DEPARTMENT OF WATER AFFAIRS & FORESTRY

CODE OF PRACTICE: VOLUME 2

POND SYSTEMS

GENERAL GUIDELINES

(July 2008)

CONTENTS

TERMS FREQUENTLY USED

General

Aerobic: Condition/environment where adequate free oxygen is available for aerobic microorganisms to grow – the electron acceptor is molecular oxygen (O_2) and latter is reduced to water (H_2O).

Anaerobic: Condition/environment lacking oxygen where only anaerobic microorganisms can grow – no O_2, NO_2^- or NO_3^- is present and the organism generates its own electron acceptor internally.

DWAF: Department of Water Affairs and Forestry.

Facultative (Pond): Pond where aerobic conditions prevail at the surface and anaerobic conditions prevail in the bottom sediment.

PE: Population Equivalent. This term is used to express the total flow and load discharged into a sewage works in terms of population, e.g. number of users.

Primary: Generally the first stage of a treatment process.

Pond System: System of dams that are designed to receive and treat wastewater, utilising mainly natural resources, e.g. solar energy, algae and a variety of microorganisms, to physically and biologically remove solids, organic matter, nutrients and reduce pathogens. Often called lagoons, e.g. USA.

Retention Period: Average time that a liquid or solid is retained in a containment structure.

Secondary: Treatment process that follows the primary treatment stage.

Tertiary: All treatment processes that follow after secondary treatment.

Chemical

BOD: Biodegradable Oxygen Demand = measurement of oxygen utilized by microorganisms during oxidation of organic material contained in wastewater.

BOD_5: Oxygen utilized within 5 days (BOD_5) of microbial activity. This duration was selected to minimize the effect of nitrification.

COD: Chemical Oxygen Demand = measurement of the amount of oxidisable organic matter, *viz* the amount of oxygen required to convert all organic carbon constituents to CO_2 and H_2O.

DO: Dissolved Oxygen = measurement of the dissolved oxygen available in a water body.

DOL: Daily Organic Load = people served times BOD or COD discharged per person per day.

Flow

ADWF: Average Dry Weather Flow = average total quantity of sewage received per day divided by 24 hours.

PDWF: Peak Dry Weather Flow = maximum flow during peak hours. Generally assumed (if not specifically measured) as twice the ADWF.

AWWF: Average Wet Weather Flow = average flow during the rainy season, which includes rain- and groundwater infiltration into the sewer. Generally assumed (if not specifically measured) as three times ADWF.

1. INTRODUCTION

In the Water Resources Management Act, 2004 (Act No. 24 of 2004), there are conditions laid down to ensure that proper wastewater treatment is provided and to facilitate good operation of different sewage treatment systems and their methods of disposal. The act's main objectives are to use and protect one of our most valuable natural resources, namely water, and to encourage reuse of the treated effluent.

Biological treatment processes, which include activated sludge processes, trickling filters (biofilters), oxidation ponds and even the self-purification powers of rivers, all operate on essentially the same fundamental biochemical principles. They differ from one another primarily in the method of adding and utilising dissolved oxygen. In this manual, pond systems as a biological treatment process will be addressed. There are many different pond systems in use throughout the world, with the most common names being anaerobic/aerobic-, stabilisation-, oxidation-, facultative-, algae-, evaporation- and maturation ponds.

The construction, operation and disposal off effluent using of a pond system is subject to a wastewater discharge permit from the Department of Water Affairs and Forestry (DWAF).

Generally, open ponds can not produce a final effluent complying with the currently applicable Namibian standards for effluent discharge, *viz* the General Standard of Act No. 24 of 2004. Therefore, final effluent produced by a pond system will not be allowed for discharge into the environment. However, this effluent would be suitable for limited reuse, provided maturation ponds and proper disinfection is included. Limited reuse would typically include gardening, lawns, sports fields and certain agricultural produce. Where new ponds are constructed and the final effluent is not reused for irrigation, they should be of sufficient size (area) to ensure that all water is evaporated. Since water is a scarce commodity in Namibia, reuse thereof is strongly encouraged. A reuse permit obtainable from the Department of Water Affairs is required for this purpose.

Certain sections of a pond system need to be lined with an impenetrable artificial material to prevent infiltration into the soil and possible contamination of the groundwater. This aspect is very important to protect our scarce potable water resources and is addressed in this manual.

Pond systems may only be considered if the ultimate load does not exceed 5 000 PE (population equivalents) or 800 kℓ/d (DWA, 1978).

From a health point of view, there is little difference between pond effluent and raw sewage (DWA, 1987; Pivelli *et.al.*, 2008) and the premises on which the ponds are constructed should therefore be properly fenced-in at all times. Humans and animals should be prevented from accessing the fenced-in area. Pond effluent should be regarded as a great potential danger to public health and animals.

Please note, these guidelines only apply to pond systems on its own, where no advanced treatment is provided downstream. Where a pond system forms part of an advanced treatment system, the design parameters thereof may be altered to suit the overall treatment system of the supplier.

This manual addresses treatment of wastewater by means of pond systems. It includes design information and strives to present information that may be helpful to owners and operators of pond systems, individuals performing compliance inspections, sampling and writing or assessing technical reports on which permit conditions are based.

2. DEFINITION AND BACKGROUND INFORMATION

Some background information on sewage characterisation needs to be given before the principles of biological filtration can be further elucidated.

2.1 DOMESTIC SEWAGE CHARACTERISATION

Domestic sewage is a diluted suspension of human discharges in water. The polluting material is mainly of an organic nature (organic carbon) and ammonia nitrogen (main constituent of urine). Organic material consists of a soluble and insoluble portion, each again with a biologically degradable and undegradable fraction.

The strength of sewage is indirectly obtained by determining chemically the amount of oxygen required to fully oxidize organic and inorganic matter to carbon dioxide and water. The load placed on a treatment plant varies substantially throughout a typical day and week and, to design a new plant, a wastewater expert should rather be consulted to determine the flow and make-up of sewage for each particular set-up.

2.1.1 FLOWRATES

The amount of sewage generated is classified in terms of different flows that can reach a treatment plant and is expressed as:

- AVERAGE DRY WEATHER FLOW (ADWF). The average dry weather flow is the average total quantity of sewage received per day divided by 24 hours and must be averaged over 12 months. For example, average sewage received over the last year was 10 m³ a day:

  ADWF = 10 000 ℓ/d ÷ 24 h = 417 ℓ/h; Design for ADWF = 420 ℓ/h

- PEAK DRY WEATHER FLOW (PDWF). Peak dry weather flows are maximum discharge figures into a plant (or septic tank) during a specific day when it is not raining. It is usually assumed that this figure is double the ADWF. From above example:

  PDWF = 840 ℓ/h

- AVERAGE WET WEATHER FLOW (AWWF). The wet weather flows are maximum flow rates recorded during the rainy season and include infiltrated (rain) water into the sewer. It is usually estimated to be three times the average dry weather flow. From above example:

  AWWF = 1 260 ℓ/h

Please note, care must be taken in the design and lay-out of a town to prevent stormwater from being collected and directed into the sewage reticulation network. This specifically applies to stormwater run-off on individual premises, roads, parking areas and sports fields. Reason being, that stormwater, if discharged into a treatment plant, places a high instantaneous hydraulic load on the plant (for which treatment plants are not designed) and will result in washout of micro-organisms especially in submerged-growth systems such as activated sludge plants.

