PERFORMANCE EVALUATION OF SELECTED WASTE STABILIZATION PONDS IN ZAMBIA

By

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To my wife, Iredy, my daughter Chandiona
and my son, Mateyo.

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ABSTRACT

The Matero Ponds, chelston Ponds, Ndeke Ponds and Mindolo Ponds, were the four waste stabilization ponds studied in order to evaluate their performance on sewage treatment.

The studies on these ponds included collection and analysis of the design details. Construction, operation and maintenance of the ponds were also studied. Influent and effluent samples from the ponds were tested in the laboratory for pH, permanganate values, suspended solids, bacteria and biochemical oxygen demand. The results obtained were compiled together with the test results recorded by the authorities of the ponds.

The results were analysed and the performance of the ponds for sewage treatment were evaluated. It was found out that bacteria reduction for all the ponds was not satisfactory. Besides, the removal of suspended solids in the Matero and Chelston Ponds was also poor. The deficiencies of pond performance were attributed to the designs, overloading and operation of the ponds. The pH, permanganate values and biochemical oxygen demand results from the ponds were satisfactory.

To improve the performance of the ponds it was suggested that the ponds should be extended and rearranged. The construction, operation and maintenance of the ponds should also be improved.

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1. INTRODUCTION

It is important to realise the need for sewage treatment. Sewage treatment is important so as to reduce the pollution on water courses to which the sewage is discharged. Reduction of this pollution on receiving water courses is for health, economic and esthetic reasons. There are many methods for sewage treatment. The examples are activated sludge and trickling filter plants. However waste stabilization ponds have many advantages over other methods. This is especially true for tropical and subtropical regions where the climatic conditions suit their operation. Waste stabilization ponds have certain disadvantages as well but these are to a great extent offset by the numerous advantages. Zambia is a developing country in tropical Africa, and it is situated south of the equator.

The provision of adequate sewage treatment and disposal at low costs and low demand of professional manpower, while attaining the required effluent quality is very important to Zambia. This is so because there are insufficient financial resources and professionally trained manpower for the expensive and complicated sewage treatment methods. It is therefore important that waste stabilization ponds are utilized in Zambia as much as possible. A lot of research should be done on waste stabilization ponds in Zambia in order to improve their performance.

This study was carried out in order to evaluate the performance of selected waste stabilization ponds which treat domestic sewage in Zambia. The second chapter of this report is literature review on various sewage treatment methods and sewage treatment by waste stabilization ponds. The other part of the second chapter deals with the design, contruction, operation and maintenance of waste stabilization ponds.

Chapter three is on location, climatic conditions and description of the selected waste stabilization ponds. This chapter also deals with construction, operation and maintenance of the selected ponds. The other items presented in the third chapter are the methodology adopted for the studies on the ponds. The third chapter is continued with the presentation of test results of the samples from the ponds. The tests carried out were on pH, permanganate values, suspended solids (S.S), escherichia coli (E.Coli) and biochemical oxygen demand after five days incubation at 20°C ($B.O.D_5$).

E.Coli was determined because it can be more easily determined than faecal coliforms and the "die-off" for E.Coli is similar to that for faecal coliforms. The third chapter ends with the analysis of the test results of the samples from the ponds.

Chapter four of this report discusses the selected ponds and the results presented in the third chapter. This chapter also presents the various suggestions made in order to improve the performance of ponds on bacteria and S.S. reduction. the fifth chapter of this report is comprised of concluding remarks.

2. SEWAGE TREATMENT BY WASTE STABILIZATION PONDS.

2.1. Sewage Treatment.

Sewage or waste-water treatment is very essential to public health. Water supply alone can not provide full health benefits. In some cases, owing to lack of adequate sanitary facilities, an increased water supply may even cause the spread of various water related diseases. Waste water treatment aims at reducing the pollutants in sewage which may include biochemical oxygen demand (B.O.D), suspended solids (S.S), pathogenic bacteria, toxic compounds, nitrates and nitrites, phosphates and even some metallic compounds as well. The sewage treatment is important so that pollution of waters to which the effluent is discharged, is minimised to acceptable level.

2.1.1 Common sewage treatment methods.

Sewage treatment is a combination of physical and biological processes. Occasionally chemical processes are additionally employed. The common physical processes are screening, comminution and removal of grit and suspended solids by sedimentation. Biological processes involve the agency of micro-organisms and these processes constitute the most important methods of wastewater treatment. Chemical processes are not commonly used in many countries owing to the high costs of materials and the high level of operator skills.

Various common methods for sewage treatment are :

- septic tanks
- waste stabilization ponds
- aerated lagoons
- activated sludge process and
- trickling filter process.

(a) Septic tanks.

Septic tanks are small chambers of various shapes. They are usually sited just below ground level. Sewage in septic tanks is retained for one to three days (Mara 1976).

During the detention time in the septic tanks, the solids settle to the bottom of the tank where they are digested anaerobically. A thick scum crust forms at the surface and this helps to maintain anaerobic conditions in the tanks.

Although the digestion of the settled solids is reasonably good, some sludge accumulates and the tank should be desludged at regular intervals which may vary from one to five years(Mara 1976) according to size and the number of users. The effluent is disposed to other treatment works like waste stabilization ponds where it is further treated. Another common method for the disposal of septic tank effluent is subsurface irrigation in drain field trenches. This effluent can also discharge to water courses. Septic tanks are used for families or small communities. Figure 1 shows a plan and cross section of a two compartment septic tank.

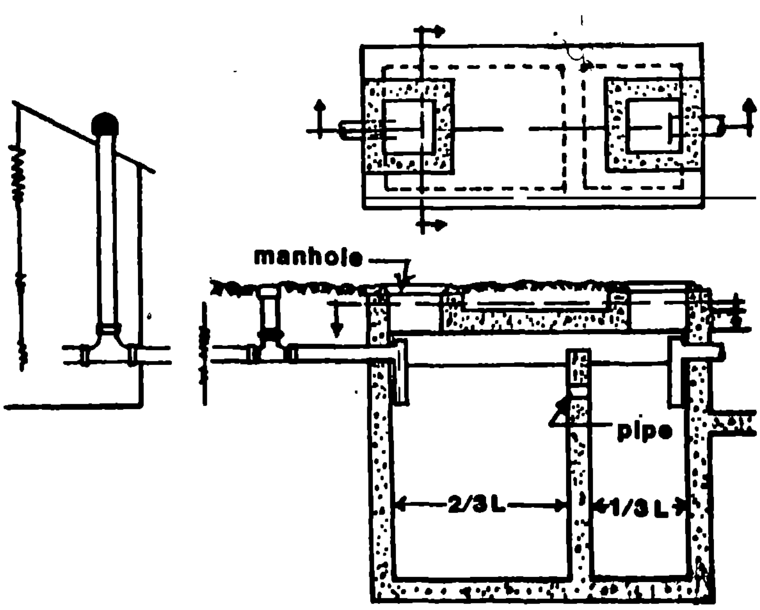

Figure 1. Two compartment septic tank (Baumann et al 1980).

(b) Waste stabilization ponds.

Waste stabilization ponds are large shallow basins enclosed by earthern embankments in which wastewater is treated by natural processes involving algae and bacteria. The basic principles of sewage treatment in all ponds is the same. The reduction of pollutants is accomplished by bacteria and algae and proceeds slowly in ponds without artificial or mechanical aeration and cirulation. For the reason that no artificial aeration or circulation is involved, long detention times and large basins are required. Detention times in ponds of thirty or even fifty days are common (Mara 1976). In many highly developed countries where land is valuable and scarce, waste stabilization ponds are no longer being built (Baumann et al 1980).

The use of waste stabilization ponds is very important, especially in tropical and subtropical regions, because there is favourable climate and sufficient land is normally available at low and affordable cost. The other main reasons for their importance are:

- low costs for design, contruction, operation and maintenance
- high degree of performance with regards to B.O.D, S.S. and pathogenic bacteria removal.

Figure 2 shows typical arrangements of waste stabilization ponds.

(c) Aerated lagoons.

Historically the aerated lagoons were developed from waste stabilization ponds for use in temperate climates where mechanical aeration is used to supplement the algal oxygen supply during cold seasons. Figure 3 shows a diagram of a mechanically aerated lagoon of the facultative type. This lagoon is of the facultative type because there is an aerobic layer near the surface and an anaerobic layer at the bottom.

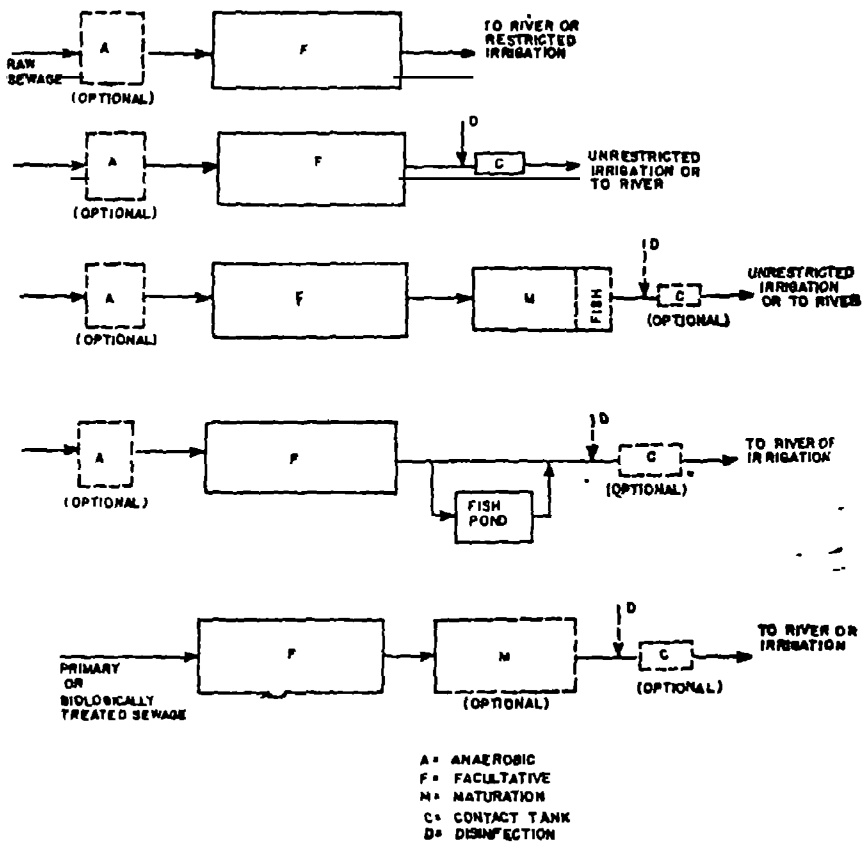

Figure 2. Typical arrangements of waste stabilization ponds (Arceivala 1973).

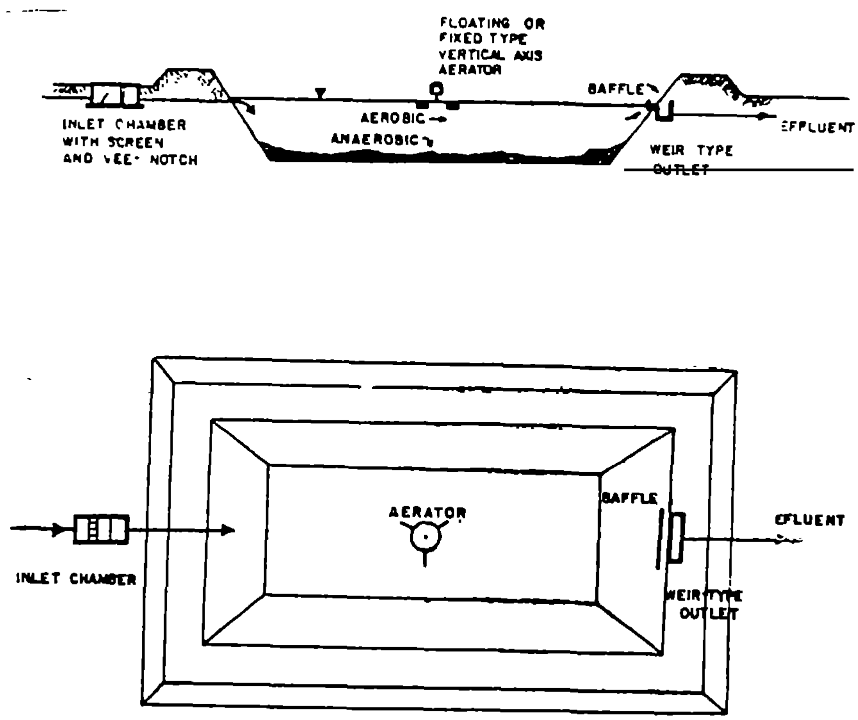

Figure 3. Diagram of a mechanically aerated lagoon of the facultative type (Arceivala 1973).

(d) Activated sludge process

Activated sludge process is the standard method of sewage treatment in temperate climates. The activated sludge process comprises of five stages of sewage treatment which are :

- pretreatment (by screens and grit chambers)
- pre sedimentation (in sedimentation tanks)
- aeration (in aeration tanks)
- final sedimentation and
- sludge treatment (e.g. on drying beds or in anaerobic digestors).

Even if the activated sludge process of sewage treatment was developed for temperate climates, there are many of these plants in hot climates. An example of these plants in hot climates is the activated sludge treatment works at Kitwe in Zambia, which was designed to treat 58000 cubic metres of sewage per day.

Costs generally militate against activated sludge process, especially where cheaper sewage treatment plants like waste stabilization ponds could be utilized. However in some cases economic analysis has shown that for large populations the activated sludge plants are cheapest. Nevertheless the activated sludge plants may still not be advisable for use in developing countries because there are limited foreign exchange reserves for the equipment which usually has to be imported. The other reason is that there are insufficient professionally trained people in most developing countries to operate the activated sludge plants. Figure 4 shows a flow diagram of an activated sludge plant.

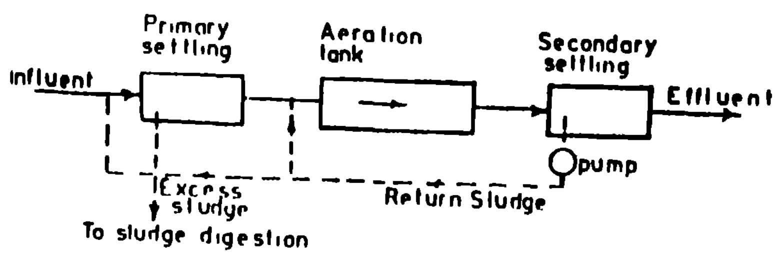

Figure 4. flow diagram of an activated sludge plant (Al-Layla et al 1980).

There are various modifications of the activated sludge process. One of these modifications is the oxidation ditch. The essential operational features for oxidation ditches are that they receive screened sewage and provide longer detention time than activated sludge plants. The hydraulic detention time in oxidation ditches is normally 0,5 to 1,5 days and the detention time for solids is 20 to 30 days (Mara 1976). The long detention times for solids are achieved by recycling.

These long detention times in oxidation ditches ensure minimal excess sludge production and a high degree of mineralization in the sludge that is produced.

Also handling and treatment of sludge from oxidation ditches is almost negligible because these small amounts of waste sludge can be dewatered readily without a lot of odour on drying beds. Figure 5 shows different types of oxidation ditch layouts.

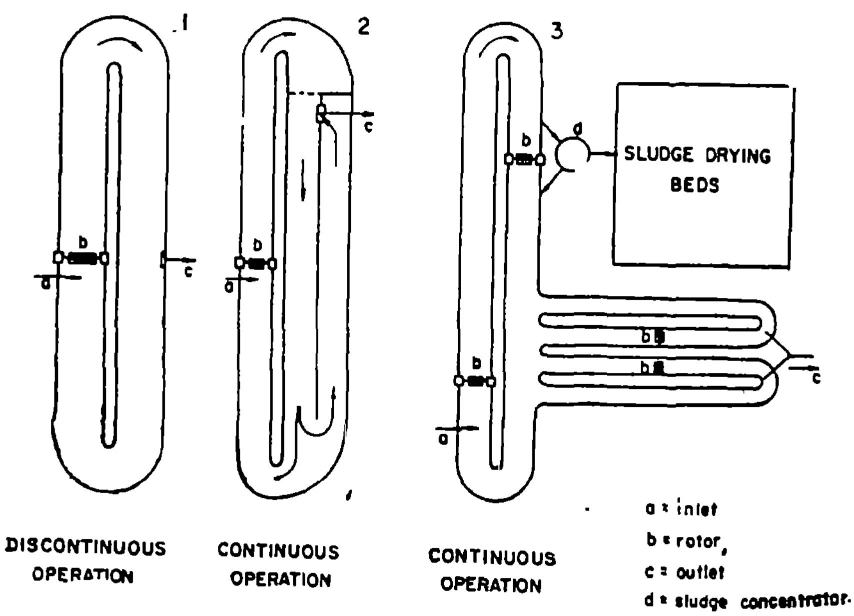

Figure 5. Different types of oxidation ditch layouts (Arceivala 1973).

(e) Trickling filter process.

Sewage treatment in trickling filter process is similar to the stages in the case of activated sludge process. However one of the differences is that the biological treatment takes place in trickling filters instead of aeration tanks or basins in activated sludge process. Figure 6 shows a flow diagram of a two-stage trickling filter plant. This arrangement could be used for treating very strong waste waters.

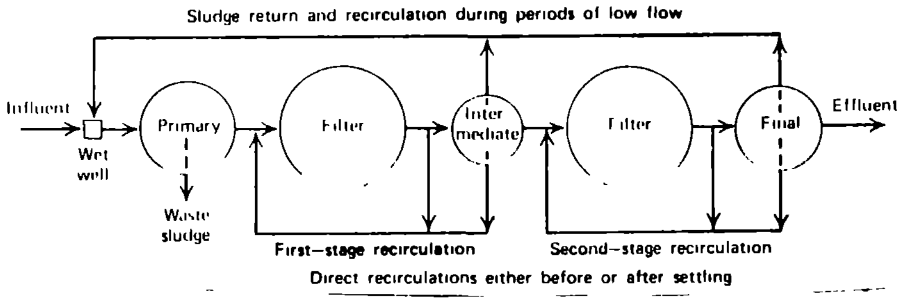

Figure 6. Flow diagram of a two - stage trickling filter plant (Hammer 1977).

The trickling filter process has some modifications. An example of such modifications is the high rate biofiltration process. The media for sewage treatment in high rate biofiltration towers is like those used in trickling filter units. Plastic is an example of the medium used in high rate biofiltration towers. Figure 7 shows an example of the media used in high rate biofiltration towers.

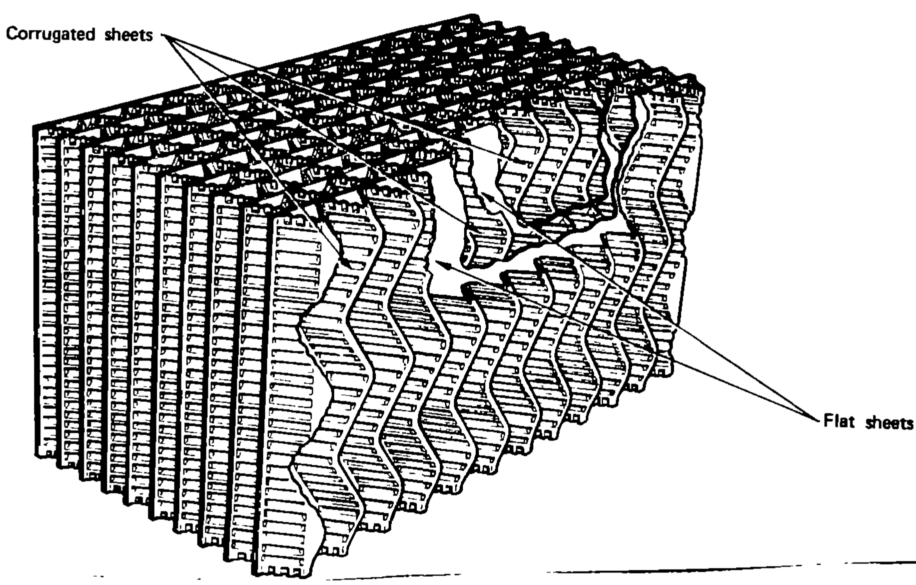

Figure 7. Plastic media in biofilters (Hammer 1977).

High rate biofilters are sometimes used in temperate climates to treat sewage. They are also used for treating biodegradable industrial wastes. In hot climates the high rate biofilters could be used for treating industrial wastes from industrial areas where space limits the use of other treatment methods.

In combination with the methods mentioned for sewage treatment, chlorination can be used in order to give further reduction in bacteria.

There are also some tertiary treatment methods which could be used together with the sewage treatment methods described already. These tertiary treatment methods could be sand filtration, lagoons and different chemical processes. The tertiary treatment methods are used to improve the quality of the effluent from waste water treatment plants.

2.1.2. Waste stabilization Pond types.

Waste stabilization ponds are in three types, namely:

1. anaerobic ponds
2. facultative ponds and
3. maturation ponds.

These pond types could be arranged in parallel, series or a combination of both arrangements. However, irrespective of whichever arrangement, the first ponds in series are anaerobic ponds, followed by facultative ponds and finally maturation ponds.

Waste stabilization ponds are classified according to the relative dominance of the two processes of degrading organic wastes and these processes are either anaerobic or aerobic process. Marais et al (1961) indicated that anaerobic conditions, as will be seen later, depend on B.O.D. concentration in the pond and the depth of the pond.

Marais et al (1961) also indicated that anaerobic conditions generally prevail for very high values of B.O.D. and for pond depths greater than two metres.

(a) Anaerobic ponds.

In anaerobic ponds anaerobic conditions prevail throughout. These pond cells operate under heavy organic loading rates as they are the primary units in pond systems. Caldwell et al (1973) report that organic loads on anaerobic ponds are generally between 0,022 to 0,11Kg. $B.O.D_5/m^2/day$. It should be noted that $B.O.D_5$ is about two-thirds of the ultimate B.O.D. value as indicated by Mara (1976). Anaerobic ponds rely on anaerobic digestion to achieve the removal of organic wastes.

Caldwell et al (1973) also report that the removal of $B.O.D_5$ in anaerobic ponds ranges from 50% to 80%. Anaerobic pond depths range from 3 to 5m. (Mara 1976). Anaerobic ponds in a series arrangement are followed by facultative ponds and then by maturation ponds.

(b) Facultative ponds.

These pond cells follow anaerobic ponds or they can be the primary ponds if organic loading to ponds is light.

Facultative ponds operate under lighter organic loading rates than anaerobic ponds. This loading on facultative ponds generally ranges from 0,002 to 0,009 Kg $B.O.D_5/m^2/day$ (Caldwell et al 1973). They also reported that the $B.O.D_5$ removal in facultative ponds is between 70% and 95% and depending on the concentration of algae that develop in these pond cells, $B.O.D_5$ removals as high as 99% have been recorded.

