend on circumstances.

Sewage from Black residential areas usually yields a high grit load because of sand used for cleaning utensils. As high as 0,17 m^3 per 1 000 m^3 can be found, whereas the wastewater from White areas may contain one sixth of this amount. Screenings would, on average, amount to 0,05 m^3 per 1 000 m^3.

All screenings and detritus should be treated with calcium hypochlorite (chloride of lime) and buried to avoid fly nuisances and the spread of disease. Sun drying under fly-mesh screens and incineration of screenings may also be possible in places.

Wherever night-soil or conservancy tank effluent is discharged into a pond system, a proper bar-screen system which can be readily cleaned, must be provided. Any other type of coarse screen; e.g. square mesh metal grids, are ineffective, because they are very difficult to clean.

Flow meters and other measuring devices

A flow measuring and recording device should be installed ahead of the primary pond in a facultative system to allow the loading of the pond to be checked and to furnish data for use when the system needs extending.

If a sophisticated measuring device is not installed provision should at least be made in the channel leading to the pond for a removable 90 ° V-notch weir for use when the loading to the pond system has to be checked.

For maturation ponds too, a knowledge of the flow will assist in keeping a check on the pond loading. If the raw wastewater is measured at a works, a flow recorder for the pond system would be required only if some of the total flow is diverted for other purposes before reaching the ponds.

Aqua privies, septic tanks, settling and Imhoff tanks

Pretreatment of wastewater before it enters the pond system is advantageous. As a rule of thumb, it may be assumed that the reduction of BOD in a septic tank or aqua privy of one or more days retention is of the order of 40%, largely owing to the separation of sludge from the liquid. Such sludge settling and degradation also takes place in a primary pond with no pretreatment, except that the sludge accumulated in winter would hardly be digested and is an additional load on a facultative pond, leading to possible anaerobic conditions when the season warms up towards spring and summer (see the section on *Seepage Losses*, p. 29). This can be largely avoided with pretreatment, but it does not mean that the pond can necessarily be reduced in size according to BOD removed in the pretreatment. In such cases pond size might be reduced by 10% but not more than 20% at most. With very little sludge accumulation the primary pond would last much longer than without pretreatment.

For small and isolated communities or in instances where less sophisticated modes of sanitation would be acceptable, the above system could be of economic advantage.

Anaerobic pretreatment as mentioned previously is also aesthetically advantageous, since the floating layer of scum which appears periodically on these ponds is seldom found when pretreatment is practised.

Pretreatment in a settling tank and digester (e.g. Imhoff tank) is also a method of reducing the load on an existing system.

Pond appurtenances and other physical features

Inlets to primary ponds and short-circuiting

Plug flow conditions cannot readily be obtained in a pond, since some short-circuiting inevitably occurs. In view of this tendency, maximum average detention must be strived for. This can be achieved by setting the other extreme condition, that of complete mixing, as the ideal and to this end pond appurtenances must be constructed and sited with great care.

Water discharging from the inlet pipe or channel often has considerable momentum, which may result in short-circuiting. The inlet, which should preferably discharge near the bottom of the pond, should also be directed away from the outlet end of the pond and possibly into likely stagnant pockets such as may occur in pond corners. This applies to the inlet to each pond.

If this is not possible some means of dispersion of the flow should be adopted. The inlets to primary facultative ponds and night-soil ponds may require special features to prevent undue accumulation of sludge in one spot. Multiple inlets to bring about some sludge distribution in the pond may be desirable. Care should be taken that coarse material does not choke the inlet pipes under water.

Outlets

Outlets taking water off the surface are not recommended, owing to short-circuiting in winter caused by thermal effects of streaming and sheet-spreading of the warmer influent along the surface. On the other hand, a deep sub-surface draw-off facilitates short-circuiting in summer since the cooler influent tends to move along the bottom. As a compromise, submerged or baffled outlets are preferable as the effects due to thermal stratification will be reduced and floating scum will be prevented from passing out with the effluent. The baffle should reach to about 0,3 to 0,5 m below the surface. Examples of inlet and outlet arrangements are shown in Figure 5.

When succeeding ponds, in both stabilization and maturation pond systems, are at the same level, submerged oversized connection pipes could be used which would greatly reduce the momentum of the outflowing water and so contribute to slow and better mixing. This, however, may bring new problems, because despite the considerable retention time provided in pond systems, peak or surge discharges entering the first pond are quickly transmitted through the system, and a similar peak outflow from the final pond will follow within a very short space of time, unless the final overflow weir is constricted to allow a balancing out over the whole system.

The rapid transmission of surge discharges is due to the fact that very little build-up of head is needed to convey the peak or surge through the whole pond system. A highly variable rate of outflow would be undesirable where effluent is to be pumped to a point of reuse, or where chlorination or some other form of final treatment is to be practised, as equipment would have to be large enough to cope with peak loads, and would have to be adjustable to cope with constantly varying flows.

Under such circumstances connection pipes or overflow weirs between ponds should be of the minimum permissible size; this will make it possible to use the capacity of the ponds themselves to balance out surges. For ponds to deal with up to 680 m^3 per day, when flow balancing is needed, 10 cm diameter pipes or overflow weirs 15 cm wide, are suggested. It is not expected that blockage of 10 cm pipes or 15 cm weirs will often occur, but emergency overflows should be provided.