2.1.2 LOAD (SEWAGE STRENGTH)

The strength of sewage arriving at treatment works varies considerably, depending largely upon the domestic living standards of the contributing population. Main constituents taken into consideration to characterise sewage include:

- Oxidisable organic material, or substrate e.g. COD or BOD;
- Nutrients, mainly N and P;
- Solids concentration.

The loading of a treatment plant is the quantity of polluted water (flow and organic matter) that will flow into the system per day and determines the size of the system. The following are the most common parameters used to measure organic matter:

- Chemical Oxygen Demand (COD)

  The COD test measures the amount of oxygen required to chemically oxidise organic compounds in the wastewater to carbon dioxide and water. Pond system designs are based on the daily COD load that is discharged into the ponds. It is therefore important to obtain a fairly accurate figure for design purposes. The test itself takes about 4 hours.

- Five-day Biochemical Oxygen Demand (BOD_5)

  The BOD test measures the quantity of biologically degradable organic matter in a wastewater in terms of the amount of oxygen required by microorganisms to oxidise it to carbon dioxide and water. The test is usually conducted over a period of five days and therefore called BOD_5.

In domestic sewages there is a fairly constant COD/BOD_5 ratio of about 2:1. As a general approximation, it may be assumed that the organic load discharged by humans is approximately 100 g COD per person per day.

A wastewater expert should be consulted to determine the make-up, volume and strength of sewage for each particular set-up. COD and BOD tests are complex and should be undertaken by an approved and recognised (in the wastewater treatment field) analytical laboratory only.

2.2 ESTIMATING ORGANIC LOAD

The daily organic load, either expressed as COD or BOD, is used as the main design parameter for sizing pond systems. This figure can be estimated from the number of people that discharge wastewater into the pond system but may vary depending on the diet and social structure of the population served. For design purposes the load estimation criteria as given in Table 1 can be used.

TABLE 1. Load Estimation Criteria (Voysey 1988) per Capita

Type of Area Serviced	Hydraulic load l/p*/d	Organic load (g BOD/p*/d)	Organic load (g COD/p*/d)
Affluent residential area, fully sewered	135-200	54-60	115-130
Residential area with denser housing > 20 houses/ha, fully sewered.	80-150	50-56	105-120
Conservancy tank, contents carted to ponds, with bathrooms, basins and kitchen sinks connected.	80-150	45-54	96-115
Conservancy tanks (or septic tanks) with no bathwater, basins and kitchen sinks connected.	50-60	35-40	75-85
Townships with water supply standpipes and externally collected wastewater.	50-60	35-45	75-96
Schools – no boarders	20-30	20-30	40-60

* p denotes person (= per Capita)

Average concentration of the BOD of raw municipal sewage discharged into a treatment plant system can be calculated using Table 1 as follows:

$$P_o = (b/q).10^3$$

Where: P_o = BOD concentration in the influent to the pond (mg/l)
b = BOD contribution per person per day (g BOD/p/d)
q = Effluent discharged per person per day (l/p/d)

2.3 INDUSTRIAL WASTEWATERS

There is no "typical" composition for wastewaters discharged by different industries. The COD of an industrial effluent can be as low as 100 mg/l, or even as high as 350 000 mg/l (e.g. synthetic petroleum industry). Also, when comparing wastewaters discharged by similar industries but in different plants, large discrepancies in constituents have been found to exist. The reason being, that even a small change in water management policy by the individual plant operators can result in totally different compositions and volumes of final effluent being produced.

For design and evaluation purposes each industrial plant must therefore be treated as unique and a full assessment of each effluent stream of its **COD and especially BOD** must be undertaken. Table 2 shows how the relationship between COD and BOD values can differ even in the medium to low COD-ranges of various industrial effluents when full biological treatment is employed. However, it needs to be stressed that these are indications only and each effluent needs to be analysed to determine its true composition and biodegradability.

TABLE 2. COD, BOD relationships for different Industrial Effluents (Eckenfelder, 1996)

	Influent		Effluent	
Wastewater	**BOD (mg/L)**	**COD (mg/L)**	**BOD (mg/L)**	**COD (mg/L)**
Pharmaceutical	3,290	5,780	23	561
Diversified Chemical	725	1,487	6	257
Cellulose	1,250	3,455	58	1,015
Tannery	1,160	4,360	54	561
Protein Process	3,178	5,355	5	245
Tobacco	2,420	4,270	139	546
Paper Mill	380	686	7	75
Vegetable Oil	3,474	6,302	76	332
Vegetable Tannery	2,396	11,663	92	1,578
Hardboard	3,725	5,827	58	643
Saline Organic Chemical	3,171	8,597	82	3,311
Coke Ovens	1,618	2,291	52	434
Coal Liquid	2,070	3,160	12	378
Textile Dye (organic base)	393	951	20	261
Kraft Paper Mill	308	1,153	7	575

3. POND SYSTEMS/TYPES

3.1 BACKGROUND

Wastewater treatment ponds are designed to treat organic wastewaters by natural purification through both anaerobic and aerobic processes. Latter processes are mutually interdependent and are maintained by different microorganisms, which have the ability to effectively break down and utilise complex organic waste materials. Algae (together with fungi) utilise simple degradation products while producing the oxygen required by the aerobic bacteria for respiration. This is called symbiosis. Pond systems rely on the natural self-purification process and are therefore subject to external climatic influences, for example sunshine, temperature and wind action. The longer the exposure of the wastewater to favourable external conditions, the better the purification is likely to be. Figure 1 shows the complex algal and bacterial interdependence in such systems and the influence that external climatic conditions can have thereon.