Facultative ponds have depths ranging from 0,9 to 2,4m. (Calwell et al 1973). Greater depths allow the following two layers to develop:

- an anaerobic layer near the bottom and
- an aerobic layer near the surface.

The lower organic loading and the shallower depths enable algae to develop in the surface layer and an oxypause to form. Below the oxypause anaerobic digestion of organic wastes occurs in the absence of oxygen. Above the oxypause aerobic bacterial oxidation of organic wastes occurs in symbiosis with algal photosynthesis. The algal photosynthesis provides the bulk of the oxygen while some of the oxygen is available from surface reaeration. The oxygen is utilized by bacteria to oxidize the organic wastes and bacterial protoplasm is formed together with carbon dioxide and water. The algae in presence of sunlight uses the carbon dioxide to convert the organic wastes to algal protoplasm and produce oxygen. Thus there is symbios between algae and bacteria in facultative ponds for treating sewage. Figure 8 shows the symbiosis of algae and bacteria.

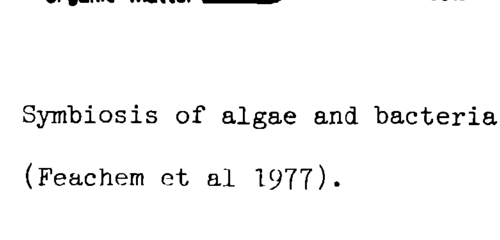

Figure 8. Symbiosis of algae and bacteria (Feachem et al 1977).

(c) Maturation ponds.

Maturation ponds follow facultative ponds and they are largely aerobic due to low organic loading rates and shallow depths. Caldwell et al (1973) report that $B.O.D_5$ loading rates to maturation ponds are generally about 0,002Kg/m^2/day. The depths of these ponds are 1,0-1,5m. (Mara 1976). In the maturation ponds faecal coliforms, B.O.D, S.S. and ammonia are reduced further. Provided the ponds are well designed, constructed, operated and maintained the total feacal coliform removal in anaerobic, facultative and maturation pond system is often above 99% (Canter et al 1976).

As mentioned earlier, algal photosynthesis and surface reaeration provide the bulk of the oxygen for the stabilization of wastewater.

Maturation ponds may also be used for polishing effluent from sewage treatment plants like trickling filter plants or activated sludge plants. An example of such maturation ponds are the Radnor Street Sewage Ponds which treat the effluent from the Machinchi Trickling Filter Plant in Lusaka, Zambia.

2.1.3. Advantages and disadvantages of waste stabilization ponds.

One main disadvantage of waste stabilization ponds is that they can not be used world wide since they operate only under certain climatic conditions which prevail mostly in tropical and subtropical regions. The other disadvantage concerning waste stabilization ponds is that they require a lot of land where they can be constructed.

Nevertheless the disadvantages mentioned above are off-set by various important advantages.

Firstly it should be noted that waste stabilization ponds are highly adaptable to a broad range of biodegradable wastes, provided no toxic elements (which kill pond bioactivity) are allowed to the ponds. Further-more waste stabilization ponds provide considerable storage capacity which dampens the effects of sudden increases in flow or B.O.D loading.

The second advantage of waste stabilization ponds is with regard to the low costs of construction, operation and maintenance. Ponds are easily constructed at low costs. The operation and maintenance costs for ponds are also lower than the costs for other forms of sewage treatment, for the same volume and strength of wastewater treated. For gravitational waste stabilization ponds energy costs may be nil and for non gravitational ponds energy may be needed only for pumping wastewater to the ponds (Schiller et al 1982). In addition the operation and maintenance of waste stabilization ponds require minimum technical skills. Figure 9 shows an indication of the cost for waste stabilization ponds as compared to the costs for other forms of sewage treatment. The costs in figure 9 include amortization of the capital costs over 20 years at 6%.

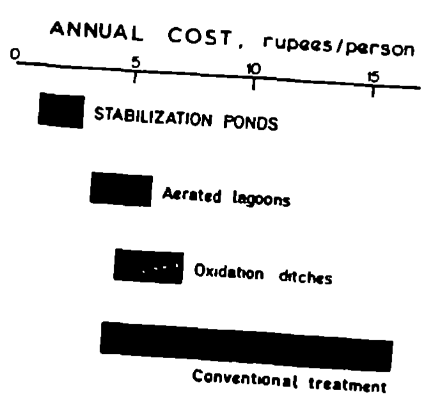

Figure 9. Annual costs of sewage treatment in India (Arceivala et al 19[illegible]).

The third advantage of waste stabilization ponds which is also very important is with regard to the efficiency of sewage treatment. The ponds have a very high efficiency of sewage treatment. Provided ponds are well designed, constructed, operated and maintained the removals of faecal coliforms are often above 99% (Canter et al 1976). The removals of B.O.D and S.S. are also high for the ponds and usually the effluent standards are satisfied.

The fourth advantage of waste stabilization ponds is with respect to the promotion of good health and nutrition. This is possible because the effluent from ponds and the proteins in the effluent can be reclaimed and used for irrigating farms and for fish cultivation. The proteins in pond effluent are mostly algae.

Admittedly the initial costs of purchasing land for waste stabilization ponds are high as compared with costs of land for other forms of sewage treatment. However the land purchased for waste stabilization ponds can be considered as an investment and the pond site may be purposefully chosen for its potential appreciation in value. This appreciation in value of the land could be seen as an advantage because the land can be easily utilized for other purposes after the life time of the ponds. The ponds should however be refilled and compacted properly before the land can be reused.

2.1.4. Conditions necessary for waste stabilization ponds.

Climatic conditions affect waste stabilization ponds with regards to processes involved in ponds for sewage treatment. The climatic factors which affect pond performance are temperature, solar radiation, wind speed, evaporation and rainfall.

In addition to the climatic conditions, land availability and the topography of the land are factors which limit use of ponds.

Temperature affects the biological activities which take place in ponds. The temperature has an effect on the rate of degradation of organic wastes due to its effect on the processes of micro-organisms.
The pond liquid temperature has a very big influence on pond performance. The optimum temperature for waste stabilization ponds is between 25°C to 32°C (Canter et al 1976). Temperature is important for ponds since the bacteria responsible for sewage treatment operate in the mesophilic temperature range as shown in figure 10.

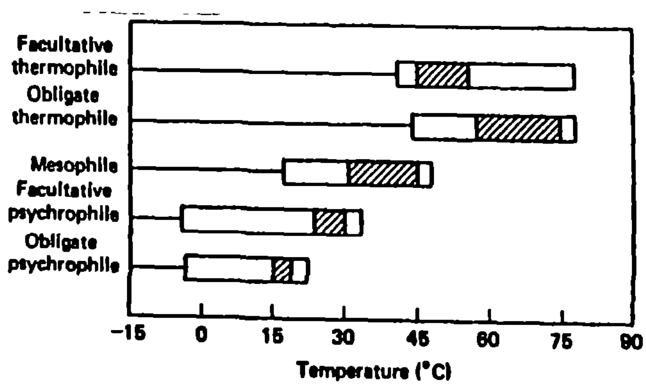

Figure 10. Temperature ranges for reproduction of psychrophilic, mesophilic and thermophilic bacteria (Benefield et al 1980).

Higher temperatures than the mesophilic temperature range are not a problem. However lower temperatures cause problems as they lower the treatment efficiency because of reduced bioactivity in ponds. In the case of methanogenic bacteria which are essential for anaerobic digestion, methane production almost ceases when the temperature of water in ponds is lower than 15°C (Arthur 1983). In areas where temperature of water in ponds remains below 15°C for two months or more, Arthur (1983) states that careful consideration should be given as to whether ponds are desirable.

Temperature is also important in ponds in as far as thermal stratification is concerned. The thermal stratification can occur in ponds as a result of temperature differentials. If the stratification persists, non motile algae below the thermocline (zone dividing darker bottom layers and surface layers where there is light) can not enter the photic zone and they die due to lack of light. Thermal stratification can also cause short-circuiting. The short circuiting results due to lack of mixing and this leads to reduced treatment efficiency of the ponds because the waste water does not remain in the ponds for the designed detention time.

Solar radiation is the energy source for photosynthesis of algae in facultative and maturation ponds. Measured values of solar energy in tropical areas often exceed 270 langleys or $64,5 J/Cm^2$ as stated by Gloyna (1971). However it is stated that in tropical areas solar radiation does not seem to play a critical role for algae growth and hence oxygen production (Gloyna 1971). Periods of cloud cover in tropical regions are seldom a problem because the solar radiation in these regions during the day generally exceeds the saturation light intensity of algae in the ponds (Arthur 1983).

Wind is a prominent factor affecting the performance of ponds. Wind causes surface aeration in top layers of ponds and induces mixing in the whole body of water. Mixing in the water body is essential because it over-comes thermal stratification, distributes oxygen generated in the top layers to bottom layers, maintains the non-mobile algae in suspension, enhances algae growth and also increases the organic capacity of ponds (Marais 1970).

The depth to which wind induced mixing is felt is largely dependent on the distance the wind is in contact with the water (the"fetch"). As reported by Mara (1976) an unobstructed contact length of about 100m. is required for maximum mixing by wind action. The importance of wind action was demonstrated by an experiment conducted in Zambia on a facultative pond (Mara 1976). In this study a 2m. high wall fence without openings was eracted around the pond and within a few days the pond turned anaerobic; when the fence was removed, aerobic conditions were rapidly re-established.

Excessive wind action on the other hand may have negative effects on pond performance because the settleable solids may become suspended, thus reducing light penetration in case of facultative and maturation ponds and hence reducing the photosynthetic activity. Excessive wind may also cause erosion along the edges of ponds. To avoid short-circuiting from inlet to outlet and retardation in flow, the pond layout should be planned in such a way that there is prevention of prevailing wind along the line of flow.

Evaporation and rainfall also have various effects on pond performance. Evaporation may have a big role when determining the level of water maintained in the ponds. The evaporation loss should be considered in the design of ponds because the evaporation loss in one pond results in decreased sewage flow to the ponds that follow in series. Rainfall is also important for the hydraulic design considerations of ponds. If the rain is heavy it can induce mixing, increase aeration, contribute high dissolved oxygen to water in ponds, and in some cases breakdown stratification in ponds. These may result in improved performance of ponds.

Land is one of the important factors to be taken into account when waste stabilization ponds are to be considered as an alternative for waste water treatment. Land should be available at a reasonable and economical distance from the community to be served. The land should be available at affordable costs. The topography and geological conditions of the sites should be suitable in order to reduce the capital costs involved during pond construction.

2.1.5. Mechanism of sewage treatment in waste stabilization ponds.

The major treatment processes which occur in waste stabilization ponds are:

(a) the reservoir effect which enables ponds to absorb both organic and hydraulic shock loadings,

(b) primary sedimentation which allows the settleable solids to sink to the bottom sludge layer of anaerobic and facultative ponds and

(c) treatment of organic waste by anaerobic digestion in sludge layers and aerobic bacterial oxidation in top layers of facultative ponds and in maturation ponds.

The efficient absorption of shock loadings and equilization of loading peaks are dependent on achieving reasonably good mixing of the influent throughout the pond contents. Mixing is also important to minimize the hydraulic short-circuiting in ponds and to achieve a good vertical distribution of both oxygen and algae in facultative and maturation ponds. Non-mobile algae which are the most efficient oxygen producers rely on pond mixing to bring them into the surface layers of facultative and maturation ponds where light intensity is greatest. Mixing also destroys thermal stratification as previously stated.

Settleable suspended solids settle to the benthos (at the bottom of ponds) under the quiescent conditions found in ponds. Aerobic bacteria oxidation and anaerobic digestion treat the organic wastes and B.O.D. is reduced. The anaerobic process for treating organic wastes in anaerobic and facultative ponds is basically in two stages:

1. Organic matter $\xrightarrow{\text{bacteria}}$ new bacterial cells + mixed organic acids.

2. Mixed organic acids $\xrightarrow{\text{bacteria}}$ new bacterial cells + methane + carbon dioxide + water + ammonia.

The aerobic process on the other hand can be represented as a single stage process :

Organic matter + Oxygen $\xrightarrow{\text{bacteria}}$ new bacterial cells+ water + carbon dioxide + phosphates + ammonia.

The oxygen for the aerobic process is largely provided by algal photosynthesis which can be expressed as follows :

Carbon dioxide + water $\xrightarrow{\text{algae + sunlight}}$ new algal cells + water + oxygen.

The pathogenic and faecal indicator bacteria are reduced due to various pond effects. Many theories about the destruction of pathogens and faecal indicator bacteria in ponds have been suggested :

- detention time and settling in ponds,
- temperature,
- bactericidal effect of solar radiation,
- presence of toxic substances produced by algae,
- high pH values found in ponds due to algae and
- competition for food.

The faecal bacteria and indicator organisms die off reasonably quickly in ponds due to the unfavourable environment mentioned above.

The cysts and ova of intestinal parasites have a relative density of about 1,10(Mara 1976) and as a result of the long detention times they settle to the bottom of ponds where they eventually die. the longer the detention time and the greater the number of ponds in series the better is the bacterial removal.

2.2. Designing Waste Stabilization Ponds.

Treatment plants should be designed on the basis of the flow and the strength of pollutants like B.O.D, S.S. and coliforms. Caldwell et al (1973) indicated that from previous studies by Parker et al (1968) and McGarry et al (1970), it is fairly well established that pond-process performance is effected by both areal B.O.D. loading and detention time. This could be shown from typical data studied by Parker et al (1970) which Caldwell et al (1973) refered to.

This data is shown in figure 11 and it is for canning wastes. Caldwell et al (1973) also report that a similar but not necessarily identical, empirical relationship would apply for domestic sewage.

The studies conducted on canning wastes in figure 11 showed that pond performance can be improved by three techniques :

(a) Increased detention time will increase B.O.D. removal and can be accomplished by deepening the pond. The most probable cause of improvement would be the increased algal sedimentation.

(b) Decreased areal B.O.D. loading will increase the B.O.D. removal by decreasing the carbon to be processed (and recycled to algae). This decreased loading can be accomplished by pretreating the sewage.

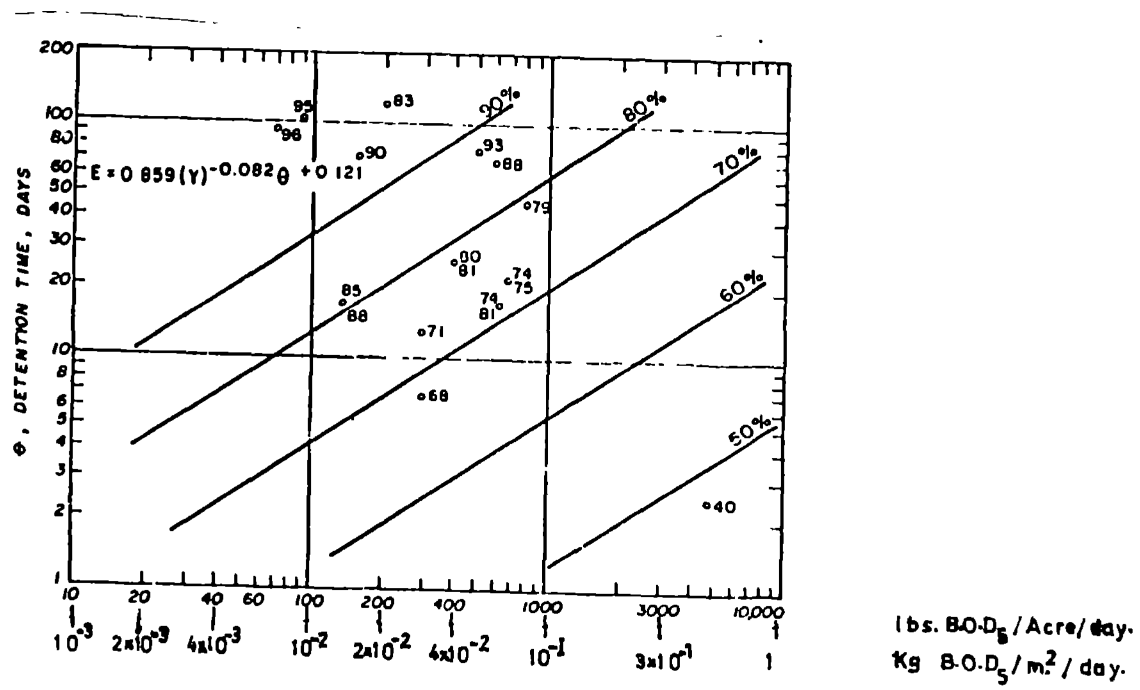

Figure 11. B.O.D. - removal relationship for ponds treating canning wastes (Caldwell et al 1973).

(c) Decreased areal B.O.D. loading and increased detention time can be accomplished by increasing the number of ponds in the system.

The third technique of improving pond performance mentioned above also agrees with the findings by Marais et al (1961) who established that for an equivalent total volume, a series of ponds is superior over a single pond. Another reason why a series of ponds is better than a single pond is because short-circuiting in reduced in a series of pond.

2.2.1. Zambian standards on influent and effluent quality of waste-water at treatment plants.

The required treatment is designed by the effluent standards on physical, chemical and bacteriological parameters. In addition to effluent standards, the Zambian Government, through the Ministry of Decentralization, has also set standards for waste-waters discharged into public sewers leading to treatment plants. Appendix A is an extract from Government of the Republic of Zambia statutory instrument number 161 of 1985 which is on the "Local Administration Regulations for Trade Effluent".

Some of the important parameters as set by the Zambian Government in Appendix A are as follows:

	Parameter	Influent to treatment plants	Effluent from treatment plants
(a)	B.O.D.	1200mg/1	50mg/1
(b)	S.S.	1200mg/1	50mg/1
(c)	pH	6-10	6-9
(d)	Temperature	60°	40°
(e)	Total phosphorus	45mg/1	6mg/1
(f)	Total ammonia	50mg/1	10mg/1

In addition to standards on influent and effluent of treatment plants, the publication also includes various other regulations which are:

(a) Concent to discharge trade effluent.

(b) Regulating the discharge of trade effluent.

(c) Methods and frequency of sampling and analysis.

(d) Measuring devices and inspection chambers.

(e) Sampling of trade effluent.

(f) Alteration and cessation of trade effluent.

(g) Accuracy in data recording and measuring devices.

(h) Charges for disposal of trade effluent.

(i) Appeals from decisions of councils.

(j) Offences and penalties.

(k) Period for compliance.

2.2.2. General design criteria and standards for waste stabilization ponds.

Once a pond system has been designed and constructed, its subsequent performance relies largely on the operation and maintenance activities and also on natural factors such as:

(i) temperature which affects aerobic and anaerobic biological activity,

(ii) solar radiation from sunlight which affects oxygen production because of the photosynthetic activity of algae and also has bactericidal effects which results in bacterial reduction,

(iii) wind action which affects mixing and surface aeration. Wind mixing in ponds reduces stratification and short-circuiting while surface aeration provides some oxygen which is used by bacteria for oxidizing the organic wastes,

(iv) rain-fall and evaporation which eventually affects the detention time in ponds.

The ponds depend on natural phenomena which vary with seasons over the year. It is therefore clear that designs for ponds should consider the effect of seasonal factors and include them where necessary. Even if it is generally true that ponds perform worst at the coldest time of the year, there are certain cases where worst performance of ponds in terms of B.O.D.-removal does not always occur in coldest or warmest months. Lumbers et al (1985) show that there are cases where worst performance corresponds to coldest months while in other cases there is no major variation in pond performance with seasons.

Lumbers et al (1985) also indicate that rather than using data from the coldest months when designing facultative ponds there are some phenomena which would argue for the hottest months to be considered. This is because it is during the hottest months that:

(a) bacterial activity is fastest,

(b) the interchange between the sludge and the liquid layers is greatest and

(c) the dissolved oxygen in the pond is lowest.

Further research should be done in order to find ways to avoid big seasonal variations in the quality of effluent from ponds.

The design of waste stabilization ponds is partly rational and partly empirical. According to research and practice already experienced ponds have been established in various depth ranges. Mara (1976) stated that the range of depths most commonly recommended for ponds are as follows :

anaerobic ponds	2,0 - 4,0m.
facultative ponds	1,0 - 1,5m.
maturation ponds	1,0 - 1,5m.

Mara (1976) also reports that length and breadth ratio should usually be in the range 2:1 to 3:1 and they are obtained from the pond mid-depth (bottom) area, i.e. assuming ponds have vertical sides. This mid-depth area of ponds is given by:

$$A = \frac{Q\,t}{D} \qquad (1)$$

where A = mid-depth area of ponds, m^2.

Q = volumetric flow rate, m^3/day.

t = detention time in pond, days.

D = pond water depth, m.

2.2.3. Design of anaerobic ponds .

The anaerobic activity progresses in two steps

1. Liquefaction and acid formation and

2. methane fermentation.

Mathane fermentation is practically absent below 15°C of water temperature (Arceivala 1973) but for temperatures higher than 15°C, the methane fermentation increases four-fold for every 5°C rise. Marais et al (1961) have indicated the digestion rate to be

$$Ks = 0,002(1,35)^{T-20} \quad (2)$$

where T is the temperature in °C

The above equation shows a very sharp effect of temperature on the rate at which gas evolves from the sludge layer. Hence one of the main factors to be considered when designing anaerobic ponds is temperature. Arceivala (1973) stated that temperature of 12°C is suitable for anaerobic ponds. Higher temperatures are however better for the anaerobic ponds. Another item of interest when designing anaerobic ponds is the volumetric organic loading rate which should be between 0,1 and 0,4Kg $B.O.D_5$ per m^3 per day (Arthur 1983). Arthur (1983) also states that values around 0,1kg $B.O.D_5$ per m^3 per day should be used for areas with air temperature of about 12°C while values around 0,4kg $B.O.D_5$ per m^3 per day should be used where there are uniform annual warm temperatures of 27° - 30°C. It is reasonable to assume a linear relationship for loading rates between air temperatures of 12°C and 30°C.

The third item after temperature and volumetric organic loading rate is the influent $B.O.D_5$ concentration in mg/l. This value should be the value of the wastewater to be treated by the anaerobic pond to be designed. The anaerobic pond detention time is then calculated by dividing the influent $B.O.D_5$ concentration in mg/l by the volumetric organic loading rate in grams $B.O.D_5/m^3$/day. However the optimum detention time for anaerobic ponds is five (5) days (Mara 1976).

Even if Arceivala (1973) states that detention times beyond five days are not generally desirable because the ponds may tend to act as facultative ponds, Mara(1976) argues that detention times less than five days for anaerobic ponds are not recommended because :

1. the bacteriological quality of the final effluent is poorer (i.e. the reduction of faecal bacteria is lower),
2. B.O.D. removal is lower,
3. the interval between successive desludging interval is smaller and
4. the risk of odour release is greater.

Sludge accumulation in anaerobic ponds requires that the ponds are cleaned periodically. Therefore the fourth item to be considered in design of anaerobic ponds is the sludge accumulation while the fifth item is the desludging interval. Arceivala (1973) states that sludge accumulation in anaerobic ponds is 0,03 to 0,05m^3/capita per year while Mara (1976) reports values between 0,03 to 0,04m^3 per capita per year. As stated by Mara (1976) the desludging interval in anaerobic ponds should be from two to five years.