An alternative to using the capacity of the ponds as balancing storage is, of course, to build an additional dam for storing effluent from the final pond and to withdraw from the storage dam either at a constant rate or as and when required, e.g. for irrigation.

Multiple inlets and outlets

These should only be provided where feasible to counteract possible stagnation in certain corners of a pond.

Depth of ponds

The depth that ponds in a system should have is a matter for conjecture, as pond performance depends more on surface area and retention time. A depth of 1,2 m for stabilization and maturation ponds is generally accepted in this country, largely as primary ponds shallower than 1 m will be unduly affected by sludge deposition and these as well as secondary ponds would possibly also be affected by the growth of water weeds.

The permissible surface loading of the primary pond in a stabilization pond system increases only slightly with increased pond depths. There is therefore very little practical advantage in constructing primary ponds deeper than 1,8 m . Where by virtue of the topography, a deeper pond, or a pond which is deeper in parts, may be cheaper to construct, it should be taken into account that the capacity of the pond to reduce the virus content will be impaired (see section on the *Impact of Pond Systems on Environmental Health*, p. 32).

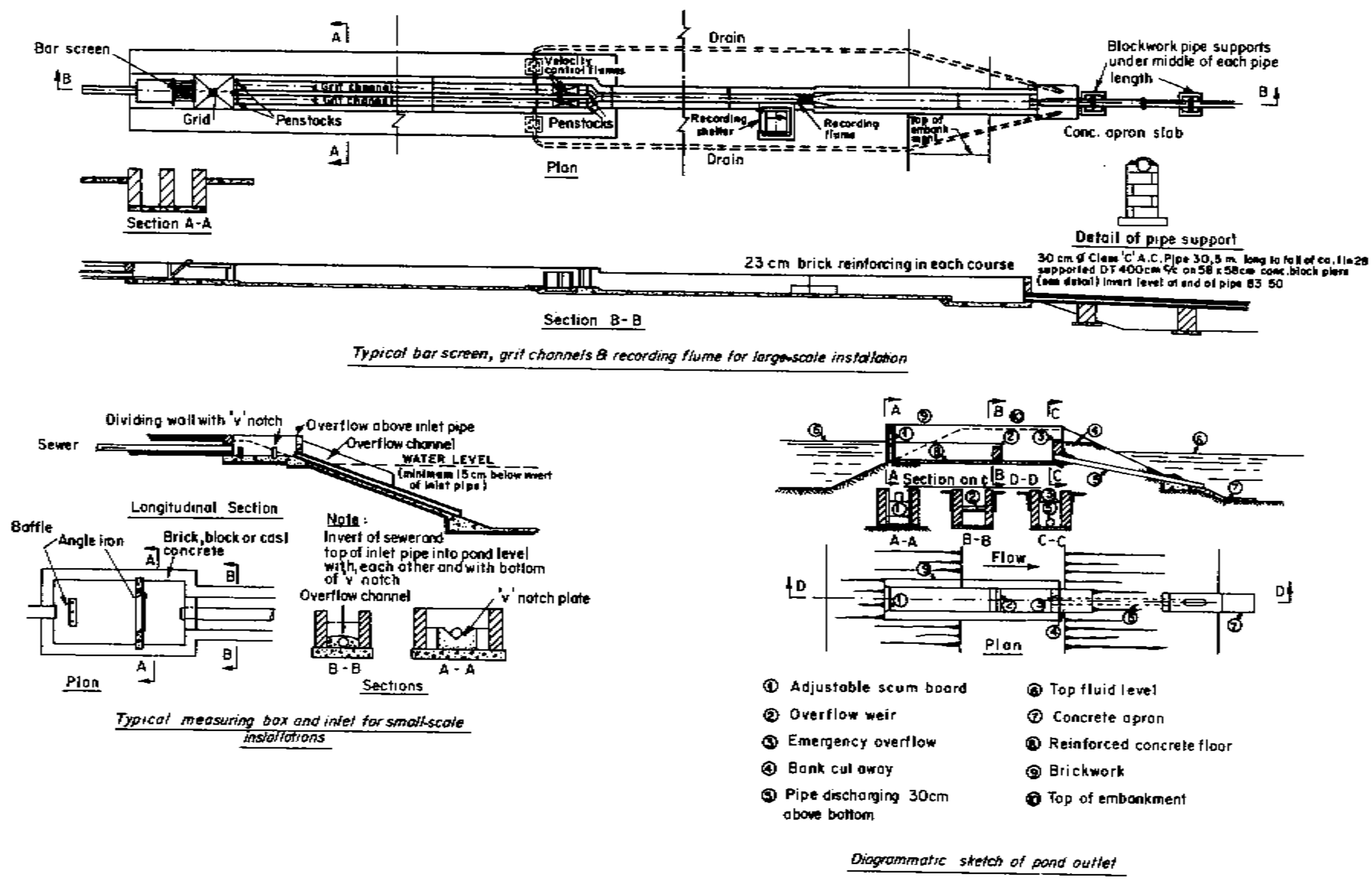


Figure 5. Typical inlet and outlet arrangements.