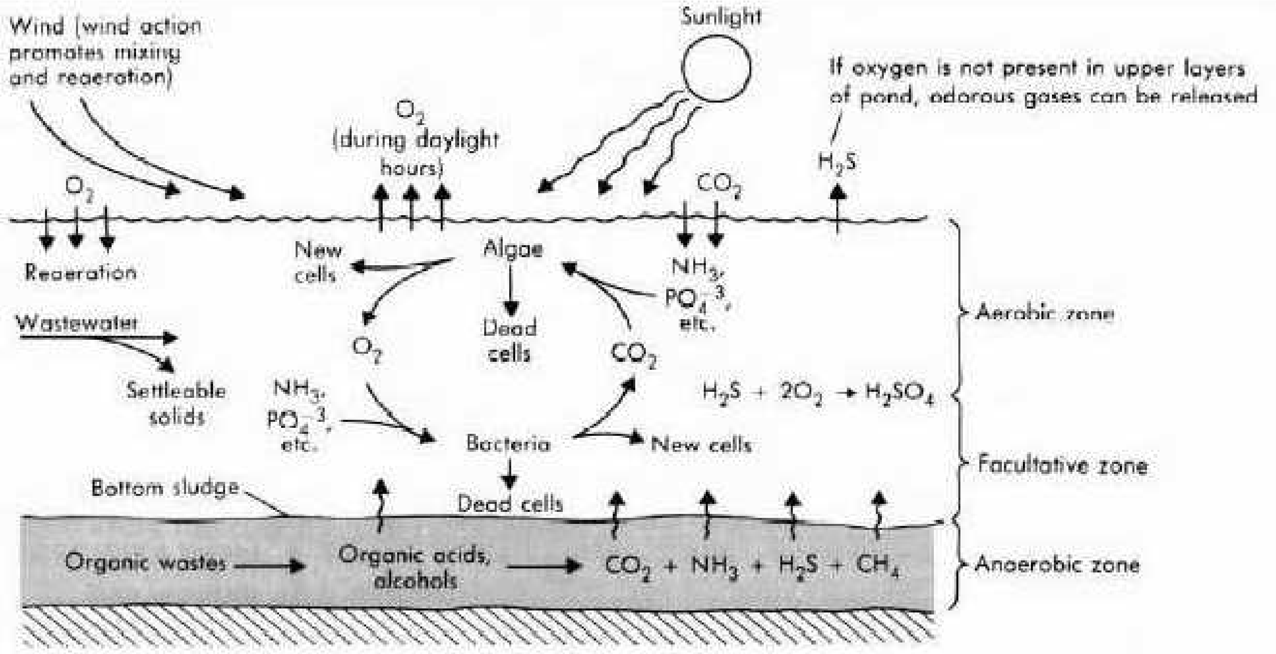


Figure 1. Interdependent processes in pond systems (Tchobanoglous and Schroeder, 1987)

A complete pond system for sewage treatment consists of an anaerobic section/pond(s), followed by a facultative section/pond(s) and aerobic section/pond(s). A maturation pond is often added to serve as polishing step if the final effluent will be reused.

Whereas pond systems mainly remove biodegradable organic material (reduce COD and BOD), they do not achieve good ammonia-nitrogen removal rates and can not be used for biological N and P removal. Also, the soluble BOD of the final effluent will be low, but total SS and total BOD will be high, which is attributed mainly to algae. Thus, the final effluent from a pond system can not achieve the required final water standards required for final effluent discharge.

DWAF does not allow any final effluent from a pond system to be discharged into the environment or to be disposed of into a river for the above-mentioned reason. Additional treatment can be provided to produce a final effluent acceptable for discharge to the environment.

The following section will discuss different types of ponds in general, whereas Section 4 will give specific design parameters and criteria to size such ponds.

3.2 BIOLOGICAL PROCESSES EMPLOYED IN PONDS

Pond systems designed for proper wastewater treatment are primarily made up of a series of individual ponds the following biological processes/treatment:

3.2.1 ANAEROBIC TREATMENT

The first set of ponds in a series of waste stabilisation ponds employ anaerobic treatment and are also called anaerobic and/or primary ponds. Since they receive all raw sewage, they are heavily loaded with organic matter and completely anaerobic conditions prevail. Anaerobic ponds are used for partial decomposition of complex organic matter and do not depend on photosynthetic algal action. They are therefore constructed deeper than other ponds further downstream, generally between 2,5 m to 6,0 m deep and are normally sized for a hydraulic retention time between 2 to 5 days. These ponds must be properly lined with a plastic liner (see Section 4) to prevent any seepage into the ground.

Anaerobic digestion relies on the equilibrium reaction between two major groups of microorganisms, *viz* acid- and methane-producing microorganisms. The acid-producing microorganisms hydrolyse (=split) organic solids to form soluble, short chain fatty acids and stable, insoluble residue (humus) as major end products. The methane-producing microorganisms then utilise and convert the fatty acids to methane gas and carbon dioxide. Whereas BOD removal rates between 50% to 80% are possible under tropical conditions with water temperatures not lower than 15°C, a figure not exceeding 60% should be assumed in designs to cater for Namibian conditions.

Anaerobic ponds generally release odours but this can be limited to an acceptable level if alkaline methane fermentation is established so that the predominant species of sulphide present is the odourless bisulphide ion (Mc Garry and Prescot, 1970). A deep pond is more conducive towards the establishment of alkaline fermentation than a shallow one. Odour nuisance may be limited or even avoided by limiting the BOD_5 load to less than 400 g/m³/d (Meiring et al., 1968), ensuring the pH value in the pond remains above 7. When necessary, lime can be added to an anaerobic pond to adjust its pH value between 7 and 8.

3.2.2 FACULTATIVE PONDS

These ponds are also generally known as secondary ponds. After treatment in anaerobic ponds, the wastewater is discharged into the secondary or facultative ponds. Aerobic conditions prevail in their upper layers, while anaerobic conditions prevail in the deeper/bottom layers:

- Suspended solids settle to the bottom of the ponds where anaerobic digestion takes place. About 30% of the total BOD reduction that occurs in the facultative pond, takes place in the anaerobic bottom layer;
- Algae grow in the upper layer and they produce oxygen by photosynthesis. The oxygen is then utilised by aerobic microorganisms whereas the algae again obtain their nutrients from the microbial by-products. The interdependence between algae and microorganisms is called symbiosis.

Because facultative ponds depend on photosynthetic algal action they are constructed not very deep, *viz* between 1,0 to 1,5 m deep. Facultative ponds are laid out as multiple ponds with a combined retention time between 10 and 20 days, of which the first pond should have a minimum retention time of 5 days. These ponds must be lined with a reasonably impenetrable geotextile liner and all necessary caution should be taken that there is no danger of polluting a groundwater source nearby.

3.2.3 AEROBIC PONDS

Aerobic biological stabilization of organic wastes is achieved by microorganisms that need oxygen to proliferate. Adequate dissolved oxygen levels must therefore be maintained in the wastewater at all times. Microorganisms that populate aerobic treatment system include bacteria, fungi, algae, protozoa and other higher animals.

Aerobic ponds are mainly used in algal culture and harvesting rather than ordinary wastewater treatment. They are shallow with a depth between 0,3 to 0,5 m and must be lined with a reasonably impenetrable geotextile liner. All necessary caution should be taken that there is no danger of polluting a groundwater source nearby.

Deeper aerobic ponds are often used for industrial wastewater treatment of organic effluents, but forced aeration is then applied to add sufficient oxygen to the wastewater to ensure aerobic conditions can be maintained. A diverse aerobic microbial culture, not necessarily relying on algae, is maintained in these ponds.