The design of anaerobic ponds should be in such a way that together with the volume of pond determined by multiplying the quantity of flow per day and detention time, there should be an additional volume to be for sludge accumulation within the interval set for desludging operation. If this volume which is to cater for sludge accumulation is not taken into account then during the desludging interval the pond would not be operating at the designed depth and hence the performance would negatively be affected. The following example shows the methodology for designing anaerobic waste stabilization ponds.

Example 2.1

Design anaerobic ponds for a population of 10000 for an area with design air temperature of 15°C. Assume all the water consumption of 150l/capita/day ends up as sewage. Take sludge accumulation of 0,04m^3/capita per year and a desludging interval of four years. The concentration of the domestic sewage to be treated is 300mg/l $B.O.D_5$. Assume there is no effect of evaporation and rainfall in the ponds.

Solution:

(i) For the design temperature of 15°C, the volumetric loading rate is 0,15Kg $B.O.D_5/m^3$/day.

(ii) Detention time = $\frac{B.O.D_5 \text{ concentration (mg/l)}}{B.O.D_5 \text{ Volumetric Loading rate } (g/m^3/d)}$

$$= \frac{300 \text{ mg/l}}{150 g/m^3/d} = 2 \text{ days,}$$

Since detention time of less than 5 days is not recommended, 5 days is chosen as the detention time in ponds.

(iii) Depth (D):

Pond depths for anaerobic ponds are between 2 and 4m. Pond water depth of 2,5m. has been taken .

(iv) Volume of ponds:

(a) To cater for sludge accumulation

V_I = 10000 x 0,04m³/capita/year x 4 years

= 1600m³

(b) For sewage volume

V_{II} = 10000 x 150x10⁻³m³/capita/day x 5 days

= 7500m³

∴ Total volume of ponds = 9100m³

(v) Area of ponds (i.e. mid depth area)

$$A = \frac{Q\ t}{D} = \frac{10000 \times 150\times10^{-3} \times 5}{2,5}$$

$$= 3000m^3.$$

(vi) Actual depth of ponds in order to cater for sludge accumulation (d):

$$d = \frac{\text{Total Volume}}{\text{Mid depth area of ponds}}$$

$$= \frac{9100}{3000}$$

$$= 3,03m.$$

Thus to cater for sludge accumulation an additional depth of 0,53m. is required.

(vii) Number of anaerobic ponds:

2 parallel anaerobic ponds have been suggested.

Therefore the mid depth area of each anaerobic pond is 1500m².

(viii) Dimensions :

Length to breadth ratio of mid depth area of 2,4:1 has been taken

∴ Length for each pond is 60m while breadth for each pond is 25m.

The arrangement of the anaerobic ponds can be seen in figure 12.

2.2.4. Design of facultative ponds.

Lumbers et al (1985) states that almost all approaches to design of facultative ponds concentrate on the upper levels of the pond where dissolved oxygen is present for only part of the day and where soluble materials are oxidized by the activity of heterotrophic bacteria. The rate of this reaction is often assumed to be proportional to the concentration of soluble waste present and also to be highly temperature dependent. Lumbers et al (1985) states that this is only part of the activity involved. It is noted that the activity of the bacteria in the sludge accumulated at the bottom of the pond is not generally considered in design. However where temperatures in the bottom sludge exceed 15°C for part of the year , the activity and feed back of end products from the sludge zone plays a significant role in B.O.D. removal. It should be noted also that most of the time facultative ponds are largely anaerobic, as high concentrations of dissolved oxygen only exist in the upper layers during day-light hours.

It is important to maintain adequate oxygen levels in pond for providing a zone where gas rising from the pond is absorbed thus reducing the odour of the pond, and also for stabilizing soluble material from the inflowing wastewater and from the feed back from the sludge.

A rational approach to the design of facultative ponds is to assume that B.O.D. removal follows first order kinetics.

$$\frac{Le}{Li} = \frac{1}{1 + K_1 t} \qquad (3)$$

Where Le = Effluent $B.O.D_5$ concentration in mg/l

Li = Influent $B.O.D_5$ concentration in mg/l

t = Detention time, days

K_1 = First order rate constant for B.O.D. removal, day^{-1}.

Equation (2) can be rearranged to obtain the equation for calculating the detention time

$$t = \left(\frac{Li}{Le} - 1\right) \frac{1}{K_1} \qquad (4)$$

Substituting for 't' in equation (1) gives :

$$A = \frac{Q}{DK_1} \left(\frac{Li}{Le} - 1\right) \qquad (5)$$

Work in South Africa (Mara 1976) has shown that in order to maintain the pond predominantly aerobic, rather than predominantly anaerobic, 'Le' should be in the range of 50 to 70 mg/l for pond depths of 1,0 to 1,5m. The value of K_1 is about 0,3 d^{-1} at 20°C and its variation with temperature is described by the following:

$$K_{1(T)} = 0{,}3\ (1{,}05)^{T-20} \qquad (6)$$

where T is the design temperature and it should be taken as the mean temperature of the coldest month (Mara 1976).

Marais et al (1961) showed that a value of $K_1 = 0{,}17 d.^{-1}$ should be taken for South African conditions for example. Mara (1976) recommends depths between 1,0 to 1,5m. for facultative ponds. However Arthur (1983) states that there appears to be no reason why greater depths should not be used to increase the detention time and thus increase pathogen removal. Depths of facultative ponds greater than 1,2m. are advisable to allow for sludge accumulation while depths less than 1,0m. should be avoided to prevent vegetation from growing at the bottom of the pond. However the organic loading is independent of the pond depths.

Sludge accumulation in primary facultative ponds is less than in anaerobic ponds. The desludging intervals in primary facultative ponds can be twenty years or more (Arthur 1983), while sludge accumulation in secondary facultative ponds and maturation ponds is very small if not negligible to cause concern for desludging. The following example shows the design procedure for facultative ponds.

Example 2.2.

For the data in example 2.1 design facultative ponds following the two parallel anaerobic ponds.

Solution:

(i) Taking B.O.D_5 removal of 50% in anaerobic ponds, the influent B.O.D_5 concentration to facultative ponds is 300mg/l x (1 - 0,5)

= 150mg/l.

(ii) Taking B.O.D_5 removal of 70% in facultative ponds, the effluent B.O.D_5 from the facultative ponds

= 150mg/l (1 - 0,7)

= 45mg/l

(iii) From equation (6) at a design temperature of 15°C

$$K_{1(T)} = 0,3\ (1,05)^{T-20}$$

$$= 0,3\ (1,05)^{15-20}$$

$$= 0,24 \text{ per day.}$$

(iv) From equation (4) these values of $K_1 = 0,24d^{-1}$, Le = 150mg/l and Le ≒ 45mg/l give a detention time of approximately 10 days.

(v) Depths:

Facultative pond depths between 1,0 - 1,5m. are recommended. A depth of 1,5m has been selected.

(vi) Area of facultative ponds:

From equation (5) the mid-depth area of facultative ponds is:

$$A = \frac{Q}{DK_1} \left(\frac{Li}{Le} - 1 \right)$$

$$= \frac{1500}{1,5 \times 0,24} \left(\frac{150}{45} - 1 \right)$$

$$= 10000 \text{ m}^2 \text{ approximately.}$$

(vii) Number of facultative ponds and their arrangement:

4 facultative ponds taken of which 2 are to be in series after each anaerobic pond.

(viii) Area of each facultative pond cell:

$$A = \frac{10000m^2}{4}$$

$$= 2500m^2 \text{ approximately.}$$

(ix) Dimensions of each pond cell:

Length to breadth ratio between 2:1 and 3:1 to be allowed.

A ratio of 2,5:1 is taken and the length of each pond cell is 80m. while the breadth is 32m. which gives an area of approximately $2560m^2$.

2.2.5. Design of maturation ponds.

Maturation ponds serve to reduce even further B.O.D., S.S., faecal coliforms and ammonia. However, maturation ponds, which are largely aerobic in operation, should primarily be designed to achieve the desired faecal bacteria removals since the bulk of B.O.D. and S.S. are removed in anaerobic and facultative ponds. The reduction of faecal bacteria in any waste stabilization pond (anaerobic, facultative or maturation pond) has been found to follow first order Kinetics (Mara 1976):

$$Ne = \frac{Ni}{1 + K_2 t} \qquad (7)$$

where Ne = number of faecal coliforms/100ml for the effluent,

Ni = number of faecal coliforms/100ml for the influent,

K_2 = first order rate constant for faecal coliform removal, day^{-1},

t = detention time, days .

It has been shown that faecal coliform removal is more efficient with greater number of ponds in series for the same total detention time (Arthur 1983). For 'n' number of ponds in series.

$$Ne = \frac{Ni}{(1+K_2t_1)\,(1+K_2t_2)\,.....(1+K_2t_{n-1})(1+K_2t_n)} \qquad (8)$$

where t_i (where i is value from 1 to n) ,

is the detention time in the 'i th' pond, which also include anaerobic and facultative ponds.

The value of K_2 is extremely temperature sensitive (Mara 1976). It is given by the following equation:

$$K_2 = 2,6\ (1,19)^{T-20} \qquad (9)$$

where K_2 is the value of the first order rate constant for faecal coliform removal at any design temperature T in degrees celcius.

Marais et al (1961) has shown that for ponds in Zambia and South Africa a fair correlation with observed values exists at $K = 2,14d^{-1}$ for Escherichia coli, $K = 2,13d^{-1}$ for total coliforms and $K = 2,82d^{-1}$ for faecal streptococci. However for the purpose of design they selected a value of $K = 2,0d^{-1}$.

Mara (1976) states that a reasonable design value of Ni is 4×10^7 faecal coliforms per 100ml which is slightly higher than average values normally found in practice.

He also stated that as a general guide for tropical developing countries where effluent standards are not available Ne should be taken up to a maximum of 5000 faecal coliforms per 100ml.

A good design procedure for maturation ponds is to calculate the detention times in facultative ponds and anaerobic ponds and then determine the value of Ne which would result from equation (8) for two (2) maturation ponds in series each with a detention time of 7 days. If this value of Ne is not acceptable according to the effluent standards, then choose three or more maturation ponds in series each with detention time of 5 days till an acceptable value of Ne is obtained. the following example shows the design procedure for maturation ponds.

Example 2.3.

For the data in example 2.1. design maturation ponds in order to have effluent faecal coliforms concentration of 5000 cells/100ml. Take influent faecal coliform concentration of $4x10^7$/100ml.

Solution:

(i) Trying two maturation ponds in each of the two lines with the detention time of seven days for each maturation pond results to:

$$Ne = \frac{4x10^7}{(1+K_2.5)(1+K_2.6)(1+K_2.6)\ (1+K_2.7)(1+K_2.7)}$$

$$\text{At } 15°C \quad K_2 = 2,6(1,19)^{15-20} \qquad = \quad 1,1d^{-1}$$

$$\therefore Ne = \frac{4x10^7}{(1+1,1x5)(1+1,1x6)(1+1,1x6)(1+1,1x7)(1+1,1x7)}$$

$$= \frac{4x10^7}{28417} = 1,4x10^3 \text{ Faecal coliforms/100ml}$$

The value of $1,4x10^3$ faecal coliforms/100ml is acceptable with respect to the limit set by Mara (1976) of $5x10^3$ faecal coliforms per 100ml. Therefore a total of four maturation ponds, two of which are in each line will be provided. Refer to figure 12 for the arrangement of the ponds.

(ii) Depths of maturation ponds:

Maturation pond depths of 1,5m has been chosen.

(iii) Mid depth area of each maturation pond:

$$\text{Flow to each pond} = \frac{1500}{2} = 750m^3/day$$

$$\text{Area of each pond } A = \frac{Q\ t}{D} = \frac{750 \times 7}{1,5}$$

$$= 3500m^2.$$

(iv) Dimensions of each pond:

Taking length to width ratio of 2:1, each maturation pond will be 84m. long and 42m. wide. These dimensions give an area of $3528m^2$. for each maturation pond.

From examples 2.1, 2.2 and 2.3 the total mid depth area of all the ponds is $27352m^2$. Figure 12 shows the arrangement of all the ponds.

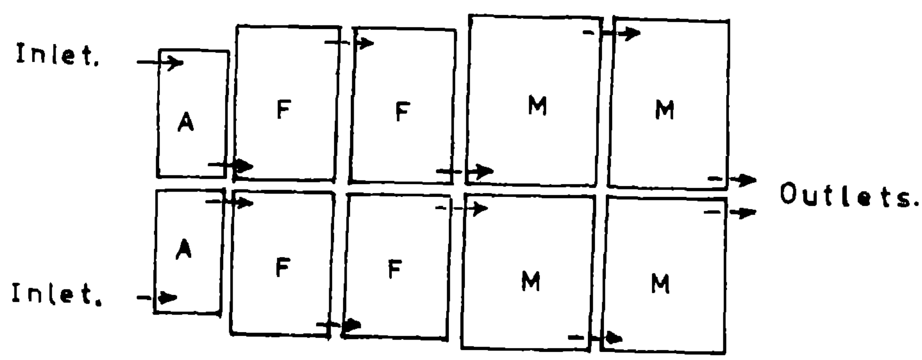

Figure 12. Arrangement of anaerobic (A), facultative (F) and maturation (M) ponds.

2.2.6. An alternative method of designing waste stabilization ponds.

Another method for designing waste stabilization ponds was set by Marais et al (1961). In their report they dealt with the criterion for determining aerobic and anaerobic conditions in ponds. To achieve this they conducted studies from which they plotted B.O.D. concentrations in ponds against the total depths of ponds. this is shown in figure 13.

From the graph, Marais et al (1961) showed that there was a clear seperation between the concentrations in B.O.D. leading to aerobic conditions and anaerobic conditions. An equation representing the limiting line is :

$$P = \frac{1000}{8 + 0{,}6D} \qquad (10)$$

where P = maximum B.O.D. concentration in the first pond consistent with aerobic conditions, mg/l.

D = Depth of the first pond in feet.

Also this value of the maximum B.O.D. concentration in the first pond can be represented by the following equation:

$$P = \frac{Po}{(1 + K_1 t)}$$

where Po = Estimate of the B.O.D. concentration of the influent to the first pond, mg/l.

K_1 = B.O.D. removal rate constant, d^{-1}. Its value for Southern African conditions was determined as $0{,}17 d^{-1}$. (Marais et al (1961).

t = Detention time in first pond, days.

Marais et al (1961) also derived that for a series of ponds, the influent and effluent concentration of either B.O.D. or faecal bacteria are related as follows:

$$Sn = \frac{So}{(1+Kt_1)\ (1+Kt_2)\ (1+Kt_3)\ \ldots\ldots\ldots\ldots(1+Ktn)} \qquad (12)$$

where Sn = Effluent concentration of either B.O.D. or faecal bacteria from the 'n th' pond.

So = Influent concentration of either B.O.D. or faecal bacteria to ponds.

t = detention time in the pond cells.

K = monomolecular constant for removal of either B.O.D. or faecal bacteria.

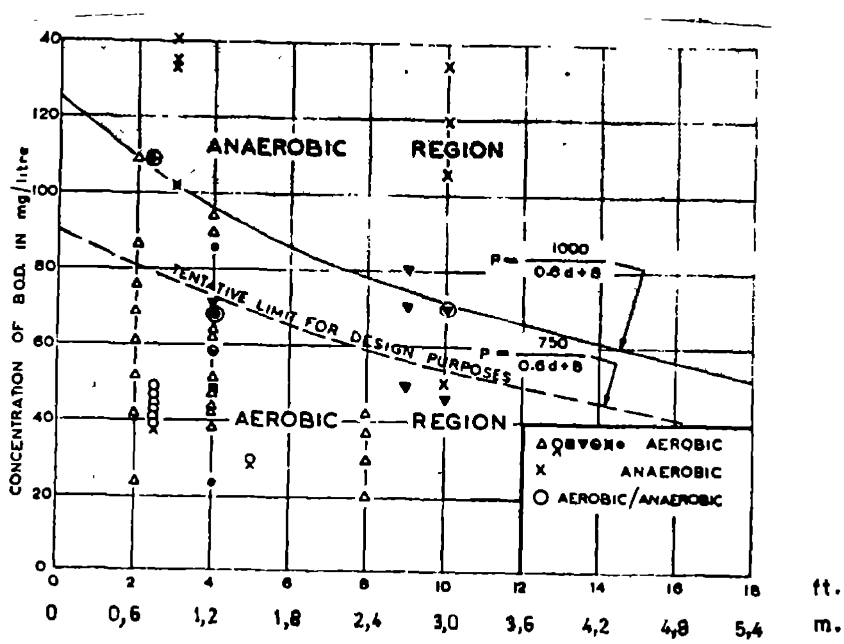

Figure 13. Plot of B.O.D. concentration in ponds against pond depths (Marais et al 1961).

If the depth of the first pond, D in equation 10 is in metres then equation 10 may be written as:

$$P = \frac{1000}{8+0,18D} \qquad (13)$$

This expression is valid only for depths between 0,6 and 3,0m. since it was for this depth range that the expression was derived. To allow for a safety factor in design the above equation should take into account a lower value for the critical concentration, say 75% as Marais et al (1961) suggested. Equation 13 then becomes,

$$P = \frac{750}{8+0,18D} \tag{14}$$

Marais et al (1961) also noted that the area/depth ratio of ponds does not have a significant effect on B.O.D. concentration in the pond. However for the purpose of design Marais et al (1961) suggested that the area/depth ratio should be at least 1000. With regards to the detention times they also suggested that the minimum detention time for the the first pond be seven days. It was also suggested that two ponds of seven days detention time each be the minimum number of secondary ponds in the system.

The design of ponds as set by Marais et al (1961) was based on three conditions:

(a) the ponds must remain aerobic in order to reduce odour problems,

(b) B.O.D. concentration must be reduced to design effluent concentration and

(c) faecal coliforms must be reduced to design level.

The design of the first pond was set to be governed by the first condition and the design of secondary ponds in size and number was governed by conditions for B.O.D. and faecal bacteria effluent quality.

The following is the design procedure suggested by Marais et al (1961):

1. Estimate the flow, B.O.D_5 and faecal bacterial concentration of the influent to the primary pond.

2. Select the depth of the first pond, which should be between 0,6 and 3,0m.

3. For this depth determine the maximum total B.O.D_5 concentration in first pond consistent with aerobic conditions from equation 14.

$$P = \frac{750}{0,18D+8}$$

where P is in mg/l and D is in metres.

4. With the value of P in step 3, determine the detention time of the first pond from equation 11.

$$P = \frac{Po}{K_1 t+1}$$

$$\therefore \quad t = \left(\frac{Po}{P} - 1\right) \frac{1}{K_1}$$

The value of K_1 can be calculated by using equation 6.

5. Determine the surface area of the first pond assuming vertical sides of pond from equation 1

$$A = \frac{Q\,t}{D}$$

6. Check that area/depth ratio does not fall below 1000. If this ratio is less than 1000 then reduce either the depth of the pond or the loading on the pond.

7. Adjust the surface area of the ponds to allow for the slopes of the banks keeping the detention time constant.

8. Select the depth of the second pond.

9. Determine the surface area of the second pond assuming the detention time to be seven days.

10. Select the depth of the third pond and determine the surface area assuming the detention time of seven days.

The total number of ponds should take into consideration B.O.D. concentration which satisfy the requirement and the concentration of bacteria to satisfy the effluent quality.

For B.O.D. the equation relating the effluent B.O.D. concentration is:

$$Pn = \frac{Po}{(K_1t_1+1)\ (K_1t_2+1)\ (K_1t_3+1)} \qquad (15)$$

where K_1 = removal rate constant for B.O.D_5

For faecal coliforms, the faecal coliforms in the effluent becomes:

$$Nn = \frac{No}{(K_2t_1+1)\ (K_2t_2+1)\ (K_2t_3+1)} \qquad (16)$$

where K_2 = removal rate constant for faecal coliforms.

If the concentration of bacteria and B.O.D. in the third pond as designed above does not satisfy the requirements, additional ponds in series should be added until the desired effluent quality is reached.

Example 2.4.

For the data in examples 2.1 to 2.3, design waste stabilization ponds which will be of aerobic conditions using the approach by Marais et al 1961).

Solution:

(i) Flow Q = $1500m^3$/day

(ii) B.O.D_5 concentration of raw sewage Po = 300mg/l

(iii) Faecal coliform concentration of raw sewage = 4×10^7/100ml

(iv) Depth of first pond cells = 1,5m

(v) Maximum B.O.D_5 concentration in first pond consistent with aerobic conditions.

$$P = \frac{750}{0,18D + 8} = \frac{750}{0,18 \times 1,8 + 8} = 90mg/l$$

(vi) Detention time in first pond cells:

$$t_1 = \left(\frac{Po}{P} - 1\right)\frac{1}{K} \; ; \quad \text{where } K_1 = 0,24 \text{ for } T = 15^{\circ}C$$

$$= \left(\frac{300}{90} - 1\right)\frac{1}{0,24} = 10 \text{ days.}$$

(vii) Surface area of first ponds:

$$A = \frac{Q\,t_1}{D} = \frac{1500\text{x}10}{1,5} = 10000\text{m}^2.$$

(viii) Check for area/depth ratio:

If two ponds will be in parallel, area for each is 5000m².

$\therefore$ the Area/depth ratio = $\frac{5000}{1,5}$ = 3333

This satisfies the requirement of at least 1000 as area/depth ratio.

Length and width of each pond will be 100 m.and 50m. respectively.

(ix) Depth of second ponds = 1,5m.

(x) For detention time of 7 days for second ponds the total area is:

$$A = \frac{Q\,t_2}{D} = \frac{1500 \text{ x } 7}{1,5} = 7000\text{m}^2.$$

Let there be two parallel ponds each with area = 3500m².

(xi) Depth of third ponds = 1,5m.

For detention time of 7 days for third ponds the total area is:

$$A = \frac{Q\,t_3}{D} = \frac{1500 \text{ x } 7}{1,5} = 7000\text{m}^2.$$

Let there be two parallel ponds each with area = 3500m².

(xii) Check for effluent quality:

(a) B.O.D_5 concentration:

$$\text{Effluent B.O.D}_5 = \frac{300}{(1+K_1t_1)\,(1+K_1t_2)\,(1+K_1t_3)}$$

$$= \frac{300}{(1+0,24\text{x}10)(1+0,024\text{x}7)(1+0,24\text{x}7)}$$

$$= 12,3\text{mg/l.}$$

This value of effluent $B.O.D_5$ satisfies the effluent quality as per Zambian standard of about 33mg/l $B.O.D_5$.