For depth of aerated stabilization ponds, see the section on *Mechanically Aerated Pond Systems*, p. 13).

Anaerobic ponds are not dependent on surface loading but on retention time and can therefore be made considerably deeper (2,5 to 4 m). For depth of night-soil oxidation ponds see the section on *Loading*, p. 19.

Pond bottoms

These are usually made level, but may be graded to suit the topography. In sandy soils it may be necessary to seal the pond bottom to avoid excess seepage, but this may double the construction cost (Table 1). The bottom of the pond may be sealed by compacting a layer of suitable soil on the floor of the pond, or with plastic sheeting. In the latter case, special care must be taken since the sheeting is easily ruptured. Where it is exposed at the water's edge it should be covered for protection against hailstones and the perishing effect of ultraviolet radiation from sunlight. Plastic sheeting is also subject to bulging if the soil is prone to evolve gas for any reason. In such cases clay or bentonite should preferably be used.

Embankments and verges

The slopes of embankments would be dictated by normal engineering practice for small dams. Fringes may be designed to prevent ingress of vegetation and damage to the embankment through wave erosion. The capital investment for stone pitching or soil-cement on the pond verges may well be repaid by saving on maintenance.

Protection of pond systems

Any pond system for waste treatment should be well protected against washaways by stormwater and the entry of natural run-off. Lead-off channels, which may be grassed, or concrete gutters may be used. These channels should be inspected after rains and be kept open.

Every pond system should be suitably fenced to keep animals and people out, yet in such a way that subsequent sludge clearing operations in later years are not hampered. Warning notices should be fixed at all entrances.

Rat and crab holes or cracks on the pond verges and embankments must be noted and closed immediately to stop leakages or breaking of the dam.

Recirculation

The purpose of recirculation in a pond system is to supply algae-laden or oxygenated water to a preceding pond with a high oxygen demand to prevent it from becoming anaerobic and giving off odours.

In a night-soil pond, water is recirculated to break up and dilute the night-soil (see the sections on *Facultative Pond Systems with Recirculation* (p. 12), *Anaerobic-Aerobic Pond Systems* (p. 15) and *Introduction of Night-soil and Desludging* (p. 20) .

6. FACTORS AFFECTING PERFORMANCE

Climatic factors

Light intensity

Light intensities are relatively high in South Africa, even during winter and, provided algae are present in sufficient numbers, photosynthetic activity in pond systems should be maintained. The exception might be the western Cape, where overcast weather can persist for several days at a time, reducing the light intensity and hence the algal oxygen production rate.

Temperature

When designing a pond system, the temperature range the water in the system will encounter is of paramount importance. It affects photosynthetic oxygen production as well as other biological reactions. While optimum oxygen production is obtained at about 20 °C, the efficiency of photosynthesis drops rather sharply for temperatures below 20 °C and less sharply for temperatures increasing towards 30 °C and beyond. Above 22 °C increased anaerobic fermentation at pond bottoms results in the formation of mats of sludge on the surface, buoyed up by occluded gases. When water temperatures approach 35 °C in warmer climates, particularly when ponds are shallow, the beneficial algal population will be severely curtailed.

Cold weather conditions on the other hand slow down algal development and in this way limit the permissible loading per unit of primary pond surface area.

Critical conditions also pertain in stabilization pond systems and night-soil oxidation ponds in early spring when warmer weather sets in. Bacterial activity is accelerated and unstabilized sludge which had collected on the pond bottom during the preceding winter becomes subjected to more rapid degradation, thus increasing the demand placed on reoxygenation at a time when algal densities may still be low, leading to possible anaerobic conditions as a result.

If pond loadings are such that algal development and the resultant photosynthetic activity can maintain aerobic surface conditions in a primary pond then effluent stabilization is still quite effective even in winter, e.g. on the Highveld.

The amount of stabilization achieved in winter during experiments in Pretoria using 2 ponds in series is reflected by filtered BOD values in Table 5. The primary pond loading during these experiments was 162,5 kg BOD/ha.d .

It therefore appears from these results that, as long as a pond remains aerobic, climatic changes have no marked effect on effluent stabilization as measured by the filtered BOD. This has also subsequently been established by investigations of 14 stabilization pond systems in the Transvaal, Natal and the Eastern Cape, viz. that the range of winter and summer temperatures in South Africa does not seem to affect the performance of ponds very much with

TABLE 5. BOD and nitrogen analysis of pond effluents (Shaw *et al.*, 1962; all values in mg/ℓ)