3.2.4 MATURATION PONDS

These are final water ponds that are mainly provided as a polishing step to ensure faecal bacterial removal, after BOD removal has taken place in preceding ponds. The final effluent from these ponds can be reused for gardening and/or limited agricultural application. A permit from the DWAF is required to reuse such water.

The number of maturation ponds required for a certain number of coliforms that need to be removed can be calculated (see later). Maturation ponds are between 1,0 and 1,5 m deep and have a retention time of 5 to 7 days per pond. They should be built on fairly impenetrable soil and all necessary caution should be taken that there is no danger of polluting a groundwater source nearby.

3.2.5 EVAPORATION PONDS

Since pond systems do not produce a final effluent suitable for discharge to the environment, no final outflow is allowed from any ponds constructed Namibia. Therefore, all water reaching a pond system has to be evaporated, if it is not reused. This is achieved by providing ponds with large surface areas to allow for complete evaporation. Sizing of these ponds is based on the evaporation- and infiltration rate and annual rainfall of the area where the ponds are constructed. They must be built on fairly impenetrable soil and all necessary caution should be taken that there is no danger of polluting a groundwater source nearby.

3.2.6 PATHOGEN REMOVAL

Faecal bacteria are mainly removed in facultative and especially maturation ponds whose size and number determine the numbers of faecal bacteria (usually modelled in terms of faecal coliforms) in the final effluent, although there is some removal in anaerobic ponds principally by sedimentation of solids-associated bacteria (Ramadan and Ponce, 2004). The principal mechanisms for faecal bacterial removal in facultative and maturation ponds are now known to be:

- Time (retention time as pathogen attenuation occurs over time);
- Temperature (faecal bacteria dies off increases with temperature);
- High pH (> 9);
- High light intensity together with high dissolved oxygen concentration.

Regarding viruses removal, little is known about the mechanisms of viral removal in pond systems, but it is generally recognized that viral removal occurs by adsorption on to settleable solids (including the pond algae) and consequent sedimentation. Some parasites can be removed as well. Protozoan cysts and helminth eggs are only partly removed by sedimentation. Their settling velocities are quite high (for example, 3.4 x10^{-4} m/s in the case of *Ascaris lumbricoides)*, and consequently some removal takes place in the anaerobic and facultative ponds (Ayres et al., 1992). However, research by Pivelli et. al. (2008) shows clearly that final pond effluent did not, bacteriologically, meet general WHO standards for save discharge and needs additional treatment if considered to be reused. For example, latter researchers have found that *Ascaris* (= lintworm) eggs were observed in 80,8% of pond effluent samples collected, of which 42,3% were found to be viable eggs.

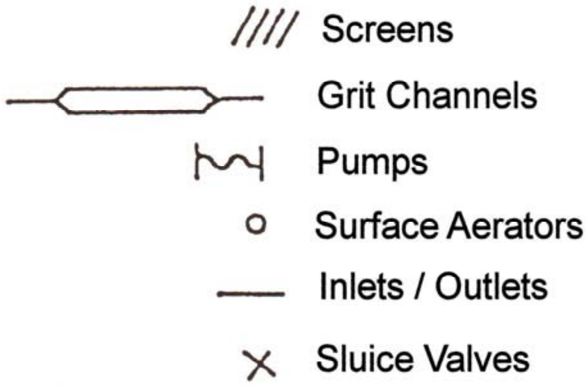
3.2.7 SUSPENDED SOLIDS

The initial biodegradable and non-biodegradable solids from domestic sewage that enter a pond system are well removed due to the low surface flows and long retention times maintained. However, the algae that then again grow in the secondary and subsequent ponds are light and result in suspended solids concentrations of 25 to 75 mg/l found in the final effluent of a maturation pond.

3.3 POND SYSTEMS

Pond systems have been applied with or without internal recycle for the treatment and disposal of domestic wastewater and organic wastes in many different ways. Some of the most commonly employed systems and their basic features will be described below. The different pond systems and recycle flows employed result in a different final quality of effluent produced for each system.

The following symbols were used:



3.3.1 OXIDATION POND SYSTEM

This system generally comprises of a primary pond with a deeper, anaerobic section and two to four secondary ponds. Maturation or evaporation ponds must follow latter. Provision is often made to re-circulate effluent from one of the secondary ponds to the primary pond to obtain a better quality of final effluent. Figure 2 shows this principle diagrammatically.

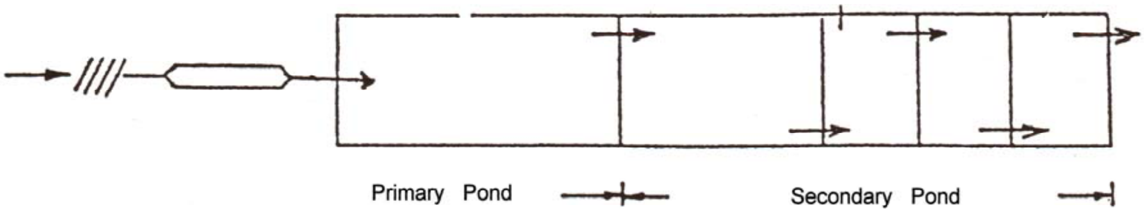


Figure 2a). Oxidation pond system without recycle

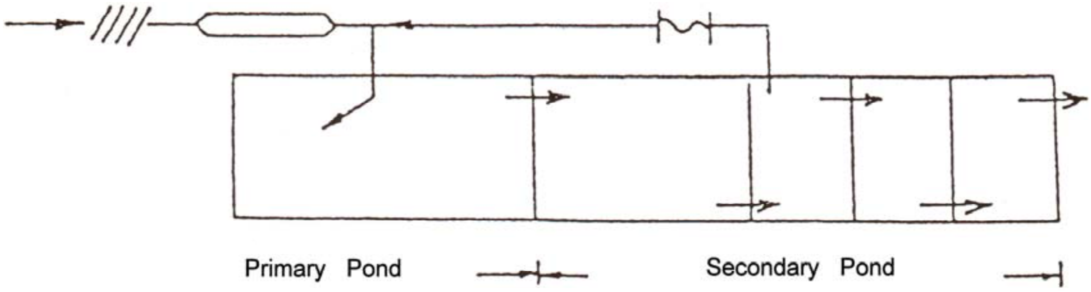


Figure 2b). Oxidation pond system with recycle

Figure 2 Oxidation Pond Systems

3.3.2 FACULTATIVE (ANAEROBIC-OXIDATION) POND SYSTEM

This system as (shown in Figure 3) has one or two anaerobic ponds followed by a primary pond and two to four secondary ponds. The effect of the anaerobic ponds is to significantly reduce the load to the primary pond and will result in a smaller overall system than above (Section 3.3.1).