(b) F.Coliforms.

$$\text{Effluent faecal coliforms} = \frac{4x10^7 \text{ faecal coliforms/100ml}}{(1+K_2t_1)(1+K_2t_2)(1+K_2t_3)}$$

$$= \frac{4x10^7}{(1+1,1x10)(1+1,1x7)^2}$$

$$= 4,4x10^4 \text{ faecal coliforms/100ml.}$$

This value of effluent faecal coliforms is not acceptable according to the level set by Mara (1976) of 5000 cells/100ml. Hence three secondary ponds each with a detention time of five days should be chosen.

(xiii) Check for effluent quality for three secondary ponds.

(a) $B.O.D_5$ has already been satisfied.

(b) Faecal coliforms.

$$\text{Effluent faecal coliforms} = \frac{4x10^7}{(1+1,1x10)\ (1+1,1x5)^3}$$

$$= 1,2\ x10^4 \text{ cells/100ml.}$$

This value is also not acceptable. then take four secondary ponds each with detention time of 5 days.

(xiv) Check : Effluent faecal coliforms $= \frac{4\ x\ 10^7}{(1+1,1x10)(1+1,1x5)^4}$

$$= 1,9\ x10^3 \text{ cells/100ml.}$$

This value is acceptable.

(xv) Area of each secondary pond:

Depth for each pond is chosen as 1,5m.

$\therefore$ Area $A = \frac{750\ x\ 5}{1,5} = 2500m^2$.

Taking length to width ratio of 2,5 : 1 then the length and width for each secondary pond will be 80m. and 32m. respectively. These dimensions give an area for each secondary pond of $2560m^2$.

Since there are two parallel lines of the pond cells, then there will be eigth secondary ponds in the pond system.

Using the approach set by Marais et al (1961) the total area of the ponds becomes:

$$2x5000m^2 + 8x2560m^2 = 30480m^2.$$

From the two design procedures for ponds shown, the former procedure which includes anaerobic ponds had total area of $27352m^2$. While the latter procedure which excludes anaerobic ponds resulted in total pond area of $30480m^2$.

An important point to note from these examples is that even if anaerobic ponds result in odour problems more than in cases where aerobic conditions prevail,there is a considerable reduction in land requirement when anaerobic ponds are included. In the examples shown in this report there is a reduction in land requirement of ten percent.

2.3. Construction Aspects for Waste Stabilization Ponds.

The major consturction work involved for waste stabilization ponds is earth work. The soil formation should be relatively impervious to avoid percolation and ground pollution. Compaction of the soil may be needed and in some cases clayey soil may be needed for spreading on the pond floor in order to seal it. Steel et al (1981) state that the permissible seepage through the basin bottom should be a maximum of 6mm per day. Percolation from a pond tends to diminish considerably with time as deposited solids themselves help to seal the bottom.

Levelling of the pond area is desirable to keep the floor within ± 10cm. of the designed elevation (Aceivala 1973). He also stated that the outer slopes of the embankment may range from 2,0 to 2,5 horizontal to 1,0 vertical and the inner slopes may be same. Even with flatter slopes than the ones stated, it is important to pitch about 30cm. below and above the designed water level to prevent soil erosion.

It is also important to consider access to ponds by maintenance vehicles. This is important particularly for sludge removal operations. Mākelā (1985) states that to facilitate access of maintenance vehicles to ponds, dike widths of at least 2,4 m. should be provided. Attempt should always be made to balance the 'cut' and 'fill' volumes in order to keep the earth-work to a minimum and hence reduce the construction costs for waste stabilization ponds. It is also important to prevent surface run-off from entering the ponds. This can be achieved by making the dikes of the ponds to be higher than the surrounding surface.

The elevation of the ponds is dependent on several factors. Some of these factros include the ground-water level in order to minimize groundwater pollution, the high flood levels in case of river discharge which should not be allowed to flow to the ponds, and farm level in case of irrigating farms with effluent from ponds.

Some other aspects of pond construction are the arrangements for pond inlets, pond oulets and pond interconnections. Arceivala (1973) recommended some arrangements for inlets, outlets and interconnections for ponds as seen in figure 14.

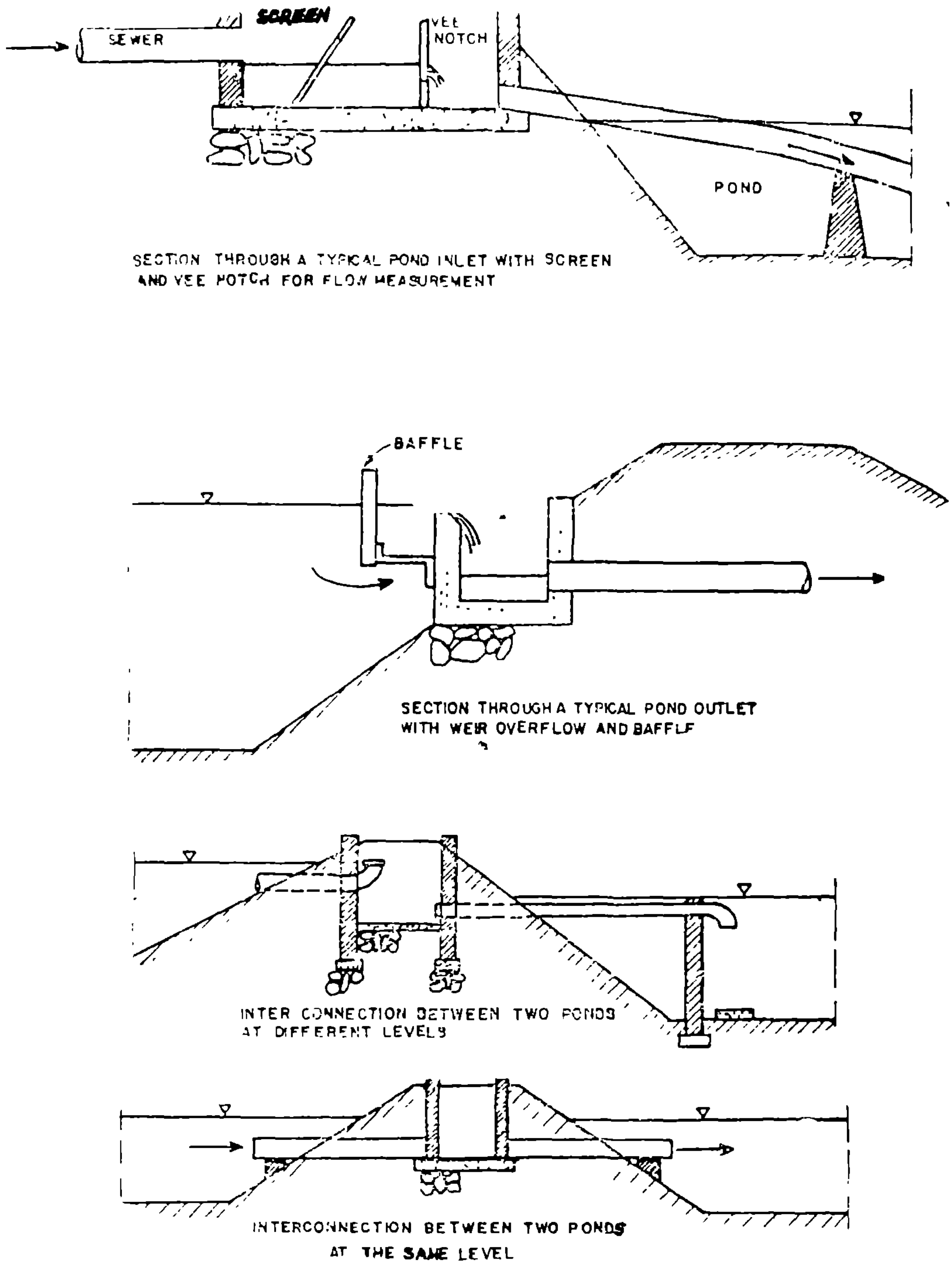

Figure 14. Typical pond inlet, outlet and interconnections (Arceivala 1973).

2.4. Operation and Maintenance of Waste Stabilization Ponds.

Operation and maintenance activities of waste stabilization ponds are relatively simple. The main operation and maintenance activities of pond systems include start-up procedures, removal of algae from pond effluent,removal of sludge from ponds, making solutions to pond operational problems, quality control on pond systems and reinstating damaged structures on the treatment system.

Pond systems are unique among sewage treatment methods for their ability to continue in operation and provide a reasonably good quality effluent despite poor or non existent operation and maintenance activities, in addition to advantages already discussed. However regular operation and maintenance activities should always be carried out on waste stabilization ponds in order to maintain a high standard of effluent, to avoid nuisance problems like mal-odours and insect breeding which may develop, to provide data for improvements in design of pond systems and to avoid rapid physical depreciation of the pond systems.

Waste stabilization ponds require simple operation and maintenance activities. If ponds can not be properly operated and maintained then there is no hope that other types of sewage treatment which are mechanically intensive can be properly operated and maintained. Good planning is important in order to achieve proper operation and maintenance of pond systems. Efficient operation and maintenance of ponds can be achieved if there are enough workers with basic skills to do the work around the treatment plant site. The operation and maintenance staff requirement for a pond system depends on the following factors:

(i) size of the ponds,

(ii) method of the preliminary treatment employed,

(iii) existence of laboratory to analyse samples,

(iv) nature of labour market in relation to workers rates of pay and

(v) availability of mechanical maintenance equipment and other facilities.

In addition to the operation and maintenance staff requirement, it is also important that the necessary tools which the workers are supposed to use are available.

2.4.1. Start-up of waste stabilization ponds.

The plan of operation and maintenance of waste stabilization ponds must include a programme for filling the ponds and initiating stabilized operational conditions. A pond does not immediately accept the full loads for which it is designed. An adjustment period equivalent to several detention periods is necessary during start-up of ponds (Gloyna 1971). The time taken to reach eqiulibrium will depend on the type of wastewater, type of ponds and the mode of decomposition.

Where there are several cold seasons,which affect pond performance, ponds should be commissioned immediately following the cold season. This allows the early months of pond operation to coincide with the warmest period of the year and enables the treatment system to become well established before the cold season (Arthur 1983). It is also advisable to start up the ponds in warm seasons when there is time for a more substantial pond biota to develop naturally (Water Pollution Control Federation 1976).

Before putting a pond in service weeds and other vegetation should be cleared from the pond bottom and interior slopes up to about 0,3m. above the maximum designed water level (Water Pollution Control Federation 1976).

Start-up of pond systems can present a number of problems like odour release and vegetation growth in the ponds. Arthur (1983) states that for ponds start-up allowance should be made for:

(a) low initial sewage flows as new connections are progressively brought into the systems,

(b) the slow establishment of the microbiological populations necessary for the treatment processes, and

(c) low initial sewage strength due to a high proportion of groundwater in the sewage.

(a) Solutions to low initial sewage flows.

Arthur (1983) suggests the following methods to cater for the low initial sewage flows:

- operating only one pond of a number of parallel anaerobic ponds,
- operating only one series of a total of two or more series of facultative and maturation ponds,
- operating only some of a single stream of facultative and maturation ponds, care being taken since the reduced number of ponds in series will reduce the pathogen removal efficiency,
- using only part of the total area of facultative and maturation ponds by bunding across them. This however causes problems of removing the bunds when the entire system is required.

Waste stabilization ponds should be filled as rapidly as possible to prevent odour release, emergent vegetation and erosion of pond embankment while the pond surface level is below the edge protection. Water Pollution Control Federation (1976) suggests the following useful measures in this regard:

- for a series of ponds, the ponds must be filled one at a time. The pond should be filled to twice the minimum depth and then half of its contents emptied to the second pond. This procedure should follow for each succeeding pond,

- if possible, before diverting the wastewater into the ponds, the first pond should be filled to its minimum depth with either municipal water or water pumped from a nearby stream or lake but care being taken to reduce silt pick-up,
- the pond bottom may be sub-divided temporarily with low dikes (0,2 - 0,5m. high). These dikes must be removed later because they impede circulation in the pond. The sub-divided portions of the ponds are then filled in succession with wastewater.

(b) Solutions for slow establishment of microbiological populations.

With regards to the slow establishment of the microbiological population necessary for the treatment processes (Arthur 1983 and Gloyna 1971) have suggested the following measures:

- Anaerobic ponds should be initially filled with raw wastewater and if possible be seeded with digesting sludge which helps in the rapid establishment of methanogenic bacteria and provides an initial buffering capacity. Where seeding has been carried out, the loading should be brought up towards the design loading rate over the following few days. Where there has been no seeding it may take longer for the methanogenic bacteria to become established, and loading should be increased gradually and slowly over the next 20 days or so.
- Facultative ponds should be seeded with digesting sludge if it is readily available and should initially be filled with water if possible before introducing the wastewater. In case of primary facultative ponds, the raw sewage should then be introduced slowly (say one tenth of the final flow rate), allowing the development of bacteria and algal populations, taking about 10 to 20 days, and reaching full loading rate after about one month. A secondary facultative pond which has been seeded

with digesting sludge and filled with water may be allowed to take the effluent as it flows from an anaerobic pond. Seeding facultative ponds with algal rich water is not generally necessary, although it may be used to speed up algal development if the algal rich water is readily available. When the ponds develop a true greenish colour, the inlets and outlets should be opened to accept the design loads.

- Maturation ponds should, wherever possible, be filled with water prior to loading. The first of a series of maturation ponds can be allowed to take effluent from the facultative pond. Other maturation ponds will in turn accept effluent from the preceding units until they are receiving their full loads. In each case, water flowing into the maturation ponds must be drawn from the algal rich surface layers of the preceding pond. Where there is no water available to fill facultative and maturation ponds before sewage is added, the ponds will be filled with raw sewage and left for 20 days for algal and bacterial populations to develop.

(c) Solutions for low initial sewage strength.

In order to tackle the problem of low initial sewage strength due to the high proportion of groundwater in the sewage, Arthur (1983) has suggested following measures:

- any anaerobic pond should be by-passed initially until there is sufficient strength and quantity of raw sewage to enable a loading of at least 0,1 kg $B.O.D_5/m^3/day$ to be achieved,
- facultative and maturation ponds should be filled with water initially, and should be kept full. Where the raw sewage is not sufficient to compensate for losses, then further water should be added. Where no water is available, the raw sewage should be used to fill the ponds.

No discharges from ponds should be made until all ponds have been filled to their design depths as specified . Everything possible should be done in terms of operation and maintenance of ponds in order to achieve a healthy growth of organisms in ponds. The appropriate chemical, biological and physical tests should be conducted on samples from the ponds. Action should be taken if the effluent quality does not satisfy the standards,

2.4.2. Algae removal from pond effluent.

The main role of algae in waste stabilization ponds is production of oxygen by their natural photosynthetic process, which is used to maintain aerobic conditions for facultative and maturation ponds. The performance of these ponds depends greatly on the proper growth of algae. The type of algae which predominates in the waste stabilization ponds depends on temperature, pH value, nutrients in the wastewater and sunlight intensity.

Algae consist of all the microscopic plants which have photosynthetic pigments but lack definite stems and leaves as in the case of higher plants. It has been estimated that there are over 15000 species of algae which have been studied (World Health Organization 1981). The most important algae found in waste stabilization ponds are green algae, brown algae (diatoms) and blue green algae (World Health Organization 1981). Each species of algae has its own amount of nutrient requirement for proper growth.

In the ponds there is metabolism of algae and bacteria. In the presence of sunlight and carbon dioxide, the algae convert the inorganic materials in the sewage to organic matter in form of algal protoplasm and also produce oxygen. The bacteria then metabolize the algal protoplasm aerobically to produce bacterial protoplasm, carbon dioxide and water as end products. The carbon dioxide is in turn used by algae. In the end the dissolved solids in sewage are converted into suspended solids as micro-organisms, and harmless elements like carbon dioxide and water.

Even if algae are important for the treatment of wastewater in facultative and maturation ponds, they should be removed from pond effluent. Studies on facultative and maturation pond effluents have indicated that effluent algae carry-over can have significant oxygen demand on receiving water courses. It was found that 0,18mg. of dissolved oxygen was required for each milligram of algae destroyed (Bare et al 1975). Removal of algae from pond effluent can thus improve the effluent quality significantly.

Several unit processes have been developed and used for algae removal in ponds and they are:

- micro-straining,
- in-pond removal methods,
- coagulation-flocculation-sedimentation processes and coagulation-dissolved air flotation processes and
- granular media filtration.

(a) Micro-straining.

Micro-strainers are effective only in removing large algae such are diatoms and blue-green algae. Micro-straining has proved to be unsuccessful for treating pond effluent primarily because some species of algae are smaller than the size of the openings of the micro-strainers (Stone et al 1975). Another reason isthat the micro-strainers areso often blocked. However this method can be used as a pretreatment unit in conjunction with other algae removal unit processes.

(b) In-pond removal methods.

(i) In-pond chemical precipitation.

The small size of algae and their low specific gravity complicate their removal processes. Certain chemicals are used to disturbilize algae suspensions and these chemicals include alum, ferric sulphate (Bare et al 1975) and magnesium ions (Stone et al 1975). the effect of the chemicals depends on pH value and the concentration of algae in the ponds.

(ii) Series ponds with intermediate chlorination.

Series ponds are recommended because they provide for algae sedimentation within the ponds. Chlorination is normally done to disinfect effluent, but it has also been found out that chlorine added to pond effluent will oxidize most of the algae and cause settling. This can be done by adding chlorine in a chlorine contact pond after the pond system.

With a reasonable degree of dosage control, disinfection or killing of algae should improve settling. However this method is relatively expensive. Moreover, the use of high dosages of chlorine could result in the production of toxic chlorinated organic compounds which may cause problems in the receiving streams (Environmental Protection Agency 1983).

(iii) Controlled discharge ponds.

Controlled discharge is defined as limiting the discharge from a pond system to those periods when the effluent quality will satisfy the discharge requirements. Controlled discharge is a good way to control concentration of algae in pond effluents where the problem is seasonal. Addition of various coagulants to controlled discharge ponds has proved to produce effluent of high quality.

Environmental Protection Agency (1983) reports that chemical treatment of controlled discharge ponds can produce excellent quality of effluents and the costs are relatively inexpensive. The various coagulants can be applied from a motor-boat. The cost of in-pond treatment and the long detention times required must be balanced against the alternatives available.

(c) Coagulation-floculation-sedimentation processes and coagulation-dissolved air flotation processes.

These processes are not recommended for small pond installations because they need highly qualified personnel for operation and possible control and also because of high capital investment. According to Stone et al (1975) 70 to 85% of algae from pond effluent can be removed by the coagulation-dissolved air flotation process.

The pH value is an important parameter in chemical coagulation. Alum was found to be an effective coagulant for algae in pH range of 5 to 9 (World Health Organization 1981). Magnesium used in conjunction with lime is effective as an algal coagulant. Lime primarily serves to raise the pH to permit the precipitation of magnesium hydroxide. At pH 11, the addition of 10mg. of magnesium per litre has been found to be sufficient for sewage grown algae removal using either sedimentation of the dissolved air flotation process (World Health Organization 1981).

(d) Granular media filtration.

The direct application of conventional filtration without pretreatment such as coagulation-flotation, has not proved successful in treatment of algae-laden waters. For effective filter operation the bulk of the algae must be removed before reaching the filter and the remaining suspended matter must be well coagulated.

In addition to the mechanical/chemical processes for algae removal from pond effluent, there is another algae removal method which is neither mechanical nor chemical in operation. This method involves the provision of troughs across the final ponds. Figure 15 is a sketch for the arrangement of the trough across a final pond.

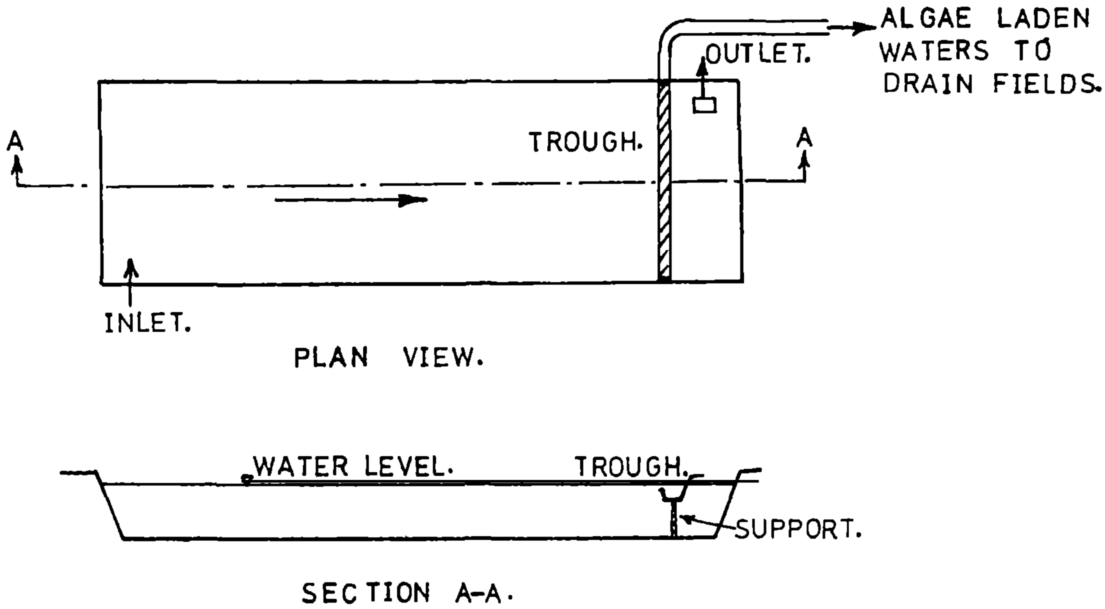

Figure 15. Arrangement of trough across the final pond for removal of algae rich waters from effluent.

The trough should be placed at a level such that water with the highest concentration of algae is eliminated from the effluent which is discharged to water courses. The water and algae trapped in the troughs should be diverted to drain fields. The outlet from the final pond should be at a lower level than the level of the trough.

2.4.3. Sludge removal from ponds.

Sludge is deposited at the bottom of ponds. The desludging intervals can be estimated even at the design stage. The rate of sludge accumulation is approximately 0,03 to 0,04m^3/capita/year (Mara 1976). The desludging intervals in anaerobic ponds may be from 2 to 5 years (Mara 1976) as already stated, while the desludging intervals in primary facultative ponds can be twenty years or more (Arthur 1983). Sludge accumulation in secondary facultative ponds and maturation ponds is very small and this does not cause concern for desludging.

However, waste stabilization ponds must be desludged when the ponds are approximately half full of sludge. Arthur (1983) states that the liquid depth should not be allowed to reduce to less than 1,0m. in facultative ponds before desludging.

There are two major methods used for sludge removal. Sludge removal can be done by raft mounted sludge pumps or by emptying the ponds of sludge after in-situ drying.

(a) Use of raft mounted sludge pumps.

Raft mounted sludge pumps are a preferable alternative where there is a short dry season limiting sludge drying time or when the sludge is very deep. One advantage for the use of raft mounted sludge pumps is that the pond can quickly be returned to normal use once the sludge has been pumped out. However the use of raft mounted sludge pumps has a disadvantage because drying beds are needed for the sludge.

(b) In-situ drying of sludge.