Year (1961)	Total BOD			Filtered BOD			Total nitrogen as N			NH_3-nitrogen as N			Filtered Kjeldahl nitrogen as N		
	A*	B	C	A	B	C	A	B	C	A	B	C	A	B	C
January	52	19	-	33	18	-	24	11,0	-	12,7	3,2	-	16,6	7,3	-
February	67	22	18	33	16	10	28	13,2	4,1	16,1	7,6	1,7	14,7	11,1	4,1
March	36	19	12	19	5	5	26	11,0	2,8	14,7	5,0	0,8	19,0	7,9	2,1
April	59	25	13	23	13	7	26	14,4	3,0	16,4	5,9	0,9	20,3	9,9	3,0
May	54	15	7	29	12	6	35	26,6	10,6	27,0	20,7	9,5	26,6	23,4	9,6
June	55	10	4	35	8	4	43	34,1	27,9	34,3	30,8	23,4	38,5	33,2	25,0
July	75	16	9	44	11	7	48	38,1	28,4	37,5	34,0	26,6	41,7	37,8	28,1
August	56	22	5	38	15	4	48	41,8	30,8	36,9	36,8	29,1	40,6	39,0	30,6
September	55	10	14	27	4	8	43	43,4	24,3	31,7	34,2	19,5	35,5	37,9	21,3
October	66	15	13	22	10	7	35	34,0	9,0	22,3	31,4	5,6	27,6	33,2	7,4
November	57	60**	21	22	6	15	26	42,0**	11,8	15,8	15,6	8,6	19,7	19,5	11,1
December	77	46**	21	9	5	7	31	27,7**	12,5	12,8	12,1	5,2	16,3	13,6	71
Annual mean	59	23	14	28	11	7		28,1	15,0	23,6	19,8	10,9	26,4	22,8	12,4

*Ponds A, B and C are in series. **Dense algal growth in Pond B.

respect to COD, OA and N removal, which was the case with 11 out of 14 systems (Drews, 1982). Ponds often seemed to have clearer and better effluents in winter than in summer.

In summer the enhanced algal activity, by elevating the pH, has a beneficial effect on the effluent quality by reducing the ammonia nitrogen content. In the subsequent investigation it was found that 8 out of the 14 pond systems indicated ammonia-N removals to less than 3 mg/ℓ even in winter, this in spite of the fact that loadings on the primary ponds of these systems varied from 49 to 300 kg BOD/ha.d, as estimated. It is thought that much nitrogen is also lost by nitrification-denitrification reactions taking place within the system (denitrification in the sludge-layer).

Good phosphate removal was indicated by 7 out of 11 systems - after an initial 'running in' or adaptation period - in many instances to less than 1 mg/ℓ as P. Phosphates will of course be precipitated chemically at elevated pH values depending on the chemical composition of the water, but may also be released again in winter when pH values drop. This also appeared to be indicated by results from recent investigations (internal report).

Wind effects

Apart from wind effects providing for mixing of the pond contents a pond containing, say, low dissolved oxygen concentrations would have these increased by wind action; on the other hand if the water is supersaturated with oxygen (relative to air) owing to algal activity, the wind would tend to reduce or strip some of the excess oxygen from the water body. Dissolved oxygen in an algal active pond is by no means uniformly distributed unless the pond is well mixed mechanically or by wind.

Evaporation losses from ponds

The effect of evaporation from a pond system is often neglected in the design, as the effect for a system with normal outflow is very small (Shaw, 1961), but it could be very important in warm areas with high evaporation rates, especially when ponds are unloaded or overdesigned (see the section on *Detention Time*, p. 13).

All these climatic factors influence one another and therefore the effects may be very variable and are uncontrollable.

Seepage losses

Seepage losses from ponds would affect performance only in that detention time would be proportionately increased and the rate of build-up of pond salinity, reduced.

It is obvious from data presented in Table 6 that seepage losses can be high and vary over a wide range according to the geology of the pond base and the composition of soil used in the construction of the walls. Consequently, the prevention of pollution of underground water supplies and the curtailment of losses where the reclamation of water for reuse is of primary importance, necessitate that special attention be given to site selection and the sealing of the pond base and walls. (See also *Pond Bottoms*, p. 26.)

TABLE 6. Reported seepage rates from pond systems

Literature source	** INITIAL RATES: Initial seepage rate (cm/d)	Initial seepage rate (m^3.ha.d)	Hydraulic load (m^3.ha.d)	Seepage rate as % of hydraulic load	EVENTUAL RATES: Settling-in period	Eventual seepage rate (cm/d)	Eventual seepage rate (m^3.ha.d)	Hydraulic load (m^3.ha.d)	Seepage rate as % of hydraulic load	Geology of pond base	Place
California (W.P.C. Board)	22,4	2 240	3 550	63	9 months	0,89	89,2	4 270	2,1	Desert soil (sandy)	Mojave California
*Neel and Hopkins, 1956	14,0	1 430	1 600	90	1 year	1,55	155,0	530	29,2	Sand and Gravel	Kearney Nebraska
+Voights, 1955	-	-	-	-	Average over 5 years 1951-55	0,86	86,0	1 030	84	Sandy soil	Filer City Michigan
CSIR (Shaw, 1962)	15,2	1 530	610	Exceeded inflow rate	approximately 1 year	0,76	76,4	560	13,6	Clayloam and shale	Pretoria
Windhoek Mun. (private comm.)											Windhoek S W A
xMaturation ponds nos. 5	0,41	39,3	8 710	0,45	over period	-	-	-	-	Mica and schist	
6	0,43	43,8	13 360	0,32	14-22 June	-	-	-	-	Mica and schist	
7	0,40	3,4	8 000	0,046	1967 after all	-	-	-	-	Mica	
8	0,15	15,7	8 030	0,19	ponds in full	-	-	-	-	Mica and schist	
9	0,58	59,5	5 110	1,15	operation	-	-	-	-	Mica and schist Side wall seepage	

*Evaporation and rainfall effects were apparently not corrected for. Seepage losses were also influenced by a high water table at times.
+These lagoons were constructed in sandy soil with the express purpose of seeping away Paper Mill NSSC liquid
xPonds constructed for the express purpose of water reclamation.
**These figures were converted from British imperial units.