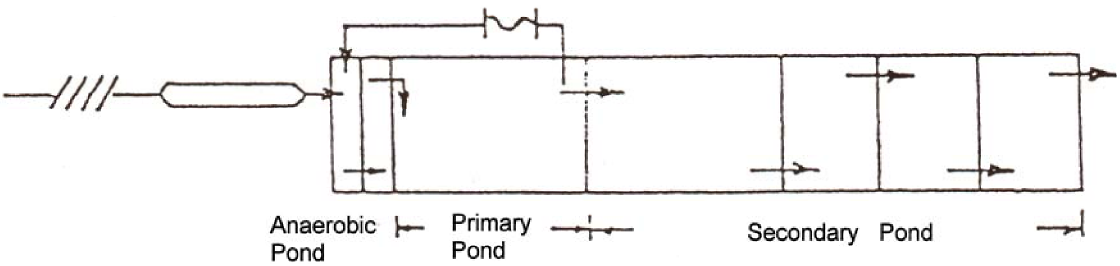


Figure 3 Facultative (Anaerobic-Oxidation) Pond System

3.3.3 AERATED POND SYSTEM

In this system a primary pond smaller than in Section 3.3.2 (above) is provided and the latter is maintained aerobic by means of induced mechanical aeration. Figure 4 shows this principle.

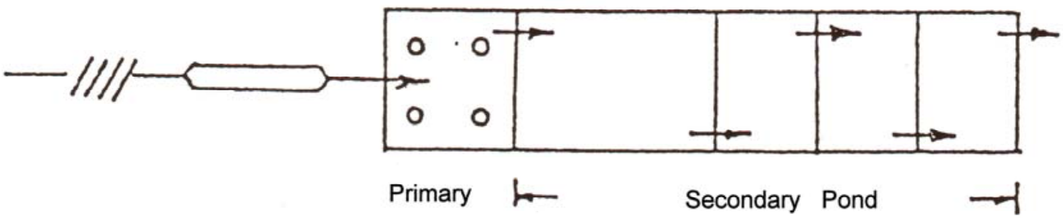


Figure 4 Aerated Pond System

3.4 CONDITIONS FOR USING PONDS

Pond system can be used to treat raw, settled or conventionally treated domestic wastewater, septic tank effluent, night-soil or conservancy tank contents. The final design depends on the treatment objectives and should be carried out by a wastewater specialist. Generally, pond systems are suitable where:

- Climatic conditions are favourable – water temperatures should not drop below 15°C;
- Land is inexpensive;
- The ultimate load does not exceed 5 000 PE's (population equivalents) or 800 kl/d;
- No skilled personnel is available;
- No electricity is available.

4. POND SYSTEM DESIGN

Before considering providing a pond system for a community, suitability of the general set-up and area intended for such ponds should be thoroughly assessed. Fairly accurate figures for the design loading (volume and COD/BOD) should then be established and general climatic conditions of the area intended should be obtained before any design can be considered. For the latter, future needs should also be taken into account, eg. population growth, influx etc.

4.1 SITE SELECTION

Most important considerations for selecting a suitable site include:

- Location. Ponds may not be built closer than 500 m from the nearest residential area and where anaerobic ponds are included, this distance should ideally be increased to 1,0 km.
- Topography. A gently sloping or flat area should be selected to ensure gravity flow from one pond to the next can be maintained. Under no circumstances should ponds be constructed in old riverbeds.
- Impenetrable underground. Ponds must be built on fairly impermeable underground/soil and the embankments must also be constructed from a fairly watertight material/soil. If no such soil is available, this should be supplied from a suitable source closest to the area. Clay or any similar material can be used for this purpose. Please note, for the anaerobic ponds soil (even clay), as only liner, will not suffice and a plastic liner must be installed.
- Ground water table. Areas with high water tables should be avoided - groundwater pollution from seepage or overflows must always be regarded as a high possibility when ponds are employed.
- Wind. Excessive winds should be avoided to prevent mixing of the facultative ponds. Ponds should therefore be constructed with their longest dimension parallel to the prevailing wind direction.
- Population served. Pond systems may only be considered if the ultimate load does not exceed 5 000 PE (population equivalents) or 800 kℓ/d.
- No power lines. Care must be taken that no power lines, above or below ground, cross the area envisaged for the pond system.

4.2 INFORMATION REQUIRED FOR DESIGN

The following minimum, reliable design information must be available for designing pond systems:

- Sewage volume discharged (ADWF and WWF – Section 2.2.1);
- Sewage strength (organic load – COD/BOD – Section 2.2.2);
- Climatic conditions (temperature, wind, rainfall, evaporation rate, sunshine).

4.3 POND DESIGN

It is advisable that a simple pond system, i.e. without internal recirculation or additional mechanical equipment, as per the below description, is provided. Reason being, that the recommended design was developed for typical Namibian conditions, is easy to follow, simple to incorporate and will definitely give a good quality of final effluent if followed conscientiously. Systems deviating from these guidelines will only be allowed if undertaken by a wastewater treatment specialist/consultant who is familiar with pond system designs. Should the reader want more information on advanced pond systems, the publication Design and *Performance of Waste Stabilisation Ponds* by Ramadan and Victor (2004) is recommended.

A complete pond system is shown schematically in Figure 5 and should consist, as a minimum, of the following individual ponds:

- Two Anaerobic Ponds;
- One Primary Pond;
- Two or more Secondary Ponds;
- Maturation and or Evaporation Pond(s).

4.3.1 ANAEROBIC PONDS

The following steps can be used for sizing the anaerobic ponds:

- Determine/estimate the daily organic load (DOL) with regards to BOD that would reach the ponds. Use the amount of people served times BOD discharged per person per day – use Table 1 (Section 2.1.2.2);
- Select the recommended volumetric organic loading rates (VOLR) for the minimum monthly (water) temperature that can be expected for the area under consideration from Table 3 below;

Table 3. Recommended Organic Loading Rate vs. Temperature (Marais, 1966)

Minimum Water Temperature (measured in coldest month) °C	Volumetric Organic Loading Rate (VOLR) (g $BOD_5/m^3/d$)
15	150
20	200
25	350
30	400

- Required minimum Anaerobic Pond Volume (V):

$$V\ (m^3) = \frac{\text{DOL [in g BOD/d]}}{\text{VOLR [(in g } BOD_5/m^3/d)}$$

- Select a convenient depth for this pond between 2,5 and up to 7,0 m and determine the required surface area for this pond. Optimum depth for treatment efficiency is ca 4,0 m with depth up to 7,0 m if biogas collection is considered (Ramadan and Ponce, 2004);
- Check retention time using the estimated daily volume of sewage discharged to the ponds. The hydraulic retention time of one anaerobic pond should be between 2 and 5 days.