This is a good method where there is a long dry season or when the sludge layer is not so deep, say 1,0m or less (Arthur 1983). The main disadvantage of this method is that it may not result in complete sludge drying. The surface of the sludge dries to form a crust while the sub-surface layers may remain wet.

Once the sludge has dried throughout its depth it should be bull-dozed or excavated to one side of the pond being desludged. To facilitate for carting away of sludge, which may be used by farmers, access to the pond must be provided by constructing ramps to ponds. Otherwise the embankment will have to be removed or flattened to allow access, and carefully re-instated after use.

Before a pond is returned to its normal use after desludging operations, all damages on pond bottom and embankments must be repaired. Proper start-up procedures mentioned earlier should be done to bring back the desludged pond into operation.

2.4.4. Pond operational problems and their possible solutions.

Despite operational simplicity of pond systems, problems can develop and these can cause reduction in operational efficiency, nuisance and damage to structures of the system. The following are possible pond operation problems and their solutions as stated by Arthur (1983), Water Pollution Control Federation (1976) and Gloyna (1971);

(a) Odours during start-up of anaerobic ponds.

If pH is below 7 add lime, preferably as slurry at the inlet to anaerobic ponds. If there is present dissolved oxygen in the pond, increase the loading rate to maintain anaerobic conditions and in order to establish a good scum mat use straw or polystyrene.

(b) Loss of liquid volume because of sludge deposition, leakage or evaporation.

Sludge must be removed for more efficient operation. To eliminate leakage problems the ponds will require draining and sealing with impermeable soil or plastic membrane or a sealing clay such as "volclay" may be added to the pond. Inability to maintain liquid levels because of evaporation may be alleviated on a short term basis by adding water from a stream or lake into the pond.

(c) Vegetation growth during pond start-up.

Remove all vegetation from the bottom before filling the pond and fill the pond rapidly to a final pond liquid depth of more than one (1) metre. Any vegetation growing through water surface during filling should be removed by using a boat.

(d) Poor algae development during pond start-up.

Algal inhibition may be caused by poor nutrient balance or toxic compounds in the influent to ponds. To solve such a problem the wastewater concerned must be pretreated before discharge to the sewarage system. If the poor growth of algae is not because of poor nutrient balance or toxic compounds in the wastewater, then seed facultative and maturation ponds with algal rich water which will speed up algal development.

(e) Algal scum on facultative and maturation ponds.

Break up algal scum with water jets or from boats. In persistent cases add copper sulphate in the pond concerned to give a solution of about 1.0mg/ l.

(f) Vegetation growth at water's edge, on embankments and through pond surface.

For vegetation growth at water's edge, spray the water's edge with weed killer. Periodic grass mowing or bushing is the best control for embankment vegetation growth. It can also be controlled by applying a suitable herbicide. In order to control the vegetation growth through the pond surface, increase pond depth or loading rate in order to shut the light off from the bottom of pond, or remove weeds from pond bottom by using a boat.

(g) Burrowing animals or insects in embankments.

Plug holes on embankments, remove any animal food supply growing close to ponds, trap or poison the burrowing animals and spray insects.

(h) Fly or mosquito nuisance.

To eliminate the problem of fly or mosquito nuisance, keep ponds clear of vegetation, remove scum from facultative and maturation ponds and spray scum layer of anaerobic ponds. Also remove any exposed sludge banks and stock maturation ponds with fish. If significant insect breeding takes place,then larvicidal measures should be under taken. The following larvicides have been used effectively in some ponds:

(a) a thin layer of kerosene or diesel oil,

(b) 3% grammer isomer and

(c) 2% malathion .

Caution should however be exercised when using these substances, for excessive use may produce harmful effects on receiving water courses.

Larvae in maturation and under-loaded facultative ponds may be successfully controlled by introducing certain fish such as 'Tilapia Mossambica' which feed on the larvae.

(i) High algal concentration in effluent from pond systems flowing to receiving water courses.

Draw off effluent from below the surface or from wherever algal population is low or removing algae from pond effluent with procedures already discussed earlier.

(j) Lightly loaded ponds causing waste of space, insufficient treatment and production of algal mats.

To tackle this problem, use fewer ponds but care should be taken effluent requirements are not violated, especially with regard to faecal bacteria concentration.

(k) Overloaded ponds causing poor effluent quality.

Add more pond units either in series or in parallel. Increase operational depth of anaerobic ponds. Also another measure is addition of an oxygen source like sodium nitrate in quantities of 5 to 15% by weight of influent B.O.D. The nitrate should be spread evenly throughout the pond or it may be added in the inlet manholes.

(l) Overloaded ponds causing odour nuisance.

Add more units in parallel to anaerobic and/or facultative ponds. Increase operational depth of anaerobic pond. Use surface aeration for facultative ponds or interpond recirculation for primary ponds.

(m) Short-circuiting causing poor treatment and odour problems.

Improve recirculation by adding more inlets and/or outlets, or use baffles. Improve wind mixing if possible by erecting a wind screen. Clean out the sludge if necessary.

(n) Low temperatures which affect pond performance.

Temperature should always be considered when designing ponds. However, when two or more ponds are provided, series operation may be used during cold season to improve the effluent quality.

(o) Low light penetration in facultative and maturation ponds due to excessive liquid depths, excessive turbidity and algal or scum mats.

Measures to eliminate this trouble include reducing liquid depth to 1,5m., removing storm flows from sanitary sewer lines and breaking up scum mats.

2.4.5. Maintenance of pond systems.

Physical maintenance of waste stabilization ponds requires that regular inspection be made to determine deficiencies and deterioration. The physical plant maintenance involves correction of bank erosion, lining and rip rap deficiencies, animal burrow damage and access road deterioration. There should always be good access roads to the plant and to individual ponds. Roads must be maintained as all-weather roads. Any necessary repairs to the embankment must be made immediately after the damage has been noticed by the operators.

Good vegetation control should be exercised on the pond systems. The control of vegetation must be accomplished on a regular basis. The following are basic steps as stated by Water Pollution Control Federation (1976):

(a) Clearing all trees and shrubs from the ponds and the top and sides of embankments. This reduces potential leakage along the tree roots in embankments and also minimizes transpiration and organic load on ponds due to leaves falling from plants.

(b) Shallow rooted, perenial grasses may be planted on the embankments from about 0,3m. above the design water level on the inside slope.

(c) Grass should be mowed on a regular basis. When mowing equipment is used care should be taken to minimize the danger of overturning along the embankment slopes.

(d) The ponds should be kept clear of rooted vegetation.

For good maintenance activities to be carried out on the plants, a pond system requires the following basic tools as stated by World Health Organization (1981):

- garden implements such as rake, hoe, mattock and shovel,
- tools such as spanners, pipe-wrench, saw, screw-driver, hammer, chisel, drill, pliers, scissors, protective garments, helmets, rubber boots and gloves and
- small boat.

With these tools and equipment the operator would carry out small repairs and keep the plant in good shape. These tools and equipment should always be available and be properly maintained.

2.4.6. Quality control on waste stabilization ponds.

Quality control on waste stabilization ponds is important since the analytical measurements and the data obtained are used to determine the most efficient mode of operation and to provide data for future expansions. The data obtained is also important since it provides a basis for improvements in the design of waste stabilization ponds.

For any size of waste stabilization pond systems, provision should be made for determining the quantity of influent and effluent, measuring important physical, chemical and bacteriological parameters like temperature, S.S., $B.O.D_5$ and coliform counts. For large waste stabilization pond systems, routine flow and analytical measurements should be made.

Flow measurement is most simply accomplished using either a V-notch or a rectangular weir. In case of influent to pond systems, the use of weirs can create difficulties through the build-up of solids upstream of the plate. A more satisfactory device for measuring the quantity of influent to waste stabilization ponds is a Parshall flume although this is costlier to install and requires expert construction. For flow measurement it is satisfactory to install a Parshall flume for influent and a weir for effluent.

Flow measurements should be taken periodically, say daily, and recorded. Daily and seasonal variations in quantity of flow should be noted along with the characteristics and performance of the ponds. Measurements to indicate the B.O.D. concentration, the number of coliforms per 100ml, S.S. etc of wastewater should be done on influent and effluent of ponds. These measurements should be conducted periodically, normally weekly, and can be carried out by inspectors from a central laboratory. Samples for determining the temperature, $B.O.D_5$, S.S., coliforms and other parameters should be taken at the inlet and at the outlet of ponds.

In order to make for better quality control and more efficient operation of waste stabilization ponds, the following additional measurements must be conducted:

- pH of influent and effluent from pond systems,
- diurnal pH and oxygen fluctuations in ponds,
- nutrients in the influent and effluent of pond systems,
- oxidation-reduction potential in the ponds, particularly in the anaerobic pond units,
- chemical oxygen demand of influent and effluent of pond systems particularly if industrial wastewaters are involved,
- ultimate B.O.D. of influent and effluent of pond systems,
- sulphate ion content of influent waste-waters and
- the biochemical degradation rate K_T for various temperatures.

Not all these measurements are necessary for the operation of small or medium sized waste stabilization pond systems, but they might be desirable for the best management of larger and complex pond systems including research establishments.

3. STUDIES ON SELECTED WASTE STABILIZATION PONDS IN ZAMBIA.

The studies on waste stabilization ponds in zambia were conducted on four waste stabilization ponds. These ponds were selected from Lusaka, which is the capital city of Zambia, and Kitwe, which is one of the three cities in the country. the ponds studied in Lusaka included the first series of the Matero Ponds and the Chelston Ponds. In Kitwe, the Ndeke and the Mindolo Ponds were studied.

The selection of these ponds was based on factors like:

- availability of design data,
- availability of long record of experimental results,
- availability of climatological data and other information,
- type of sewage treated and
- ease of travelling to the ponds.

3.1. Location and Climate of the Selected Waste Stabilization Ponds.

The two cities from which ponds were selected are located in tropical regions. Due to non availability of a meteorological station in Kitwe, certain climatological data like temperature and evaporation were estimated from the data available for a nearby station in Ndola. The locations of these three cities in Zambia, namely Lusaka, Ndola and Kitwe, can be seen in figure 16. Ndola is about 55 Km. from Kitwe . The altitude of Ndola is about 20m. higher than Kitwe's altitude of 1250m. above mean sea level.

The location and climate of Lusaka and Kitwe are shown in table 1.

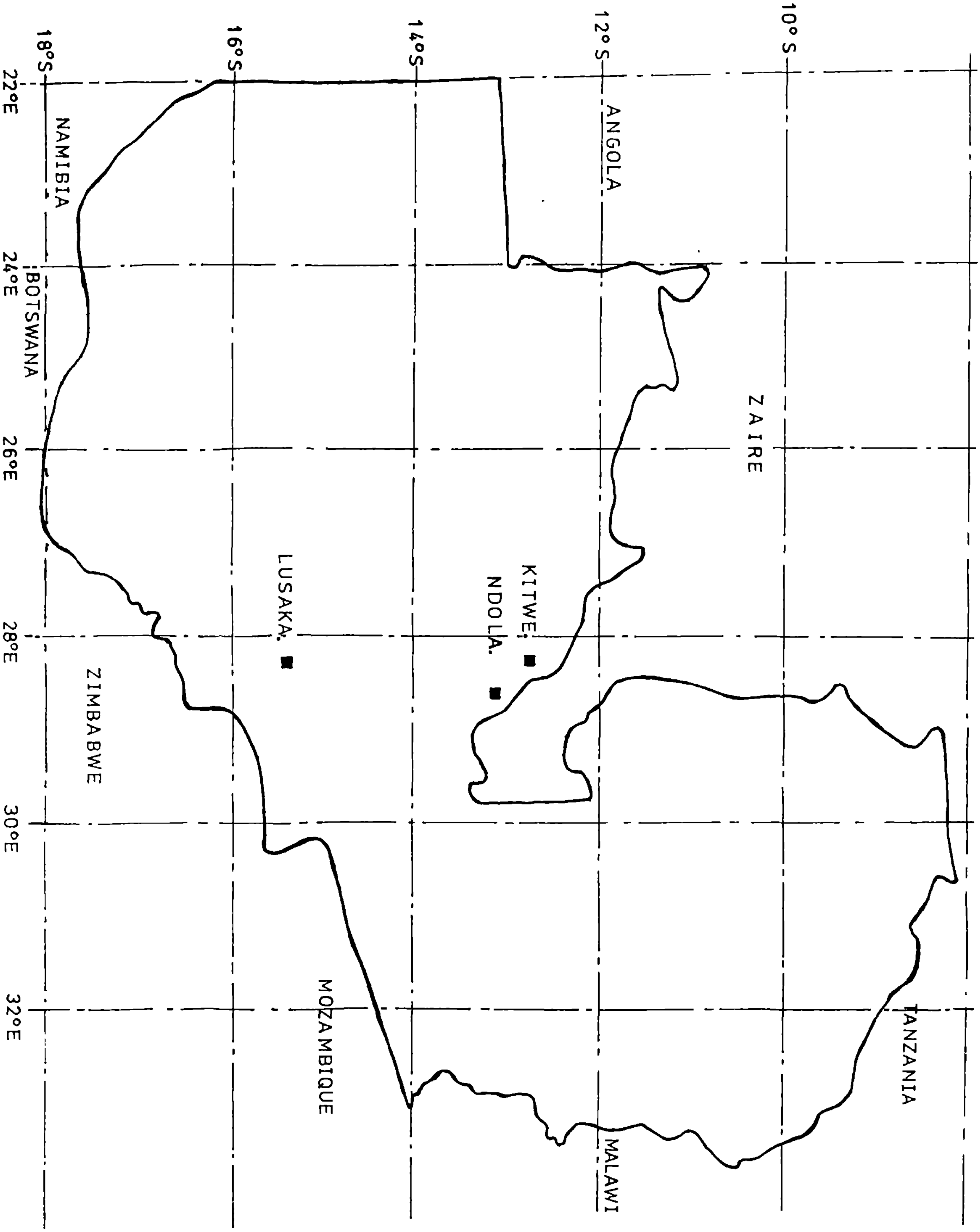

FIGURE 16. LOCATION OF LUSAKA, NDOLA AND KITWE.

Table 1. Location and climate of Lusaka and Kitwe.

	Lusaka	Kitwe
Longitude.	28°19'E	28°12'E
Latitude.	15°25'S	12°50'S
Altitude, metres above mean sea level.	1154	1250
Average annual rainfall, mm.	800-900	1400
Period of rain.	Oct.-May	Oct.-May
Value and month for maximum average temperature.	24°C in Oct.	23,7°C in Oct.
Value and month for minimum average temperature.	15°C in Jul.	15,2°C in Jul.
Average annual evaporation, mm.	222	205

The temperature values are averages between the maximum average temperatures and the minimum average temperatures. The temperature data for Lusaka is for a period between 1966 and 1980 while the data for Kitwe (estimated from data for Ndola) is for a period between 1950 and 1980. The evaporation data are averages for periods of 1975-1980 and 1963-1980 for Lusaka and Kitwe respectively.

3.2. Description of the Selected Waste Stabilization Ponds.

3.2.1. Description of the Matero Ponds.

The Matero Ponds have nine pond units which are in three parallel lines. Each line has three pond units arranged in series. These ponds can be seen in figure 17. The ponds have been developed in three phases. The first phase of these ponds were studied.

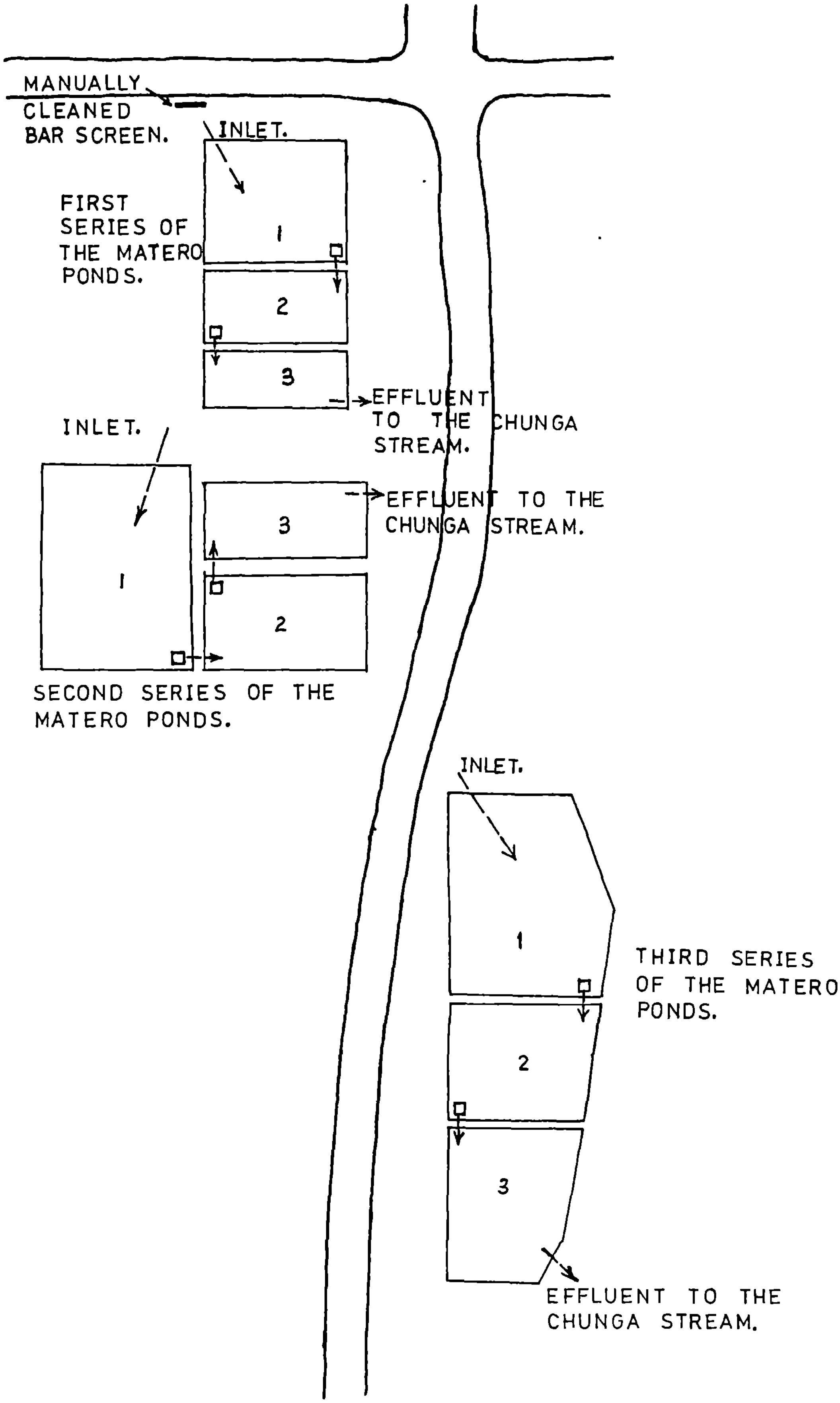

FIGURE 17. THE MATERO PONDS IN LUSAKA.

Each of the three phases of the Matero Ponds treats about the same volume of wastewater daily. The ponds under study (the first phase) were designed and constructed in 1961. These ponds were designed to treat domestic sewage at a daily flow of $1130m^3$ on average. The details of these ponds are shown in table 2.

Table 2. Details of the first phase of the Matero Ponds.

Area, m^2.	12200	3600	2200
Depth, m.	1,2	2,0	1,5
Detention time, days.	13	7	3
$B.O.D_5$ loading	0,02 $Kg/m^2/day$.		

The Matero Ponds were designed such that aerobic conditions prevail in the ponds. Upstream of the ponds there is a manually cleaned bar screen. The float meter which used to record the flow just before the ponds is no longer functioning due to buglary. The inlet to the first pond consists of a pipe which discharges sewage at the bottom near the centre of the pond. The effluent from the Matero Ponds discharges into the Chunga Stream along which gardening is done by the surrounding community.

3.2.2. Description of the Chelston Ponds.

The Chelston Ponds were designed to treat domestic sewage. The design flow is $1130m^3/day$. There is a pretreatment tank prior to the ponds. These ponds are comprised of three pond units arranged in series as shown in figure 18.

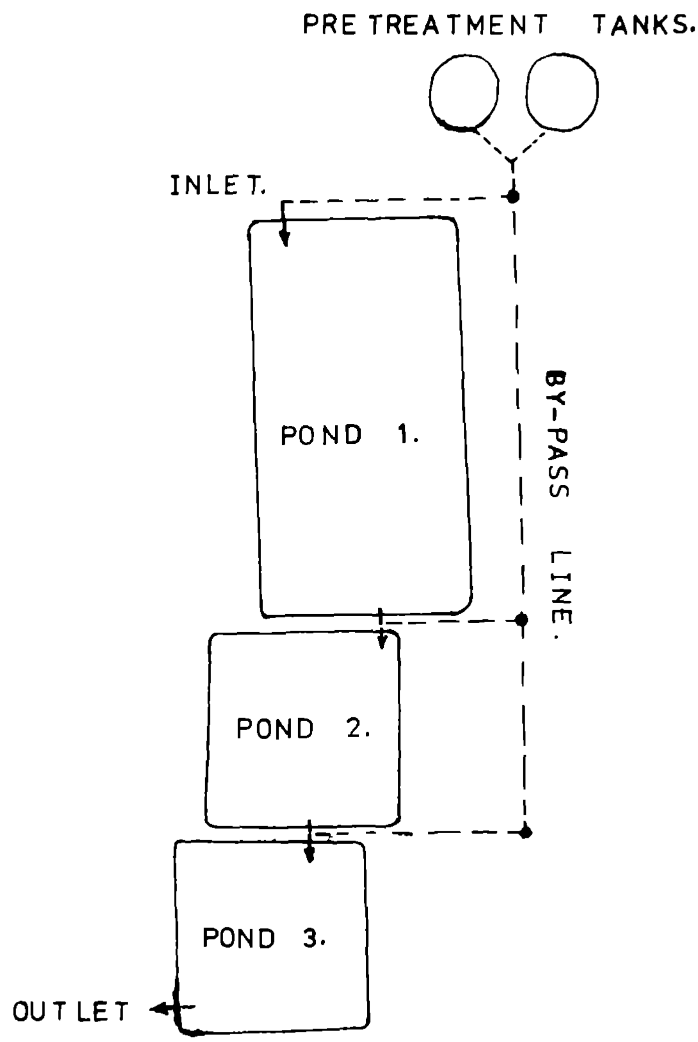

FIGURE 18. THE CHELSTON PONDS IN LUSAKA.

There is no screen prior to the chelston Ponds. Just upstream of the first pond unit there is a 90° 'V-notch' weir which is used for estimating the flow. Just like the Matero Ponds, the chelston Ponds were designed to achieve the prevalence of aerobic conditions in the ponds. The design details for the Chelston Ponds can be seen in table 3.

Table 3. Design details for the Chelston Ponds in Lusaka.