Sludge accumulation and removal methods

Sludge will of course accumulate in the ponds of a system, particularly in those which are the most heavily loaded. The rate of accumulation will depend on the pond loading and the breakdown rate of the sludge in the pond, as affected by pH, toxicity, temperature and other factors. Sludge will eventually build up to such an extent that the pond is no longer functional as a facultative unit, at which point the sludge must be removed.

Primary facultative pond

The build-up of stabilized sludge in a facultative pond is very slow, about 8 cm/a . It is very resistant to further biological degradation and it must therefore be accepted that a primary facultative pond receiving raw wastewater must either be cleaned out or replaced after about 9 to 12 years of continued use since the overlying water then becomes too shallow (less than 0,75 m) for continued satisfactory performance.

The removal of sludge from these ponds should present no problem, since it should be well stabilized and may be amenable to -

- pumping by suction pump mounted on a raft without emptying the pond; or
- lifting either manually or by mechanical means after emptying the pond and leaving the sludge to dry.

Facultative pond with recirculation

It is conceivable that sludge accumulation in the primary pond of the recirculation system will be more rapid than for the normal facultative pond system, so that removal of the sludge from the primary pond of the former system may be required more frequently.

If the system is not a temporary scheme being used while a full-scale works is being planned or under construction, it may be desirable to provide for duplicate primary ponds in parallel so that cleaning operations can be carried out with greater facility. A primary pond with increased depth (say 1,8 m) without reduced surface area would have obvious advantages.

Aerated pond system

The aerated pond is not an activated sludge system in the conventional sense as mixing is not sufficient to eliminate build-up of sludge in basin corners and between aeration units (Hinde, 1965). Aeration is usually applied only near the surface and the slow circulation in the aeration pond permits settling of solids and sludge in the bottom of the pond for anaerobic digestion. Although heavier sludge debris will accumulate in the aerated pond, some lighter sludge particles (activated sludge) will be carried over to the second pond where they will settle and degrade anaerobically. Whether and when sludge has to be removed from these ponds can only be established by observation and pond monitoring.

Anaerobic-aerobic (An-Ae) system

(Refer to the section on *Sludge Accumulation*, p. 16).

Before sludge is removed from a pond to a sludge lagoon or onto land for ploughing in or for composting, it should be left to stand for some time (3 to 4 weeks) to allow anaerobic stabilization of the sludge to proceed.

Night-soil oxidation ponds

(Refer to the section on *Introduction of Night-soil and Desludging* p. 20).

When well stabilized, this sludge can be ploughed in on land or used for composting and the compost placed on land to be ploughed in. When the night-soil pond becomes anaerobic even when kept full of water it is either being overloaded or it needs desludging. If the pond is correctly loaded, sludge should accumulate at more or less the same rate as for the facultative primary stabilization pond.

Maturation ponds

When the sludge separation units prior to maturation ponds are working efficiently, there would be negligible accumulation of sludge in these ponds. However, it has been found that in practice this is not always the case and it can happen that considerable amounts of sludge, which is often light, are accumulated. If this sludge does interfere with the action of the maturation pond system, it might be pumped to primary settling on the works or to land and ploughed in.

7. HEALTH ASPECTS

Impact of pond systems on environmental health

The high building and maintenance costs of conventional wastewater purification plants and the highly skilled supervising staff required, as well as the concomitant labour problems, more often than not deter small municipalities and other communal authorities from installing a wastewater reticulation system. If the economy resulting from the use of stabilization ponds could therefore be a factor in enabling a town to install water-borne sanitation at a much earlier stage than would otherwise be possible, environmental health would benefit.

A primary stabilization pond effluent is similar in bacteriological quality to humus tank effluent. If, therefore, the introduction of a stabilization pond brings about the disappearance of a large number of individual pit latrines or septic tanks, or the trenching of night-soil and the associated regular and unhygienic removal of sanitary pails, then these facilities would have been exchanged for something infinitely more acceptable.

The same argument is put forward with reference to the aqua privy which, if it functions properly, has many attractive features and advantages such as economy, low water consumption, hygienic operation and simplicity of use, but which fell into disrepute for reasons described by Vincent *et al.* (1962). However, these units have been put to good use in combination with stabilization ponds to provide sanitary facilities for unsophisticated communities.

After a stabilization pond system has been put into operation, the time required to fill the ponds is such that no effluent is discharged until the biological associations have been well established and a good quality effluent has been ensured.