- Provide two of these ponds in parallel. Reason being, these ponds take the major load of settleable solids and therefore need to be desludged every ca 5 years, when the basin is ca half full of sludge. Sludge accumulates at a rate of ca 30 to 50 l/p/a. For desludging, the pond is taken out of operation and left to dry out, while the second anaerobic pond is utilised. When dry, the sludge is removed, either manually or mechanically. The dry sludge can be safely used for agricultural purposes. Care must be taken not to damage the artificial liner when emptying the sludge.
- Adequate provision must be made to access the anaerobic ponds for cleaning purposes. This may entail vehicle access (eg ramp) into the pond.
- The anaerobic ponds must be provided with an artificial, durable liner, e.g. 1 mm thick plastic sheeting, despite being built on/with an impenetrable soil. A water tightness test with certificate from the supplier that guarantees that the liner was installed correctly and is leak proof must be provided to DWAF after construction. The liner must be properly protected against possible damage after installation, e.g. by covering it with a layer of soil.

4.3.2 PRIMARY POND

Whereas many good formulae can be found in literature for calculating the size of the primary pond, the following, easy guideline is recommended for use (DWA, 1987):

- Determine/estimate the daily organic load (DOL) with regards to COD that would reach the ponds. Use the amount of people served times COD discharged per person per day – use Table 1 (Section 2.1.2.2).
- Alternatively, use an average COD discharge figure of 100 g/p/d and multiply by the number of people served by the pond system;
- Assume a figure of 400 kg COD being removed per hectare per day, i.e. this would be the "cleaning capacity" for these ponds;
- Calculate the total primary pond surface area (A_s in m²) required would be;

$$A_s\ (m^2) = \frac{\text{DOL [in kg COD/d]}}{\text{400 kg/ha/d}} \times 10\ 000\ m^2/ha$$

- Use a pond depth of 1,3 m (water).

<u>Alternatively</u>, a calculation based on retention time can be used based on the following formulae (Drews, 1983), with the minimum retention time in the primary pond given by:

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

where:
R = retention period (days)
P_o = BOD in inflow to the pond (mg/l)
P = achievable outflow BOD (mg/l) in the pond consistent with aerobic conditions (see below)
C = constant dependent on air temperature (see Table 4)

As an acceptable value for P, the following empirical formula is given.

P = 600/(1,97 d + 8), with d the depth of the pond (d in m), which should be chosen between 1,2 and 1,5 m.

TABLE 4. Temperature dependent constant for primary pond design - C value (Drews,1983)

Average air temperature during coldest month	Below 7 ºC	7 – 10 ºC	Above 10 ºC
C - value	0,14	0,17	0.20

4.3.3 SECONDARY PONDS

Subsequent ponds can be based/sized purely on retention time. A vital feature for the efficient reduction, of faecal bacteria especially is that the ponds should be arranged in series. It has also been shown that nitrogen reduction is better in a tertiary pond than in a secondary pond, suggesting that nitrogen removals improve with increased overall retention times.

The absolute minimum allowable sizing would be two ponds in series, each with a hydraulic retention time of 5 days and water depth of 1,3 m. It is, however, strongly recommended to design the first of the secondary ponds with a minimum of 10 days retention time, while subsequent ponds in series should have 5 days retention each. All successive ponds must also have a water depth of 1,3 m (DWA, 1987).

4.3.4 MATURATION PONDS

The final effluent from maturation ponds is suitable for limited reuse, e.g. for gardening, lawns or limited agricultural applications. (Permit from Department of Water Affairs is required!) The final effluent, before reuse, must be properly disinfected.

Maturation ponds should be designed with a water depth of 1,0 to 1,5 m and retention times of 5 to 7 days for each such pond (DWA, 1987). Multiple ponds in series should be provided and it is recommended that a total of at least twenty-five days retention time, based on the average daily volumetric inflow to the primary pond, should be provided.

4.3.5 EVAPORATION PONDS

Where the final effluent from a pond system can not be reused, all water must be evaporated.

A map of annual evaporation and precipitation (rainfall) figures for Namibia is available from various institutes, e.g. the Department of Water Affairs (1963). The surface area (A_{ev}) required for total evaporation of the effluent can be calculated from the following formula using the mentioned map:

A_{ev} (m²) = (365.Q.)/(Nett E/1 000)

where:

A_{ev} = Area required for total evaporation (m²)

Q = Total volumetric daily inflow into the ponds (m³/d)

E = Annual evaporation rate (mm/a)

Nett E = Nett annual evaporation rate = 0,7.E – P (mm/a)

P = Annual precipitation (mm/a)