	Pond 1	Pond 2	Pond 3
Length, m.	155	79	79
Width, m.	79	79	79
Area, m^2.	12245	6241	6241
Depth, m.	1,2	1,2	1,2
Detention time, days	11	6	6
$B.O.D_5$ loading		0,02 $Kg/m^2/day$.	

3.2.3. Description of the Ndeke Ponds.

The Ndeke Ponds are comprised of five pond units. There are two primary pond units which are arranged in parallel. The two primary ponds are followed by three pond units arranged in series. Figure 19 shows the arrangement of the Ndeke Ponds. These ponds were commissioned in 1971.

The Ndeke Ponds were designed for a flow of $2100m^2/day$ of domestic sewage. Prior to the Ndeke Ponds there are neither flow measuring devices nor screens. The sewage is discharged to the ponds just near the edges of the ponds. This can be seen in figures 20 and 21.

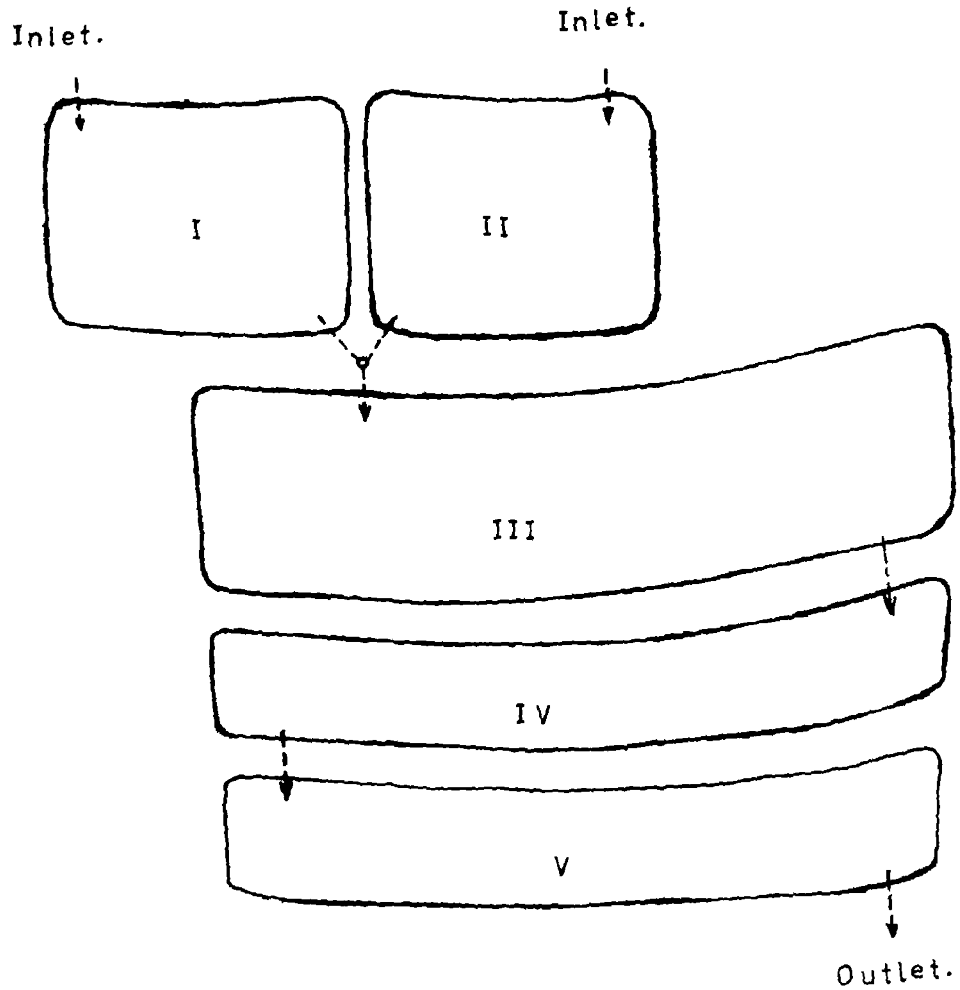

FIGURE 19. THE NDEKE PONDS IN KITWE.

FIGURE 20. SIDE VIEW OF THE INLET TO ONE OF THE TWO NDEKE PRIMARY PONDS.

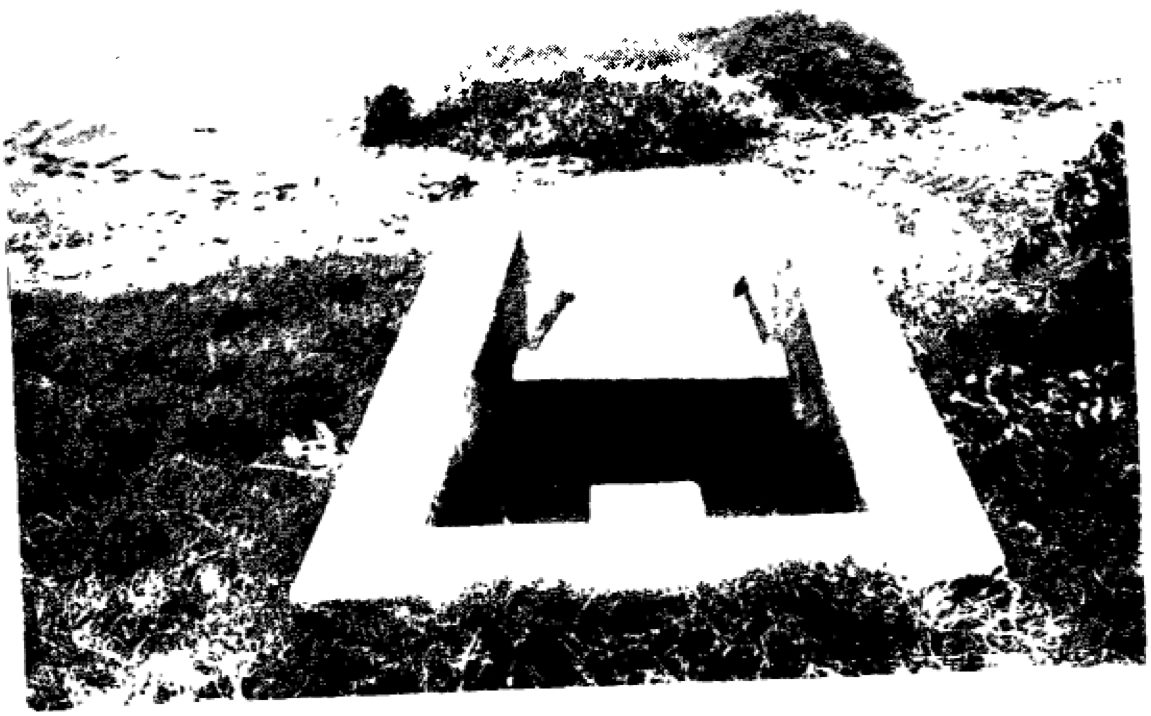

FIGURE 21. REAR VIEW OF THE INLET SHOWN IN FIGURE 20.

The Ndeke Ponds were also designed in order that aerobic conditions prevail in the ponds. Design details for the Ndeke Ponds are shown in table 4.

Table 4. Design details for the Ndeke Ponds.

	Parallel Primary Ponds		series secondary ponds		
	I	II	III	IV	V
Flow (m^3/day).	1050	1050	2100	2100	2100
Area (m^2).	7583	7583	15790	6710	7250
Depth (m).	1,5	1,5	1,5	1,5	1,5
Detention time(days).	11	11	11	4,8	5,0
B.O.D_5 loading			0,014 Kg/m^2/day.		

3.2.4. Description of the Mindolo Ponds.

The Mindolo ponds consist of ten pond cells in two parallel lines which are not identical. Each line has two parallel primary ponds which are followed by three ponds arranged in series. These ponds were designed to treat domestic wastewater. The design flow is 4740m^3/day. Figure 22 shows the arrangement of the Mindolo ponds. There are no screens prior to the ponds. The float meter for flow measurement is not functioning due to buglary.

The Mindolo ponds were also designed in order to have a prevalence of aerobic conditions. The treated wastewater is discharged to the Kafue River.

Figure 23 shows howthe flows are divided, while figure 24 shows the inlet arrangement to the Mindolo Ponds.

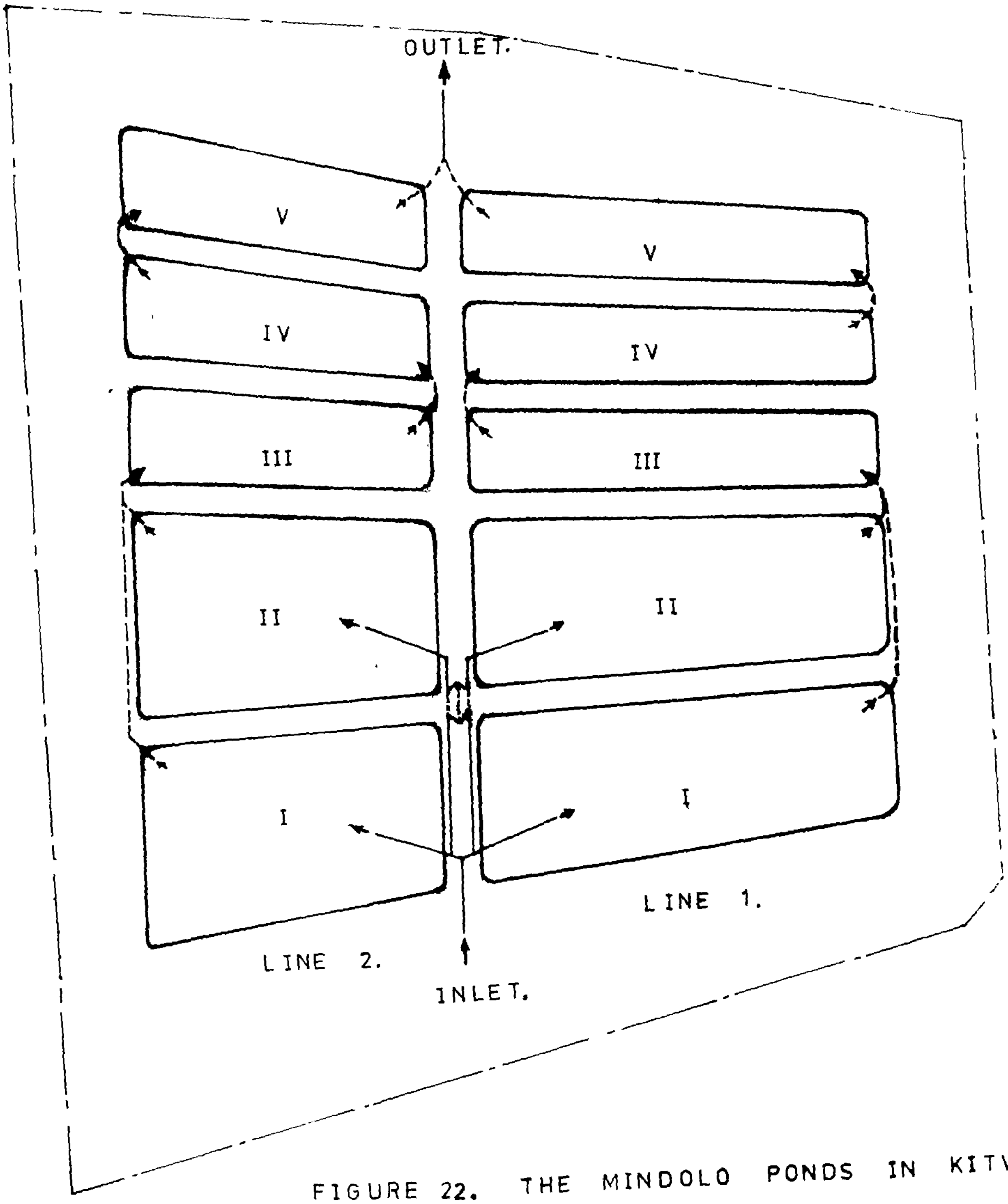

FIGURE 22. THE MINDOLO PONDS IN KITWE.

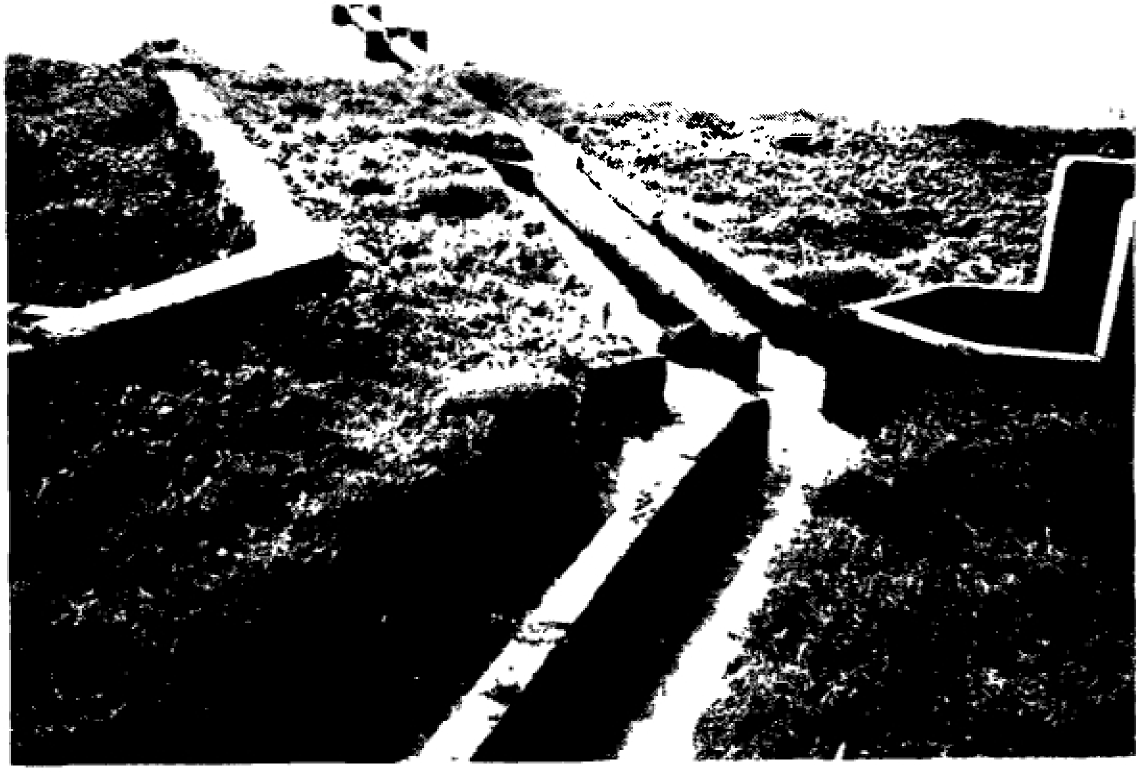

FIGURE 23. FLOW DIVIDING POINT AT THE MINDOLO PONDS.

FIGURE 2. INLET ARRANGEMENT TO THE MINDOLO PRIMARY PONDS.

The design details for the Mindolo Ponds are shown in table 5.

Table 5. Design details for the Mindolo Ponds in Kitwe.

	Line 1					Line 2				
	Parallel Primary Ponds		Series Secondary Ponds			Parallel Primary Ponds		Series Secondary Ponds		
	I	II	III	IV	V	I	II	III	IV	V
Flow, m^3/day	1185	1185	2370	2370	2370	1185	1185	2370	2370	2370
Area, m^2	14293	14293	7147	7147	7147	13562	13562	6781	6781	6781
Depth, m.	2,1	1,9	1,2	1,2	1,2	2,1	1,9	1,8	1,2	1,2
Detention time, days	25	23	5,4	3,6	3,6	24	22	5	3,4	3,4
B.O.D_5	B.O.D_5 loading = 0,015 Kg/m^2/day.									

For the selected ponds B.O.D_5 and faecal coliforms in the effluent were calculated using the design details and the values for the the removal rate constants K_1 and K_2 for B.O.D_5 and faecal coliforms respectively.

For the Matero and Chelston Ponds the removal rate constants used were 0,24d^{-1} for B.O.D_5 and 1,09d^{-1} for faecal coliforms. In the case of the Ndeke and the Mindolo ponds the removal rate constants used were 0,24d^{-1} for B.O.D_5 and 1,13d^{-1} for faecal coliforms. These were calculated by using equation 5 for K_1 and equation 9 for K_2. Equation 12 was used in calculating B.O.D_5 and faecal coliforms in the effluent of the selected ponds.

The B.O.D_5 in the influent was taken as 300mg/l while the faecal coliforms in the sewage to the ponds was taken as 4×10^7/100ml.
The results of the calculations for B.O.D_5 and faecal coliforms in the effluent from the selected ponds are shown in table 6.

Table 6. Values for effluent $B.O.D_5$,mg/l and faecal coliforms per 100ml as calculated from the design details.

	Matero Ponds	Chelston Ponds	Ndeke Ponds	Mindolo Ponds
Effluent $B.O.D_5$, mg/l.	15,8	13,8	4,8	5,8-6,6
Effluent faecal coliforms/100ml.	$7,1x10^4$	$5,4x10^4$	$5,2x10^3$	$8,1x10^3$-$1,0x10^4$

3.3. Construction, Operation and Maintenance of the Selected Waste Stabilization Ponds.

The selected waste stabilization ponds are properties of the Lusaka and Kitwe Urban District Councils. these ponds were constructed by excavating earth material and making embankments from selected earth material. The bottom and sides of the ponds were compacted properly during construction. However all the ponds studied are not lined.

Of the studied waste stabilization ponds only the Matero Ponds have screens prior to the ponds. These screens are of the bar type and they are manually cleaned.

There are staff stationed at all the selected pond sites. There are three workers at the Matero Ponds and the Chelston Ponds also have three workers. The Ndeke Ponds have four workers doing operation and maintenance duties while the Mindolo Ponds have three workers on pond site. All these workers are either, un-skilled or semi-skilled.

The main duties of these workers on the pond sites as prescribed by the authorities of the ponds are:

- cleaning screens, in case of the Matero Ponds,
- cutting or mowing grass around the ponds,
- removing vegation and floating material from the ponds and
- doing work involved during desludging.

In addition to the workers on pond sites, there are other workers employed by the councils. These are laboratory workers and they collect samples from all the sewage treatment plants in the towns and analyse the samples in laboratories run by the councils. They also collect information like flows to the ponds. The sample test results and the other information are compiled and records are kept by the district councils.

The two district councils plan on when to desludge the ponds. However desludging is not necessarily done after the design desludging interval. This is sometimes caused by lack of funds to perform the desludging operations.

For all the selected ponds it was observed that the arrangement of the inlet to primary ponds resulted in accumulation of all kinds of matter at pond inlets. There are no fences around the ponds and this results in un authorised entry by people to the pond sites. There are also crocodiles in the Ndeke and the Mindolo Ponds. These crocodiles come from the Kafue River which is near the ponds.

3.4. Methodology.

In addition to the results of the laboratory tests conducted during the study period, September 1985 to February 1986, the test results compiled by the Lusaka and Kitwe Urban District Councils were studied. Studies were conducted on $B.O.D_5$, S.S., E.Coli, pH and permanganate values of influent and effluent samples. The laboratory test methods adopted were also the methods used by the district councils.

3.4.1. Sampling.

Grab samples were collected at the inlets and at the outlets of the waste stabilization ponds. Samples were collected at about 10.00 hours. The samples were taken at about 5-10cm. from the surface of the waste-water at points where there was good mixing. The samples were then quickly transported to the laboratories for testing.

3.4.2. Laboratory test methods.

The samples were analysed as per the procedures given in 'Standard Methods for the Examination of Water and Waste Water (1965). $B.O.D_5$ was determined by establishing the dissolved oxygen (D.O) prior to incubation and also after incubating the samples for five days at 20°C. The samples were not chlorinated.

A glass fibre filter disc, whose total area is about $17{,}3cm^2$. with total open area of $12{,}5cm^2$, was used to filter the samples for S.S. determination. The volume of sample filtered was 100ml. Filtering was done by using a vacuum of at least 380mm of mercury.

E.Coli counts in the wastewater was carried in order to estimate the faecal coliforms. Instead of faecal coliforms, E.Coli were determined because it is very difficult to find faecal coliform counts. Moreover the 'die-off' of E.Coli is similar to that for faecal coliforms. Hence the number of E.Coli in the effluent reveals that almost a similar number of faecal coliforms are present. E.Coli counts were made for 100ml. of samples by using the Most Probable Number (MPN) method.

3.5. Sample Test Results.

The influent and effluent samples from the selected ponds were analysed in the laboratories for pH, permanganate values, S.S., E.Coli and $B.O.D_5$. Due to non availability of equipment and chemicals, tests for E.Coli were not conducted regularly for ponds in Lusaka. However as will be seen in section 3.4.4, an indication of E.Coli values for the effluent samples from the Matero Ponds are shown in table 7. These tests of E.Coli for samples from the Matero Ponds were conducted by the African Housing Board, Lusaka, in 1963.

3.5.1. pH values.

The graphs representing the pH values for the Matero, Chelston, Ndeke and Mindolo Ponds are on figures 25,26,27 and 28 respectively.

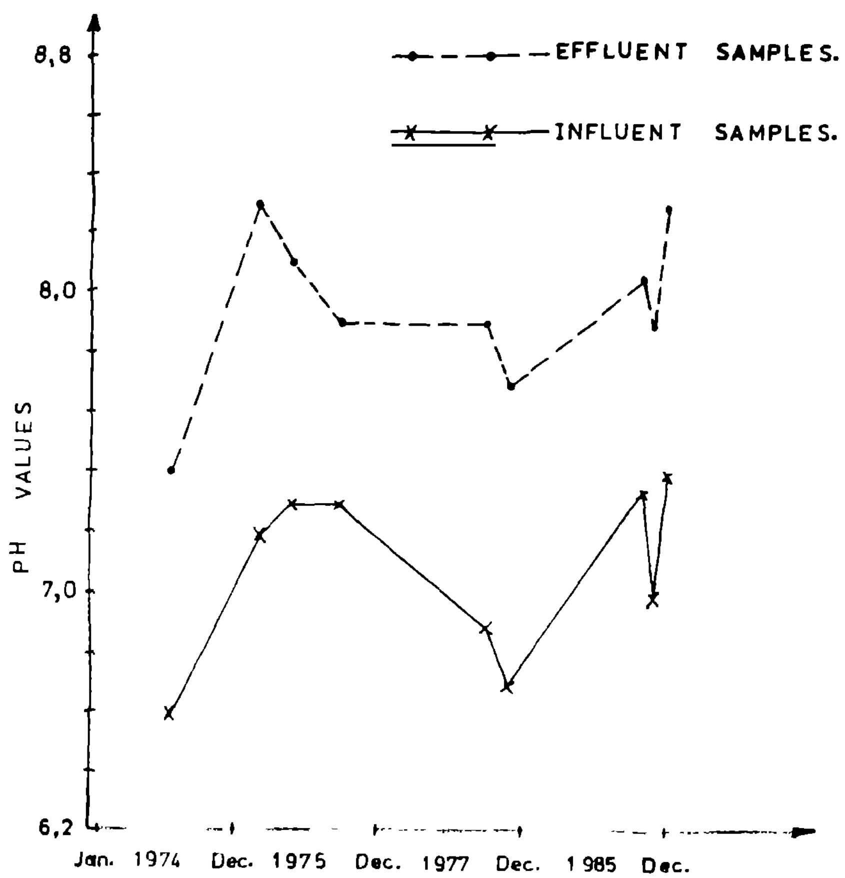

FIGURE 25. PH VALUES OF SAMPLES FROM THE MATERO PONDS IN LUSAKA WHICH TREAT DOMESTIC SEWAGE.