As far as virus removal is concerned, stabilization and maturation ponds seem to be greatly superior to conventional works, provided both systems are loaded only to design capacity. Malherbe and Strickland-Cholmley (1965a) established that reovirus and enterovirus were not significantly affected by the conventional purification processes between wastewater influent and secondary humus tank effluent. In contrast, only occasional low level reovirus and enterovirus isolations were made from maturation pond effluents (Nupen, 1974). This may be of importance in view of the conflicting findings which have been reported on the efficacy of virus destruction in effluents by means of chlorination (Weidenkopf, 1958; Carstens *et al*, 1965; Marais *et al.*, 1967).

The removal of viruses probably depends upon their adsorption onto static surfaces and their exposure to the rays of the sun. According to Malherbe and Coetzee (1965), it is concluded that from a virological point of view, a pond system should be as shallow as possible and so extensive that the retention period exceeds the normal survival time of an infectious virus. This stresses the importance of preventing short-circuiting and points towards the necessity of having a number of ponds in series.

The role of birds

It is conceivable that birds exposed to human faecal contamination might transport human pathogens mechanically to an impoundment reservoir but it is considered that the danger to human health would be slight because the water would provide an imperfect medium for bacterial growth. In this regard ponds present no greater source of contamination than, for example, would irrigation lands receiving wastewater, biological filters or garbage heaps to which birds may be attracted.

Birds may, however, act as reservoirs for arthropod-borne viruses which may be conveyed to man by mosquito vectors. It should be noted that arboviruses are entirely distinct from the enteric viruses occurring in wastewater, and are only transmitted to man by mosquitoes which have fed on infected birds. Birds attracted to bodies of water of any kind can act as arbovirus reservoirs, and the practical solution to this problem therefore lies in mosquito control.

Groundwater pollution

Groundwater pollution from seepage must always be regarded as a possibility. From tests reported in the literature (Malan, 1962) it would appear that where the pond bottom is in the zone of aeration above the watertable, the migration of bacterial pollution would be slight (of the order of 6 m). Where seepage from the pond is directly into an aquifer, bacteria may migrate for several hundred metres, the migration generally being in the direction of flow of the groundwater.

In certain geological formations, where the groundwater travels in fissures or channels, instead of permeating slowly through the soil or rock pores, the possibilities of dangerous pollution of underground waters are much greater.

Mosquito control

Apart from constituting a health hazard in some areas of South Africa, mosquitoes have a tremendous nuisance value and should not be allowed to breed freely in ponds.

Oil should not be poured on the surface of a pond as it would interfere with the transfer of oxygen from the atmosphere. However, in an emergency an insecticide could be sprayed in normal quantities around the perimeter of a pond without any serious deleterious effect.

The best mosquito control lies in the prevention of breeding, which can best be achieved by keeping the ponds clear of emergent and peripheral vegetation, and having the ponds exposed to wind action. Various investigators (Beadie and Rowe, 1960; Myklebust and Harmston, 1962; Loedolff, 1963; Scovill, 1963) have found that, under such circumstances, no significant mosquito-breeding can take place. Emergent vegetation normally presents no problem in ponds of 1,2 m or greater depth.

Fly breeding

This would only occur where there are sludge accumulations or other debris on water surfaces. In well-run stabilization, maturation and night-soil ponds, where floating debris is regularly removed and buried, there should be no danger. Fly-breeding can, however, occur in the sludge on anaerobic ponds and steps should be taken against this. Fly traps placed on the perimeter of the ponds will only partly remedy the situation (see p. 16). Screenings, detritus and organic material taken from the ponds should not be allowed to lie around on pond walls and embankments as flies are attracted to this material.

Bilharzia

Hodgson (1961) investigated the snail vectors of Schistosomiasis in a pond in Rhodesia (Zimbabwe) and found that the environment in an oxidation pond is not conducive to their propagation.

Parasites

Ova and cysts have a specific gravity of approximately 1,1 (Liebman, 1964) which would seem to cause their settlement in pond systems of long detention times. Over a year of observations on a stabilization pond series at Lusaka (Marais, 1966), no helminths, cysts or ova were found in the effluent. These findings were also confirmed elsewhere.

Reliability of pond systems

For the various pond systems, the absence of mechanical aids such as pumps and distributors makes the functioning of the systems independent of mechanical faults, corrosion and power failures (except for aerated and recirculation systems). Shock loadings are absorbed much more effectively than in conventional wastewater purification plants and much balancing out of fluctuating flows occurs. Pond systems are simple to maintain and skilled supervision is not required on a continuous basis. In South Africa with its open spaces and sunshine, but where of necessity capital must be conserved and where there is a lack of skilled labour, a priceless opportunity was offered for improving health conditions.

Maturation ponds (which include the secondary ponds of a stabilization pond system) constitute an excellent safety barrier against dangerous pollution when the conventional plant breaks down. Stander and Meiring (1963) stated that the degree of safety (as indicated by the faecal coliform count) that can be obtained in maturation ponds was comparable to that of chlorinated sand filtered effluent.