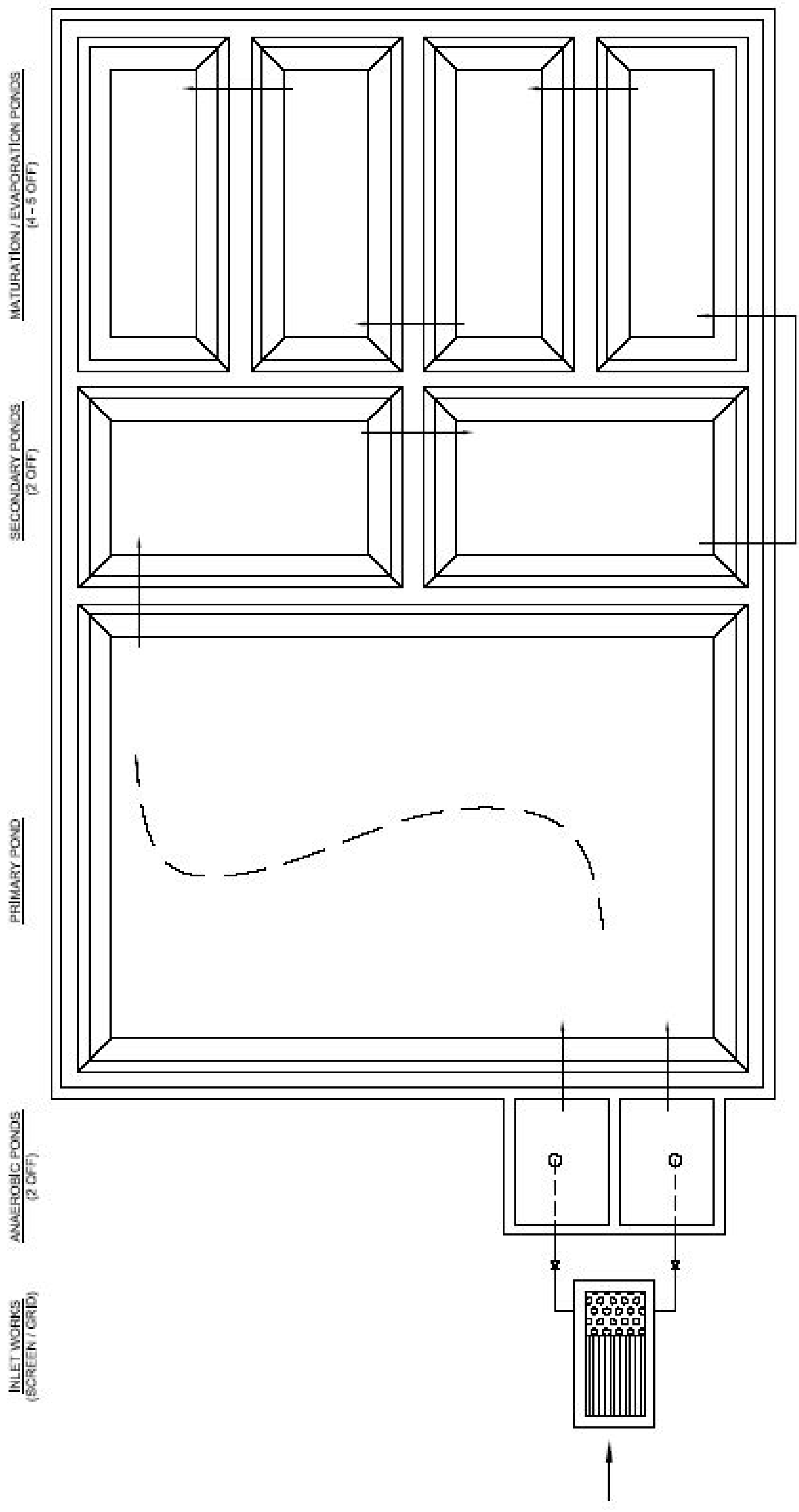


FIGURE 5: POND SYSTEM - MINIMUM REQUIREMENTS

5. PERIPHERAL/ASSOCIATED ITEMS - DESIGN

Consideration should be given to the following items that form part of the overall pond system, to ensure that the system can be easily maintained and be kept in a properly functioning condition:

5.1 SCREENS AND GRIT CHANNELS

Bar screens and detritus channels, correctly sized and designed, should be installed in front of every pond system. The screens must be cleaned daily and utmost care should be exercised that no rags, plastic bags or other large objects are discharged into the first pond. Screenings should be discarded to the municipal dumping site or buried underneath a layer of soil not less than 800 mm deep.

5.2 MEASURING DEVICES

As a minimum flow measuring device, a V-Notch weir to measure flow at the inlet to a pond system, must be provided. Additionally, a mechanical, electronic or electromagnetic flow measuring devices should also be provided. Flow discharge data is useful for load calculations and to indicate when a system needs extending.

5.3 INLETS AND OUTLETS

Inlets to the primary ponds should be submerged with provision for rodding or clearing pipes. These must be positioned and designed in such a way that maximum use is made of the whole pond volume and that short-circuiting and choking is avoided. Especially when the inlet imports high momentum to the pond contents, the flow should be directed away from the outlet or dispersed at the deepest portion of the pond.

In the case of a very large primary pond a number of suitably placed inlets should be provided, and possibly used in rotation, to facilitate mixing.

For primary ponds the inlet should terminate near the pond centre in a position where maximum benefit will be derived from prevailing winds to disperse floating matter.

All ponds should have top outlets baffled 0,3 m to 0,5 m below the surface, and located on the banks for ease access.

5.4 EMBANKMENTS AND VERGES

Ponds should be designed with a freeboard not less than 400 mm.

The ponds should always be kept free from weed growth and the embankments should be well maintained. Providing stone pitching or a concrete screed on the freeboard and extending at least 200 mm into the water will prevent weed growth and wave erosion, thereby saving maintenance cost.

The slopes of embankments would be dictated by normal engineering practice for small dams.

5.5 DISINFECTION

If the final effluent is reused, even for agricultural purposes, a disinfection step must be provided. For proper disinfection, chlorine or any other recognised disinfection method may be provided.

Chlorine comes commercially in various forms:

- As a gas (but liquefied under pressure) in steel cylinders;
- In liquid form (containers) as sodium hypochlorite;
- In solid form, commonly distributed as chlorine pills or granules (e.g. HTH).

If chlorine is used, this chemical must be added to the final effluent and be allowed to react for at least 20 minutes to kill potentially harmful microorganisms. This is done in a chlorination tank, properly designed to ensure the chlorine is spread evenly throughout the complete volume of water. Sufficient chlorine must be added to obtain and maintain a free chlorine residual above 0,3 mg Cl_2/ℓ, measured 20 minutes after application and at peak flows.

5.6 FENCING

The pond system must be completely fenced in to prevent people and animals entering the area and ample notices must be provided to warn and keep people out of this area. As a minimum, a "jakkalsproef" fence at least 1,8 m high with double-gate to allow access for trucks must be provided. The gate must be kept properly locked. No animals or people are allowed to swim in any of the ponds!

5.7 SEPTIC TANKS AND NIGHT SOIL DISCHARGE

Night soil must always be discharged into the first pond of a pond system. Where tankers are still utilised for septic tank or night soil discharging, specific consideration should be given to accommodate such equipment. The design of discharge points will depend on the type of vehicles and equipment used. Concrete ramps, aprons or 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 may be used for withdrawing water from the pond and discharging it in a mixing sump. Make-up water for the pond will generally be required to maintain the level. This water should be used for washing down aprons and chutes and for breaking up lumps in the mixing sump.

6. INFILTRATION SEEPAGE CONTROL

Groundwater pollution from seepage must always be regarded as a big possibility and poses a great health risk.

Seepage can be high and can vary over a wide range according to the geology of the pond base and the composition of soil used in the construction walls. Consequently, the prevention of pollution of underground water supplies and the curtailment of losses where the reclamation of water for re-use is of primary importance, necessitate special attention be given to site selections and the sealing of pond base and walls.

If a pond is to be constructed in a soil of high porosity, i.e. having very low clay content, or on an unsound geological formation such as found in dolomitic areas, there is a great danger of groundwater pollution and steps should be taken to seal the bottom of all ponds. Sealing could be effected by the importation and compaction of a layer of suitable soil on the floor of the pond, or otherwise with plastic sheeting. In the last instance, special care must be exerted since the sheeting is easily ruptured and should be covered to protect it against any external elements that can damage the sheeting.

Anaerobic ponds must be fully lined, regardless of the soil conditions and in all instances, with a durable artificial liner such as plastic sheeting, not less than 1 mm thick.

7. OPERATION AND MAINTANANCE

Regular maintenance should be carried out to maintain a high standard of effluent, to avoid nuisance problems, which may otherwise develop, and to avoid a rapid physical decline of the infrastructure.

Although skilled manpower is not required for routine operation, maintenance and supervision of pond systems, regular cleaning, periodic sampling and checking certain items should be attended to conscientiously. It is also important to check the inflow to the plant and reassess the number of users (population growth) once a year to ensure that the system does not become overloaded. These points will be further highlighted in this section.