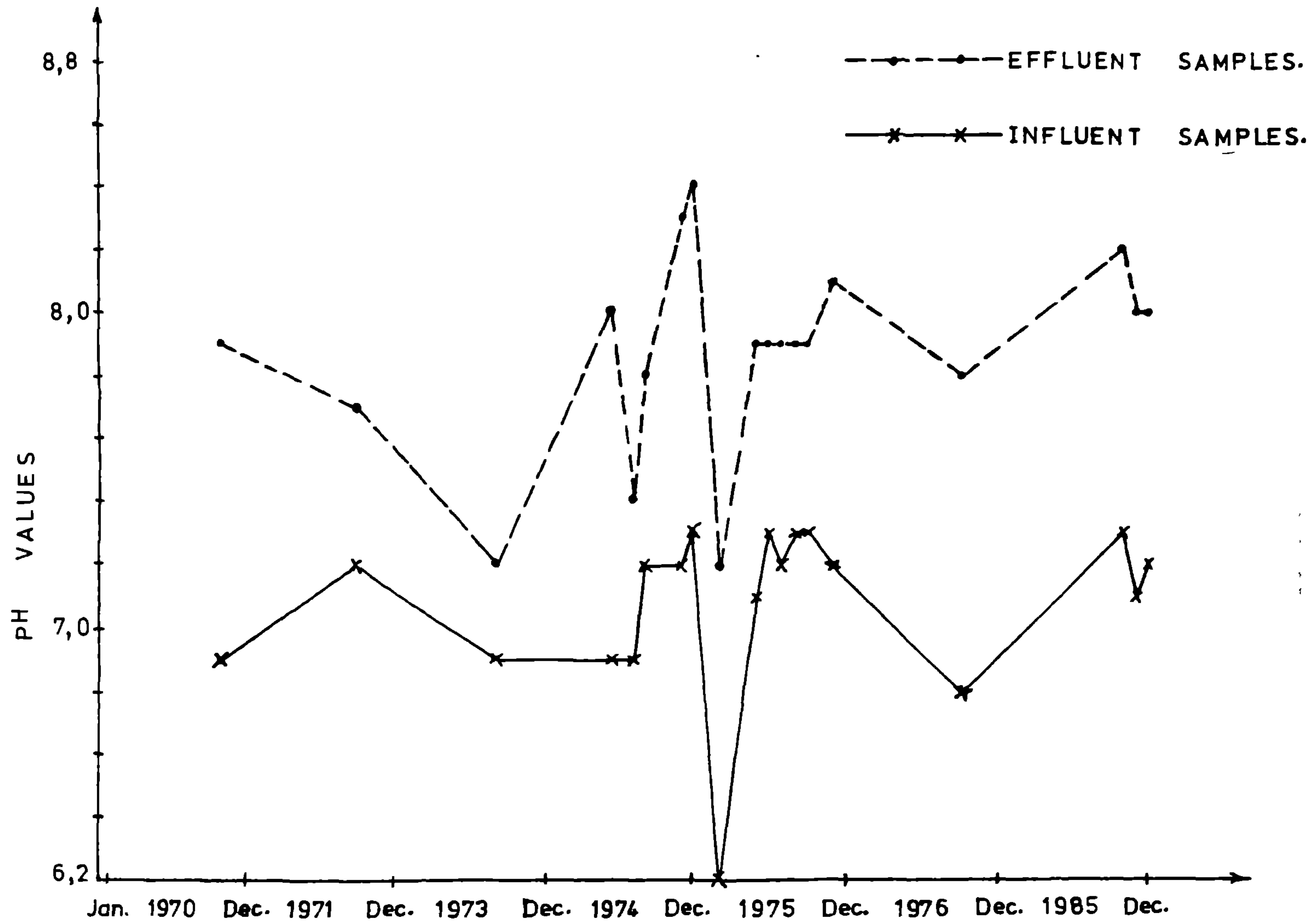

FIGURE 26. PH VALUES FOR SAMPLES FROM THE CHELSTON PONDS IN LUSAKA WHICH TREAT DOMESTIC SEWAGE.

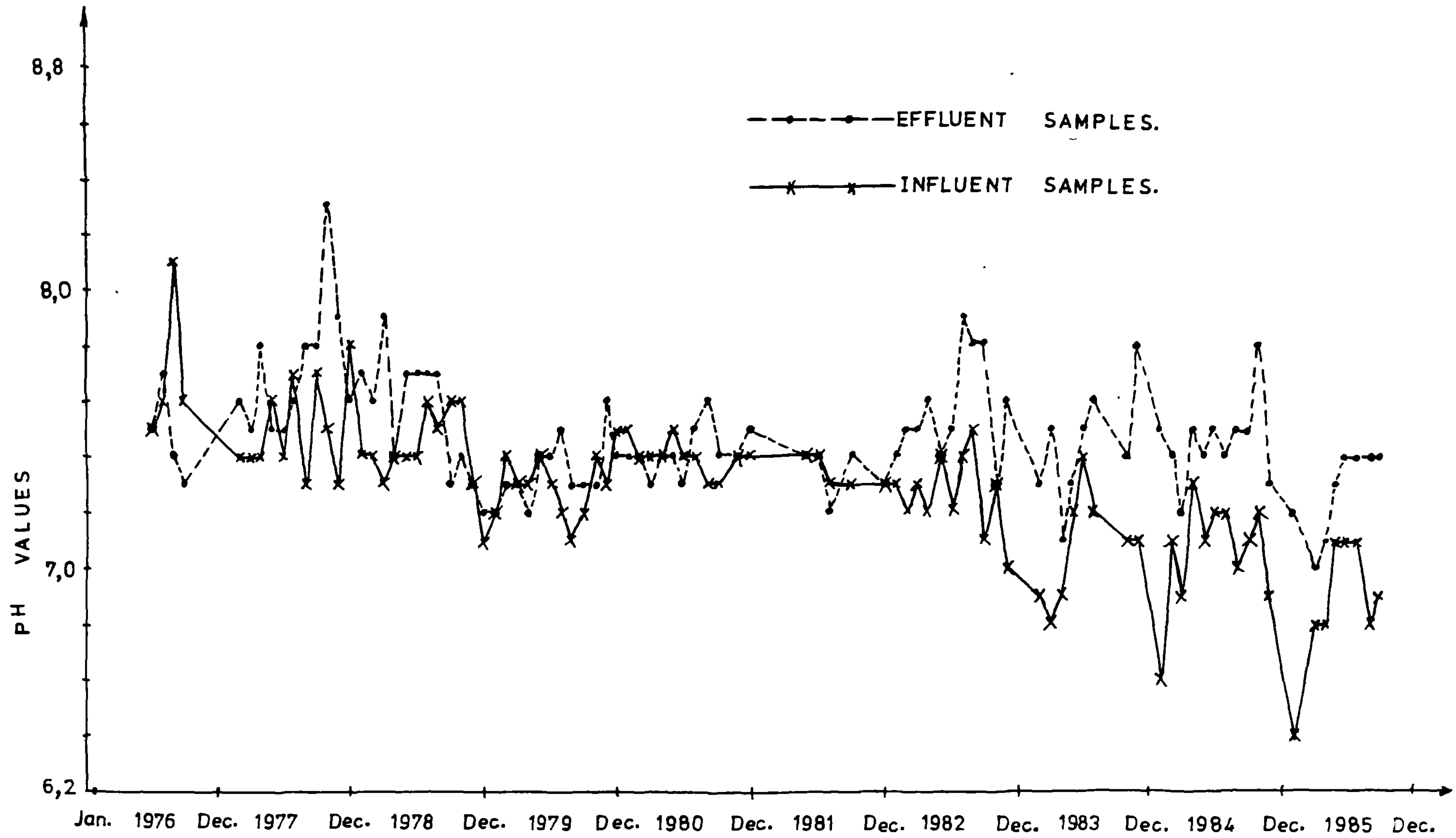

FIGURE 27. PH VALUES FOR SAMPLES FROM THE NDEKE PONDS IN KITWE WHICH TREAT DOMESTIC SEWAGE.

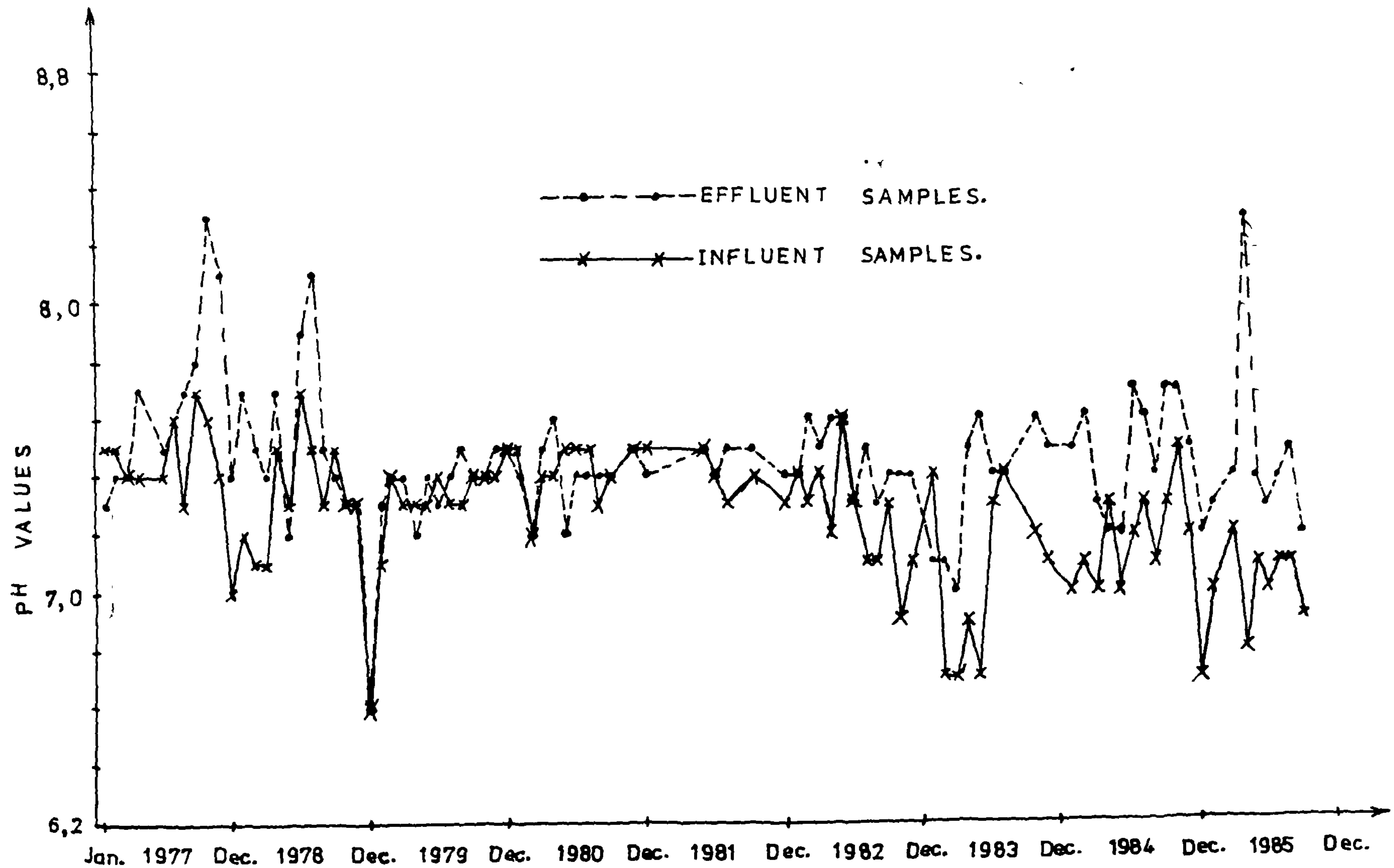

FIGURE 28. PH VALUES OF SAMPLES FROM THE MINDOLO PONDS IN KITWE WHICH TREAT DOMESTIC SEWAGE.

3.5.2. Permanganate values

The permanganate values for the influent and effluent samples from the Matero, chelston, Ndeke and Mindolo Ponds are shown in figures 29, 30, 31 and 32 respectively.

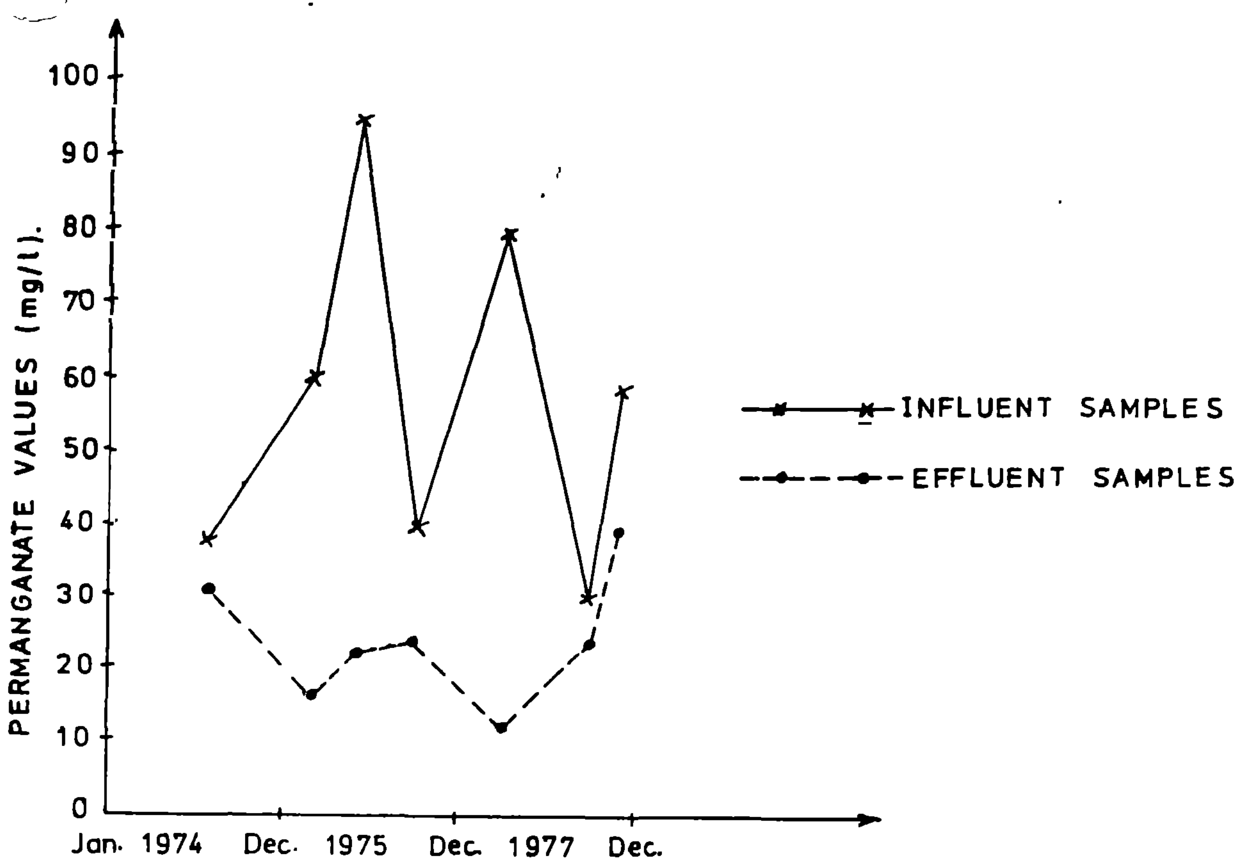

FIGURE 29. PERMANGANATE VALUES FOR SAMPLES FROM THE MATERO PONDS IN LUSAKA WHICH TREAT DOMESTIC SEWAGE.

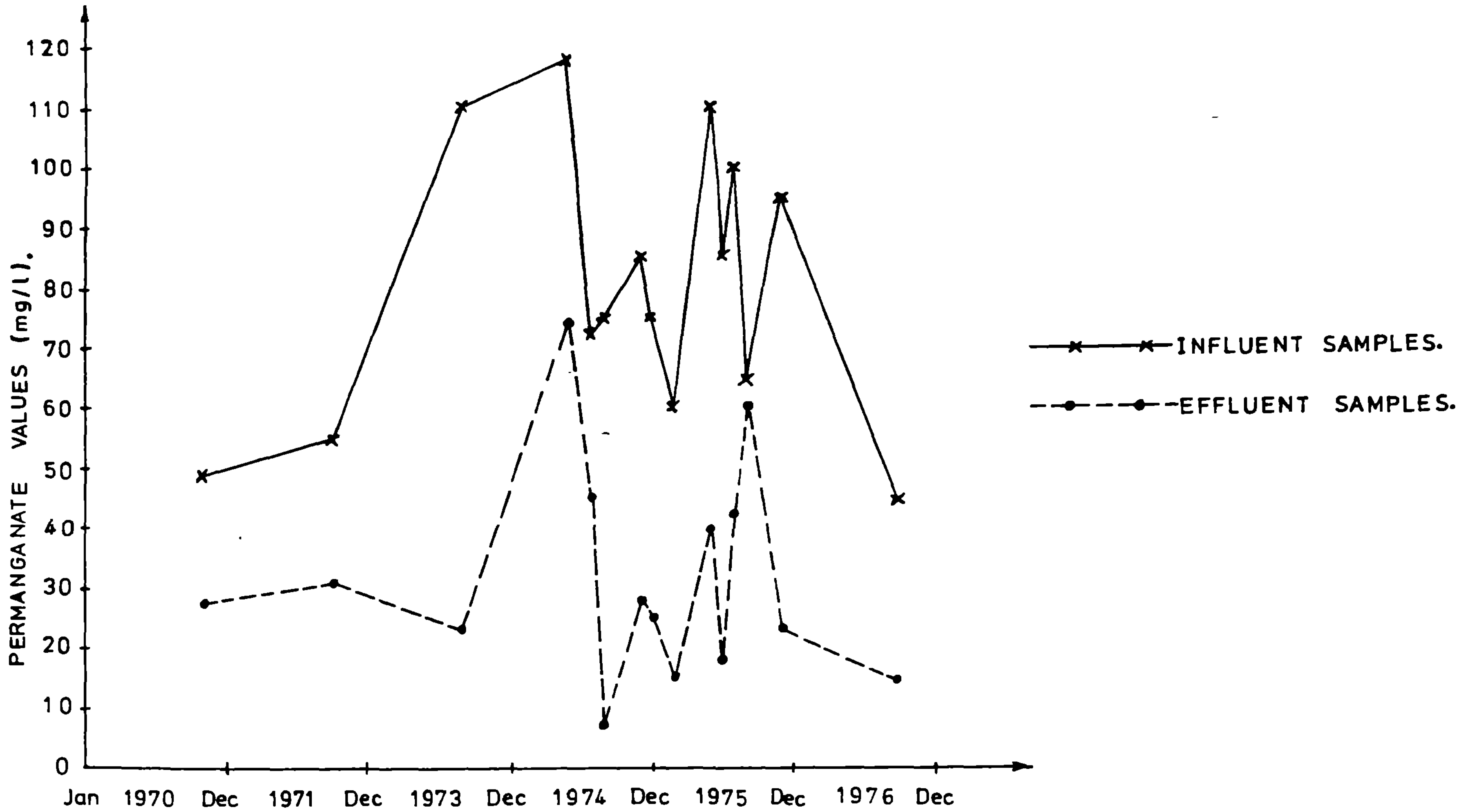

FIGURE 30. PERMANGANATE VALUES FOR SAMPLES FROM THE CHELSTON PONDS IN LUSAKA, WHICH TREAT DOMESTIC SEWAGE.

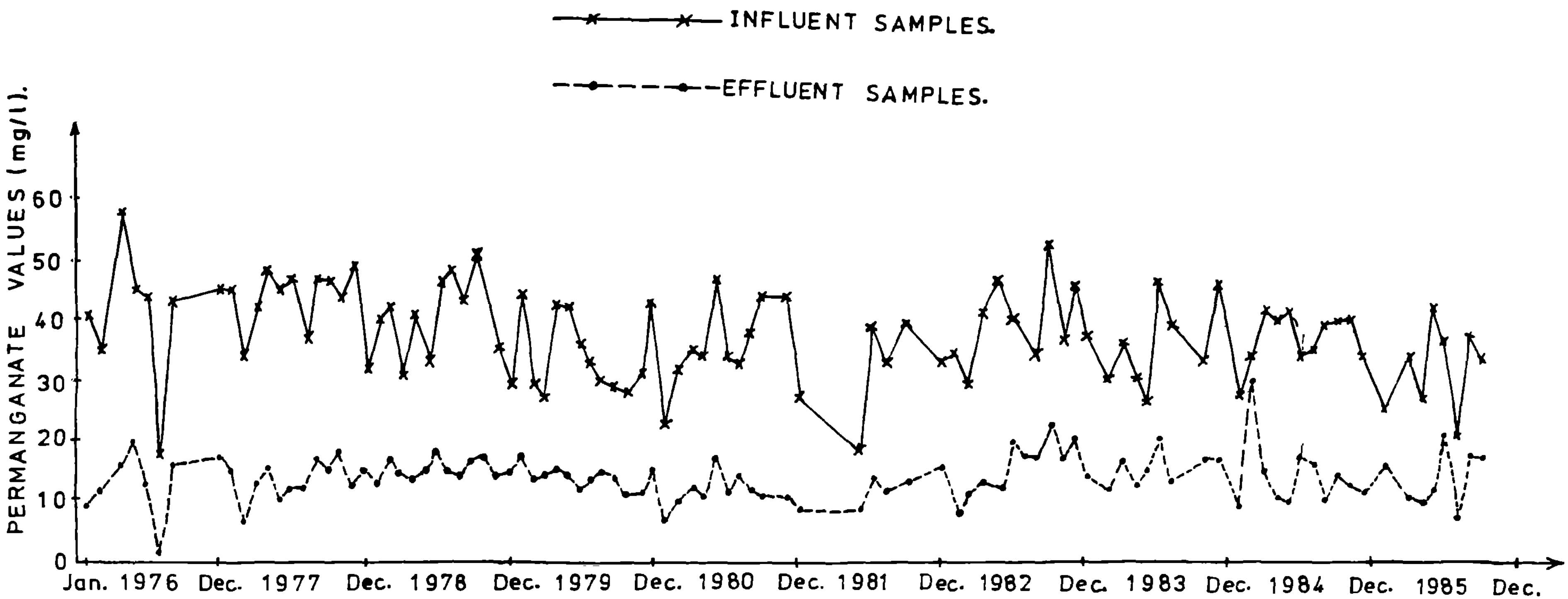

FIGURE 31. PERMANGANATE VALUES FOR SAMPLES FROM THE NDEKE PONDS IN KIWE WHICH TREAT DOMESTIC SEWAGE.