Chlorination of the pond effluent

Whether pond effluents should be chlorinated or not depends to a large extent on the manner of disposal of the effluent. Effluents from maturation ponds (also maturation rivers) are usually chlorinated since they are discharged to rivers and have to comply with the General Standard. If maturation ponds contain free-floating algae, trouble can be experienced in achieving sufficient chlorination and compliance with some of the other parameters of the standards. Stabilization pond effluents are seldom chlorinated because of the expense, and are usually supposed to be irrigated and not just run into the veld. A permit is required from the authorities to irrigate the effluent on suitable land. Chlorination is then usually not required since it would be highly impractical and very cost ineffective to achieve adequate disinfection. It has been found by Jackson and Rose (1979) that the chlorine does not destroy the coliform indicator organism but only oxidizes the algal aggregates. These should therefore be removed before chlorination is applied.

However, to prevent the spread of water-borne disease, it is imperative that stabilization pond effluents, especially from hospitals and medical clinics, be chlorinated even if they are only irrigated on land.

8. QUALITY, UTILIZATION AND FINAL DISPOSAL OF EFFLUENTS

Effluent quality

Using faecal coliforms as a yardstick, the bacteriological purification of a primary stabilization pond is of the same order as that obtained in a conventional wastewater purification plant. As it is also possible to place the design of the secondary ponds on a rational basis and to calculate the number of ponds and the detention time in each necessary to produce an effluent of a high quality, a stabilization pond system can be designed to achieve the same bacteriological purification as that obtainable in a conventional wastewater treatment works-maturation pond combination.

Although a faecal coliform count of zero per 100 mℓ cannot usually be obtained in maturation ponds, the degree of safety (as indicated by the faecal coliform count) that can be obtained is comparable with that of chlorinated sand filtered effluent (Stander and Meiring, 1963). As a final safety barrier, maturation ponds offer better security. It is emphasized, however, that these results are unlikely to be attained unless the design requirements contained in this *Manual* have been met and the ponds are satisfactorily maintained at all times.

Various workers have reported that in cases where *Mycobacterium tuberculosis* was present in the wastewater inflow, they have been unable to isolate this bacterium from a secondary stabilization or maturation pond effluent, in the latter case even when 10 ℓ quantities were flocculated and the sediment investigated (NIWR, 1965).

It seems reasonable that purified effluent destined for various purposes should comply with faecal coliform limits related to these purposes. In this regard it is necessary to take cognizance of the extent to which all natural water courses in Natal, for instance, are polluted (Kemp *et al.*, 1966). Such background information puts the upper 97,5% confidence limit of 1 000/100 mℓ (see the section on *Effluent Quality Requirements*, p. 18) in its true perspective:

Kemp *et al.* (1966) took 50 faecal coliforms per 100 mℓ and a total plate count of 5 000/mℓ (5 days at 32 °C) as the upper limits of Class I water which, with only simple disinfection, should be suitable for drinking. It appears that only in the upper reaches of the Tugela River (near the Amphitheatre in the Drakensberg) can a natural water of Class I bacteriological quality be found. It is also indicated that, even if all known sources of pollution were eliminated, no additional rivers would be placed in Class I. In general, the rivers draining the rural areas of Natal are Class II waters; i.e. do not contain more than 1 500 faecal coliforms per 100 mℓ and are suitable for drinking after conventional treatment.

The quality of final effluents from the various types of pond system will not prevent enrichment of a natural body of water, nor will it at all times comply in all respects with the requirements of the General Standard promulgated in terms of the Water Act. More important, however, as viewed from an environmental health point of view, is the abatement of bacterial pollution and the improvement in sanitary conditions as effected by the installation of stabilization ponds in preference to septic tanks, french drain systems and night-soil disposal practices.

Similarly, maturation ponds which serve as a further treatment stage to the effluents from a conventional wastewater treatment works bring about biological improvement, nutrient removal and reduction of the bacterial population in an open but controlled body of water. Where maturation ponds are not used, this task remains to be fulfilled by public waters (rivers or lakes).

Furthermore, all pond systems have an excellent buffering capacity for balancing out excessive peak flows, and therefore daily variations in the quality of effluent are likely to be greater for a conventional system than for a stabilization pond system.

A performance schedule for the various types of pond systems constructed in accordance with the design criteria recommended in this *Manual* is given in Table 7. The schedule applies almost entirely to the treatment of domestic wastes. If considerable quantities of industrial wastes are taken into a pond system, it cannot be expected that the pond effluents will necessarily show the performance delineated in the schedule.

Irrigation of pond effluent

Because the quality of the effluent from stabilization ponds does not usually comply with the South African General Standard (South Africa, Republic, 1962) in all respects, the Department of Environment Affairs (formerly Water Affairs) is not inclined to permit its direct discharge to streams, but may then have to permit irrigation of the effluent under controlled conditions. In such instances, only the overflow from the last pond may be irrigated. If lengthy rainy periods occur in an area a further irrigation or storage dam, up to 14 days retention capacity, may be required.

Discharge to rivers or other receiving water

As indicated above, discharge of pond effluents into receiving water is not favoured by the authorities. The presence of dense algal concentrations in pond effluents is a feature which, in many instances, renders the effluent unsuitable for reuse or discharge into a water course since a maximum of 25 mg/ℓ suspended solids and 75 mg/ℓ COD is specified in terms of the General Standard.