Depending on the size of the system there should be one or two unskilled operators based at the ponds. The following should be included in their operation and maintenance routine (as a minimum):

7.1 DAILY INSPECTION

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

- Clean the screens and detritus channels. Discard to municipal waste site or bury all screenings, detritus and extraneous material in prepared pits.;
- Record the inflow once a day if a flowmeter has been installed;
- Keep the embankments free of vegetation, especially at the verges;
- Look out for leakages caused by rat and crab holes and close them up;
- Clear floating debris from pond surfaces;
- Check that all overflows are clear;
- Check fence and repair immediately if damaged;
- If maturation ponds are employed:
  - Check that disinfection system is properly functioning;
  - Check that disinfection chemicals are sufficient;
  - Check dosing rates are sufficient for proper disinfection;
  - Check other mechanical items employed, e.g. pumps.

7.2 PERIODIC/INFREQUENT INSPECTION

A skilled supervisor, specialist or consultant needs to be employed to visit the ponds system at least twice per year to carry out certain inspections and tests and to advise the owner of changes in the operation or additional, periodic maintenance to be undertaken. This will include (as a minimum):

- Check, assess and report on the performance of the operator(s);
- Check, assess and report on the general condition of the site (e.g. neat and tidy, fence and gate properly maintained, etc.;
- Note and raise any concern regarding possible leaks or situation that may lead to contamination of the groundwater or endanger human and/or animals;
- Check flow meter readings (check condition of flow meter);

- Check sludge level in anaerobic pond – advise client to clean if required;
- Collect a set of composite samples of the inflow and final effluent (minimum requirement) – also refer to Section 8 below. Ideally, each pond should be sampled and analysed to assess its operation and build up a database;
- Observations of smell and colour of especially the primary pond should be noted. This can serve as check for possible overloading of the pond;
- Measurements of pH and dissolved oxygen to confirm the observations indicated by smell and colour;
- Where a maturation pond is employed:
    - o Check, assess and report on dosing rates, condition of dosing equipment, performance of the disinfection system;
    - o Check, assess and report on all other mechanical equipment installed;
- Compile a report of all findings. This report should be made available on request to the Department of Water Affairs;

8. SAMPLING AND ANALYSES

DWAF will specify the required frequency of sampling in the permit conditions. Where no frequency is specified, samples must be taken once every six months and analysed for the tests required by DWAF. These analyses must be undertaken by an approved, recognised laboratory for wastewater analyses.

The load of the wastewater entering the oxidation pond system during a normal day varies significantly, both with regards to volume and organic load, depending on the domestic activities at that time. Therefore a composite sample over 24 hours of the inflow should ideally be taken. This is not a simple process and should rather be left to be undertaken by an expert in the wastewater treatment field. However, grab samples can be used as an indication. It is only the inflow to the pond system, which will not give a proper overall picture of the load reaching the plant.

Grab samples at the outflow of each pond will give a good indication of the treatment achieved in each unit process. The following procedure describes how to take grab samples and store them for analyses by a suitable laboratory:

- Collect samples at the inlet (as inflow) or outlet (as outflow) of a specific unit process;
- Put on surgical gloves;
- Take a sealed, clean 2 ℓ plastic bottle, fill and rinse three times with the wastewater that is to be sampled;
- If microbial indicators need to be established, sterilised glass bottles should be used (obtainable from the lab that will later do these analyses);
- Fill sampling bottle completely and seal (put on cap) while still under water/while bottle overflows;
- Mark or label each bottle immediately. The labels on the bottles should clearly indicate the name of the plant, owner, exact sampling point/place (GPS-reading?), date, time and the parameters that should be analysed for;
- Store sample bottles at or below 4°C and deliver them to the laboratory to be analysed. This can be achieved by storing the sample bottles in a refrigerator and transporting them inside a cooler bag/box with ice cubes;

- Samples must reach the laboratory within 24 hours, otherwise the bottles must be preserved with sulphuric acid (H_2SO_4) or nitric acid (HNO_3) and be kept at cool temperatures;
- If microbial indicators need to be established, the samples must reach the lab within 24 hours from sampling.

9. FURTHER READING

Whereas this manual was drawn up for and is based on basic pond systems as installed widely throughout Namiba, more advanced pond systems are in use in other parts of the world. Latter systems incorporate more mechanical and electrical equipment and generally require a higher qualified supervisor and necessitate more operation and maintenance involvement. The reader is encouraged to read more in this regards from Ramadan and Ponce (2004) and use further references from their publication as background information.

REFERENCES

Ayres, R.M., Alabaster, G.P., Mara, D.D. and Lee, D.L. 1992. A Design Equation for Human Intestinal Nematode Egg Removal in Waste Stabilisation Ponds. *Water Research*, 26 (6), pp. 863-865.

DWA. 1963. Map of annual evaporation and precipitation. Department of Water Affairs, Figure 3.

DWA, 1987. Riglyne vir die Ontwerp van Sanitasiestelsels vir Klein Gemeenskappe. Department of Water Affairs. Report dated August 1987.

Drews, R.J.L.C. 1983. Pond Systems for the Purification and Disposal of Domestic Wastewater from Small Communities: Use, Design, Operation and Maintenance. CSIR Guide K15. Pretoria, South Africa.

Eckenfelder, W.W. 1980. *Principles of Water Quality Management.* Boston: CBI.

Marais, G.V.R. 1966. News Factors in the Design, Operation and Performance of Waste Stabilisation Ponds. *Bulletin World Health Organization*, Vol. 34, pp.737 – 763.

McGarry, M.G. and Prescot, M.B. 1970. Stabilisation Pond Design for Tropical Asia. Proc. 2nd Int. on Waste Treatment Lagoons, Kansas City, USA.

Meiring, P.G.J, Drews, R.J.L.C., Van Eck, H. and Stander, G.J. 1968. A Guide to the Use of Pond Systems in South Africa for the Purification of Raw and Partially Treated Sewage. CSIR Special Report WAT34. Pretoria, South Africa.

Pavelli, R.P., Günther, W.M.R., Matte, G.R., Razzolini, M.T.P., Cutolo, S.A., Martone-Rocha, S., Paternella, F.A.S., Doria, M.C.O., Matte, M.H. 2008. Sanitation Asessment of Wastewater Treated by Stabiliszation Ponds for Potential Reuse in Agricultural Irrigation Sanitation Assessment. *Water Environment Research*. Vol. 80, Number 3, March 2008, pp.205 – 211.

Ramadan, H. and Ponce, V.M. 2004. Design and Performance of Waste Stabilisation Ponds. Through internet available.

Tchobanoglous, G. and Schroeder, E. 1985. Water Quality Characteristics, Modelling, Modification. Addison-Wesley. Reading, Massachusetts, USA.

Voysey, J.A., Cicillie, G.G. and Skinner, D.H.H. 1988. Manual on the Design of Small Sewage Works. The Water Institute of South Africa. Pretoria, South Africa.

Water Resources Management Act. 2004. Act No 24 of 2004: Government Gazette of the Republic of Namibia, No 3357 of 23 December 2004.