Removal of the algae from the effluents, especially from stabilization ponds, generally does not lower the biochemical quality parameters sufficiently to make them comply with the General Standard. The reason might be that some concentration of non-degradable COD takes place owing to evaporation at long retention times. This concentration would be much less in maturation ponds where the retention time may be only about a quarter of that for stabilization ponds. Discharge of maturation pond effluent to rivers is therefore more likely to be permissible than stabilization pond effluent, even if algae concentrations here are low or have been removed (see Chapter 10).

TABLE 7. Performance schedule for ponds in South Africa

The table gives expected effluent qualities (showing maximum values) from stabilization ponds and maturation ponds constructed in accordance with recommended design criteria (not including algae flotation).

PARAMETER (mg/ℓ except where otherwise stated)		Effluent composition	
		Stabilization ponds	Maturation ponds
		For raw and settled wastewater, septic tank and aqua privy effluent	For well-nitrified secondary effluent
Colour, taste and odour		Not objectionable	Not objectionable
pH	(range)	7,0-10,5	7,0-10,5
Temperature, °C	max.	30	30
Dissolved oxygen, % sat.	min.	75	75
Faecal coliform bacteria	max.	1 000/100 mℓ (97,5% probability)	1 000/100 mℓ (97,5% probability)
BOD_5	max.	16	12
BOD_5 on filtered sample	max.	12	8
COD (total)	max.	150	120
COD (soluble)	max.	120	100
OA (total)	max.	20	15
OA (soluble)	max.	15	10
Ammonia nitrogen	max.	10	10

Reuse in industry

Except for certain applications such as coal washing, coke quenching, ore-flotation and cooling, pond effluents would have to be further treated in accordance with the quality required for the particular application.

9. OPERATION AND MAINTENANCE

Although skilled manpower is not required for routine operation, maintenance and supervision of a pond system, certain matters should be regularly checked and seen to.

Operation

Depending on the size of the system there should be one or two unskilled operators at the ponds regularly to -

- attend to the screens and detritus channels;
- record the flows once a day if a meter has been installed;
- keep the embankments free of vegetation, especially at the verges;
- look out for leakage from rat and crab holes and close them up; and
- clear floating debris from pond surfaces and clean overflows if necessary, and bury all screenings, detritus and extraneous material in prepared holes.

Daily inspection

Although the unskilled workers have these tasks to attend to, they should also be taught to inspect the pond system regularly, preferably once every day and report any untoward matter to the authority; e.g. -

- when there is a strong leak from any of the ponds;
- when the protection fence is broken;
- when a heavy storm has washed soil into a pond and stormwater has access to the pond system; and
- when the chlorine cylinder is becoming empty and needs replacement, if applicable, or when anything else has gone wrong with the chlorine dosing.

In the past, chlorination was usually applied only to maturation pond effluents (generally under control of the works manager). Lately, because of the occurrence of cholera in some areas, stabilization pond effluents are also being chlorinated, especially those treating rural hospital effluents.

Infrequent inspection

Skilled checking of the pond system need be carried out only very infrequently, say once a month, which would involve the following:

- Checking on the work of unskilled workers.
- Checking meter flow readings and meter calibration.
- Collection of samples of the influent to every pond and of the final effluent for sanitary analysis to check on pond loading.
- Observations of smell and colour of each pond especially the primary pond, as a further check for possible overloading.
- Measurements of pH and dissolved oxygen to confirm the observations indicated by smell and colour.
- Checking and maintaining any pumps or recirculation pumps.
- Checking on performance of the chlorination unit, where applicable.
- Checking on any other matter that might need attention.

10. ALGAE HARVESTING

Need for algae removal

Sewage stabilization and effluent maturation in algal ponds provide the public health engineer with a low-cost and efficient means to facilitate the introduction of water-borne sanitation in many places where such a forward step to improve environmental health conditions would otherwise not have been possible. However, the occurrance of dense algal concentrations in the effluent in many instances renders it unsuitable for reuse or discharge to a water course.

Technology for removal of algae

A feasible means of removing algae from a maturation pond effluent by dissolved air flotation has been developed (van Vuuren *et al.*, 1965) which can also be applied to stabilization ponds as a means of wastewater purification.

Pilot plant work to study the feasibility of drinking-water reclamation from wastewater (Cillié *et al.*, 1966) has demonstrated vividly the important advantages to be derived from satisfactory algae removal from maturation pond effluents since the conventional water treatment process of flocculation/sedimentation followed by sand-filtration has proved quite inefficient for this purpose.

A more recent development is to use a polyelectrolyte for flocculation of algae biomass. This has the advantage that the increase in total dissolved solids, as a result of high chemical dosages, can be eliminated.

Another promising feature is to simplify the flotation technique by utilizing the supersaturated oxygen when present to effect buoyancy of floc. This can be achieved in a flotation channel from where the scum layer can be removed manually to eliminate costly mechanical equipment. Design criteria for this mode of treatment have, however, not yet been finalized.

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APPENDIX

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