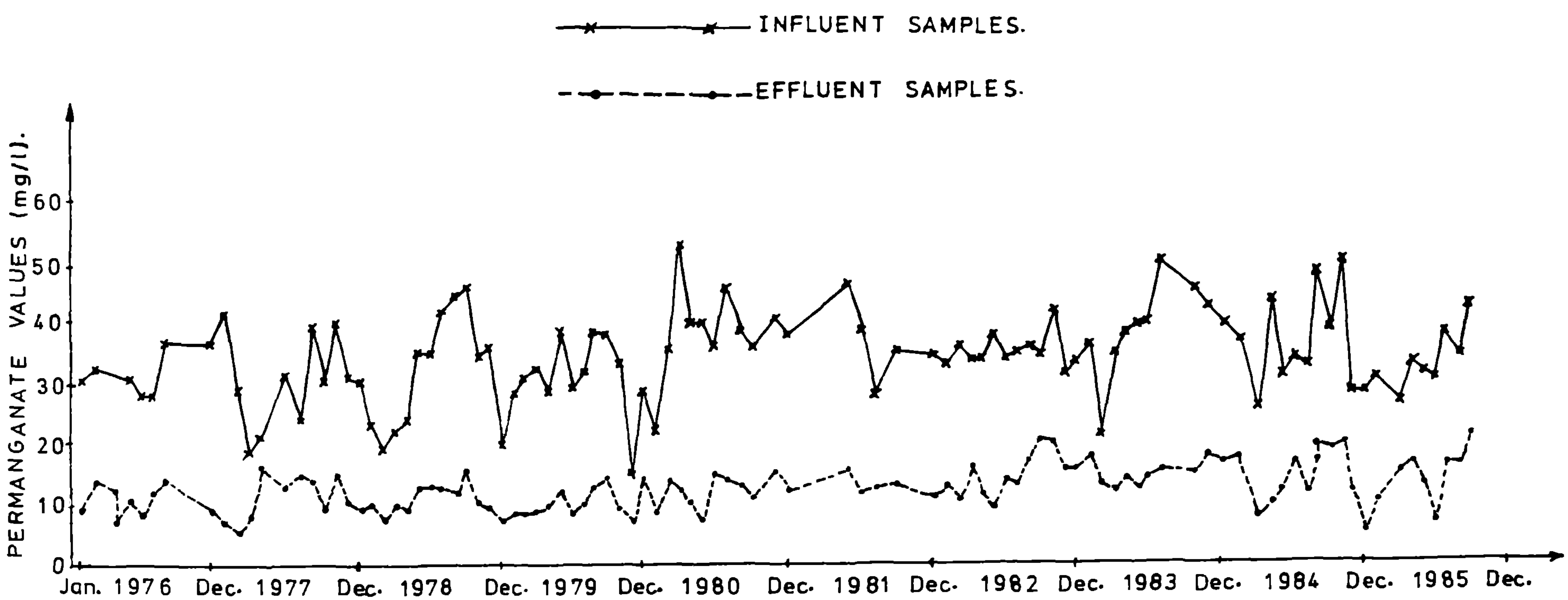

FIGURE 32. PERMANGANATE VALUES FOR SAMPLES FROM THE MINDOLO PONDS IN KITWE WHICH TREAT DOMESTIC SEWAGE.

3.5.3. S.S.

Graphs for S.S of the influent and effluent samples of the selected ponds are shown in figures 33,34,35 and 36. These figures are for the Matero, chelston, Ndeke and Mindolo Ponds respectively.

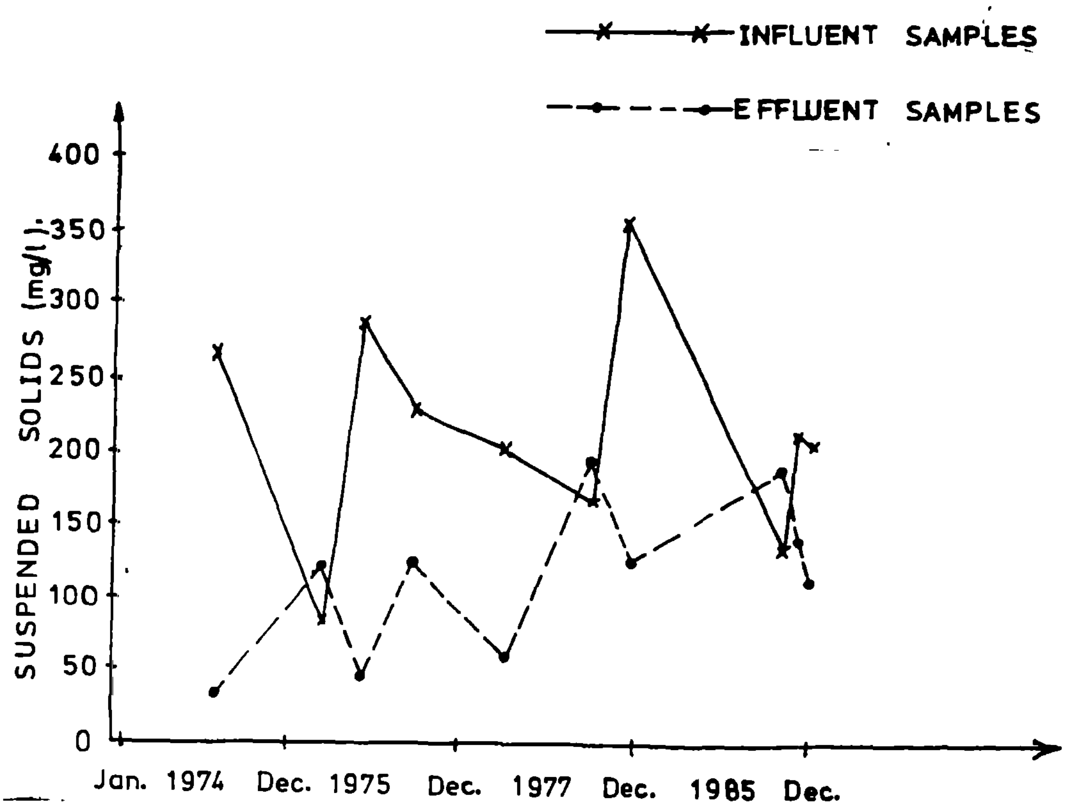

FIGURE 33. S.S. IN SAMPLES FROM THE MATERO PONDS IN LUSAKA WHICH TREAT DOMESTIC SEWAGE.

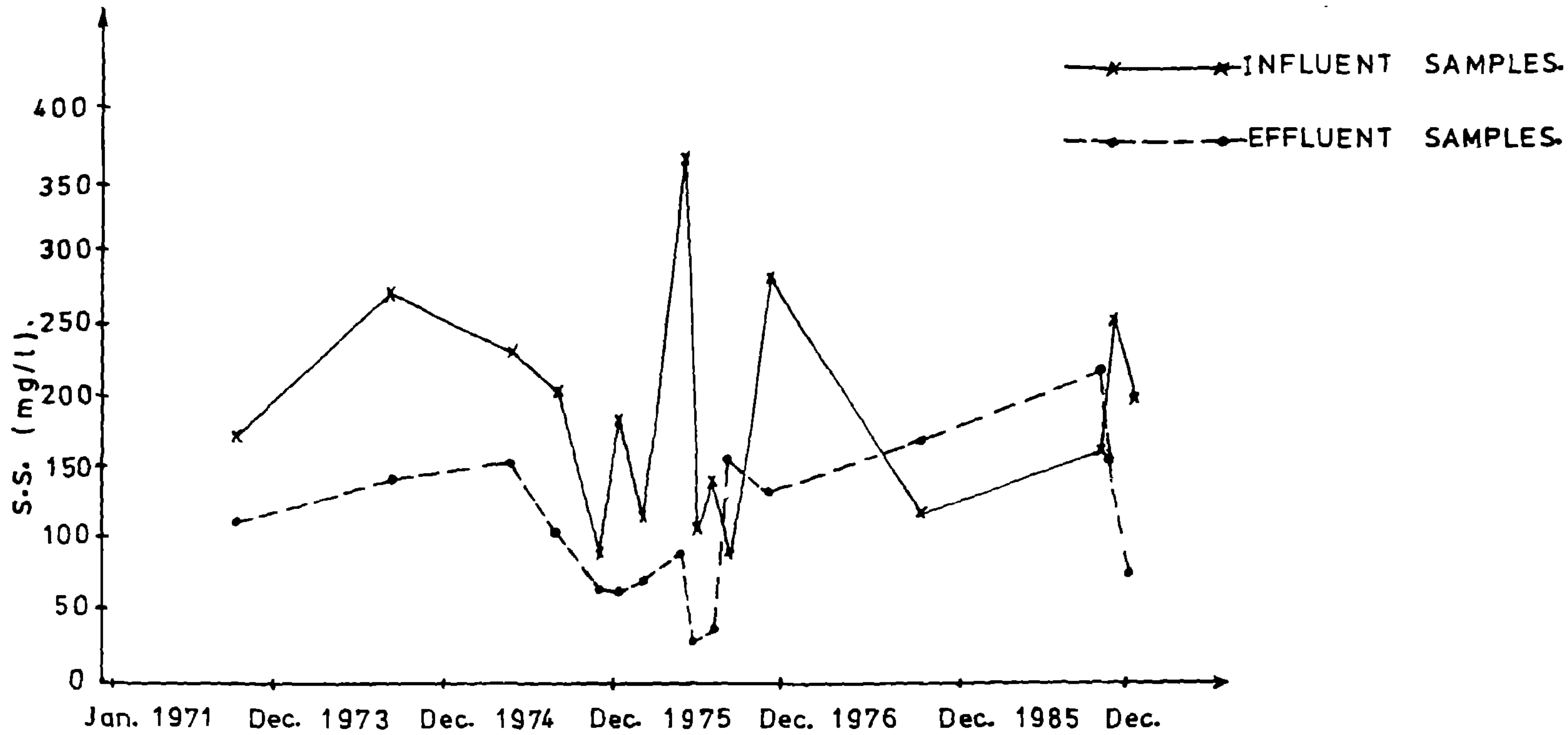

FIGURE 34. S.S. IN SAMPLES FROM THE CHELSTON PONDS IN LUSAKA WHICH TREAT DOMESTIC SEWAGE.

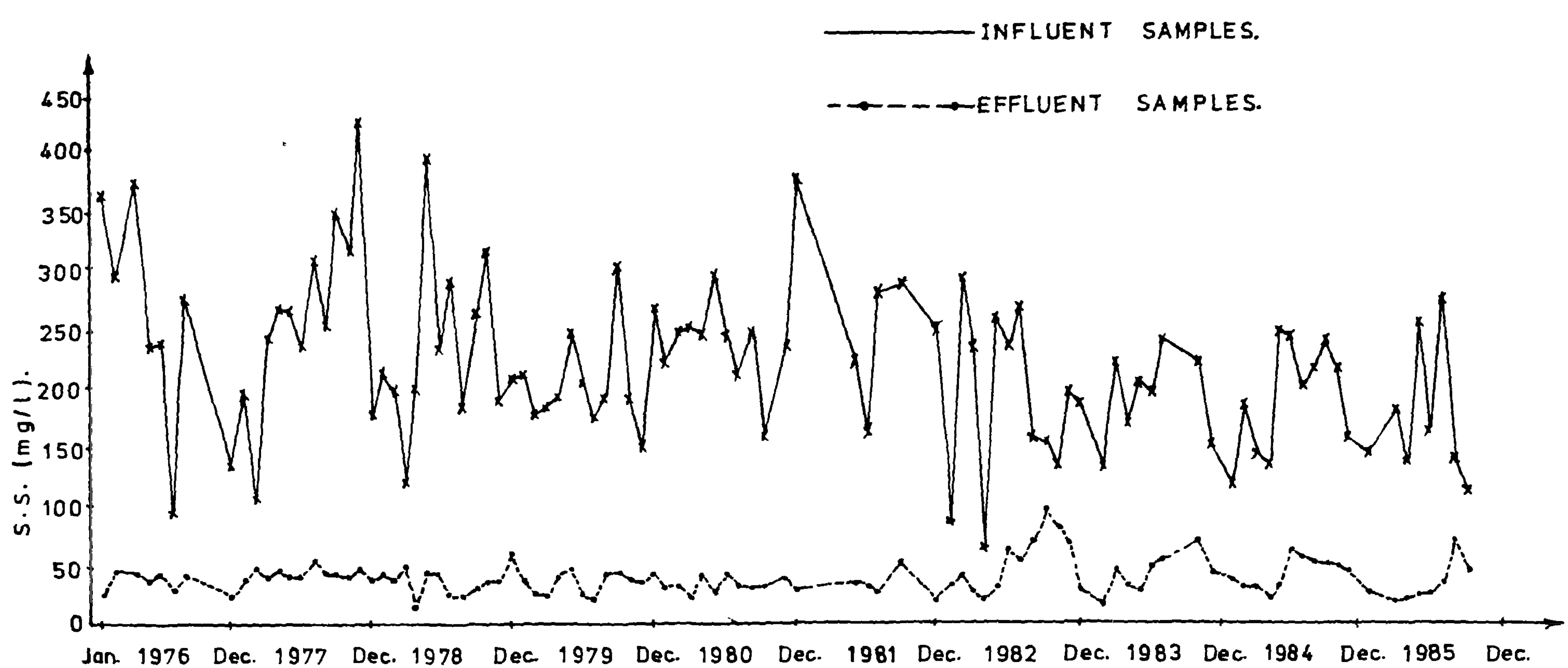

FIGURE 35. S.S. IN SAMPLES FROM THE NDEKE PONDS IN KITWE WHICH TREAT DOMESTIC SEWAGE.

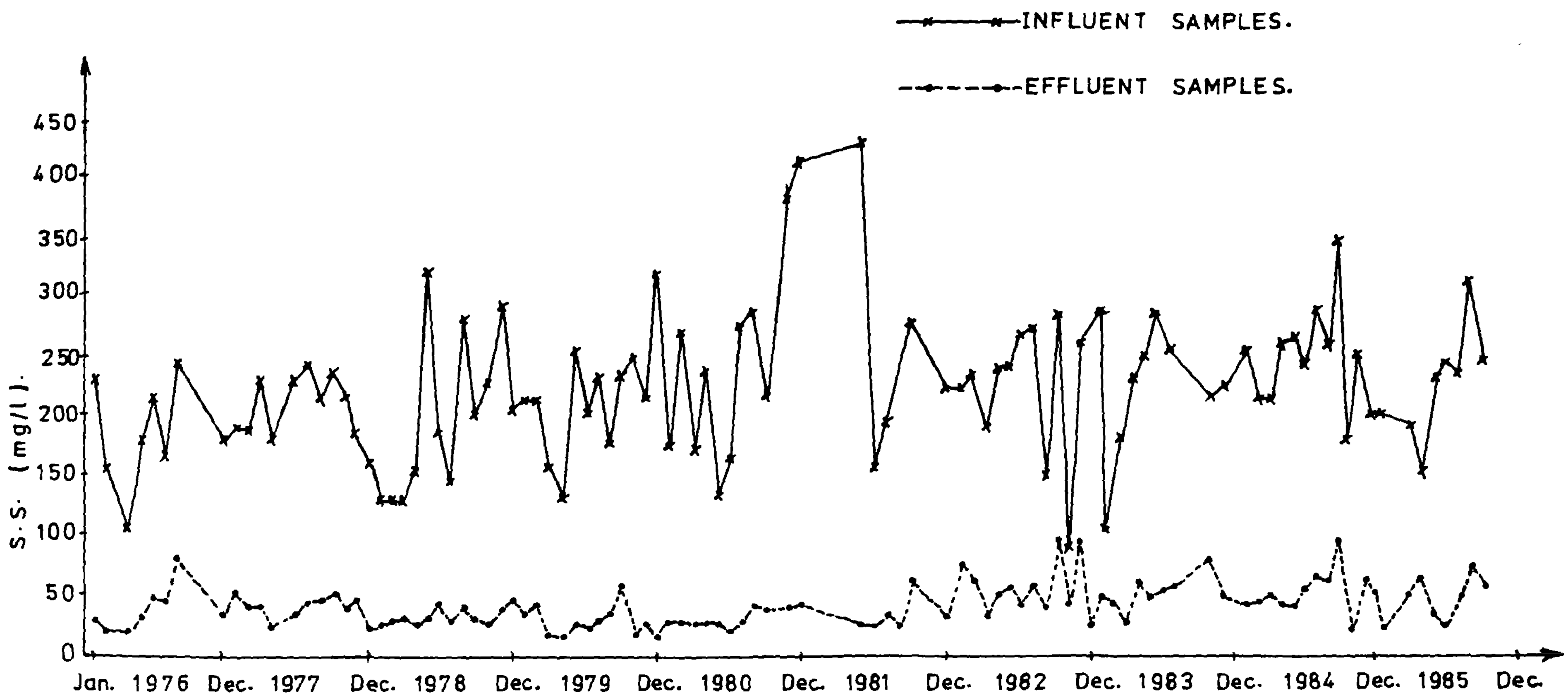

FIGURE 36. S.S. IN SAMPLES FROM THE MINDOLO PONDS IN KITWE WHICH TREAT DOMESTIC SEWAGE.

3.4.4. E.Coli.

Apart from an indication of E.Coli values for the Matero Ponds which were conducted by the African Housing Board in 1963, shown in table 7, analysis of samples bacteriologically was done for the Ndeke and Mindolo Ponds. Table 8 shows E.Coli values for influent and effluent samples together with indications on the removal efficiency for the Ndeke Ponds while table 9 is for the Mindolo Ponds.

Table 7. E.Coli values of samples from the Matero Ponds conducted by the African Housing Board in 1963.

Date of test	M P N per 100ml upstream of the discharge point	M P N per 100ml downstream of the discharge point
11/2/1963	240000	22000
18/2/1963	21000	27000
4/3/1963	17000	70000
6/3/1963	13000	49000
7/6/1963	2000	9300
11/6/1963	17000	Nil

Table 8. Average values of E.Coli for influent and effluent samples from the Ndeke Ponds and removal efficiencies.

Year	E.Coli/100ml for influent samples	E.Coli/100ml for effluent samples	Reduction of E.Coli
1978	62980000	112000	99,82%
1979	71500000	113400	99,84%
1980	131000000	123200	99,91%

Table 9. Average values and removal efficiencies of E.Coli for the Mindolo Ponds.

Year	E.Coli/100ml for the influent samples	E.Coli/100ml for the effluent samples	Reduction of E.Coli
1970	40240000	28860	99,93%
1971	38770000	45250	99,88%
1972	31820000	29000	91,91%
1973	33250000	30400	99,90%
1975	63830000	31500	99,95%
1976	29400000	26800	99,91%
1977	37430000	40500	99,89%
1978	36000000	63500	99,82%
1979	70600000	81500	99,88%
1980	62000000	43000	99,93%

Sampling and laboratory analysis of E.Coli on the Ndeke and Mindolo Ponds were done at least twice a month during the period of which the results were recorded. The lowest recorded E.Coli values are 13000/100ml and 8000/100ml for the effluent samples from the Ndeke and the Mindolo Ponds respectively. Values as high as 250000/100ml and 180000/100ml of E.Coli for the effluent from the Ndeke and Mindolo ponds respectively were also recorded.

3.4.5. $B.O.D_5$.

The samples taken from inlets and outlets of the selected pond systems were also analysed for $B.O.D_5$. Figure 37 shows $B.O.D_5$ values for samples from the Matero Ponds and figure 38 is for the sample results of the chelston Ponds. The influent and effluent sample $B.O.D_5$ values for the Ndeke and Mindolo Ponds are shown in figure 39 and figure 40 respectively.

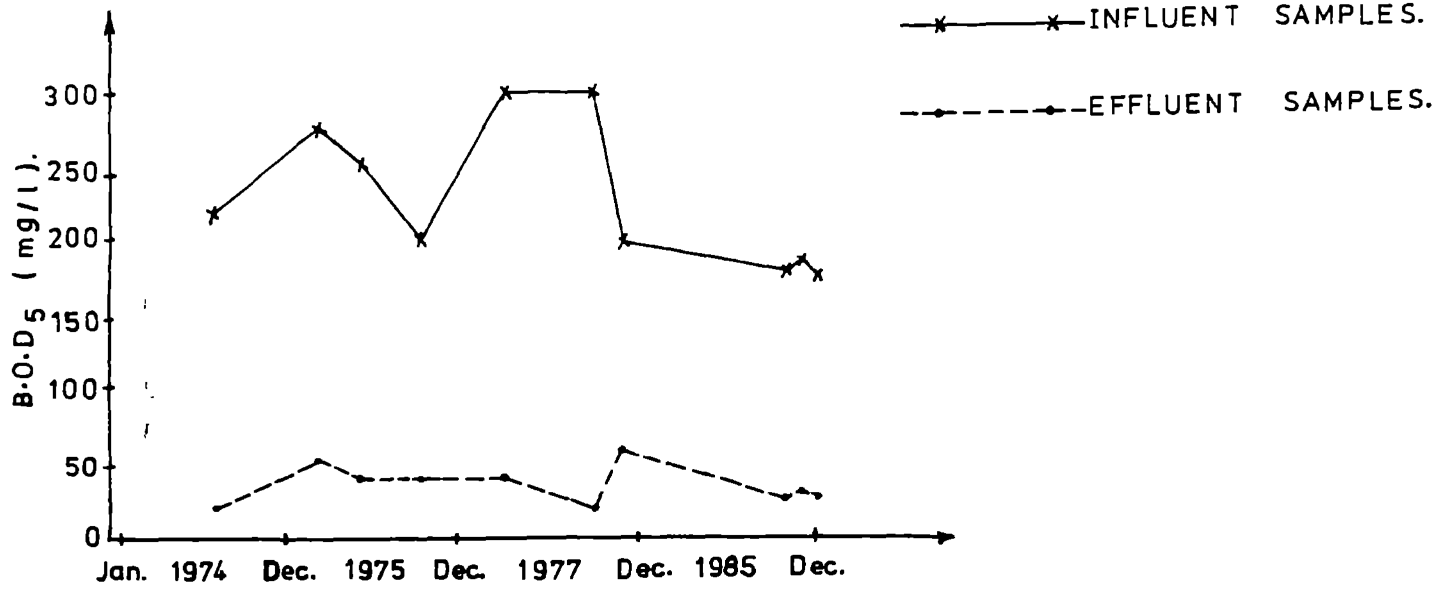

FIGURE 37. B·O·D_5 OF SAMPLES FROM THE MATERO PONDS IN LUSAKA WHICH TREAT DOMESTIC SEWAGE.

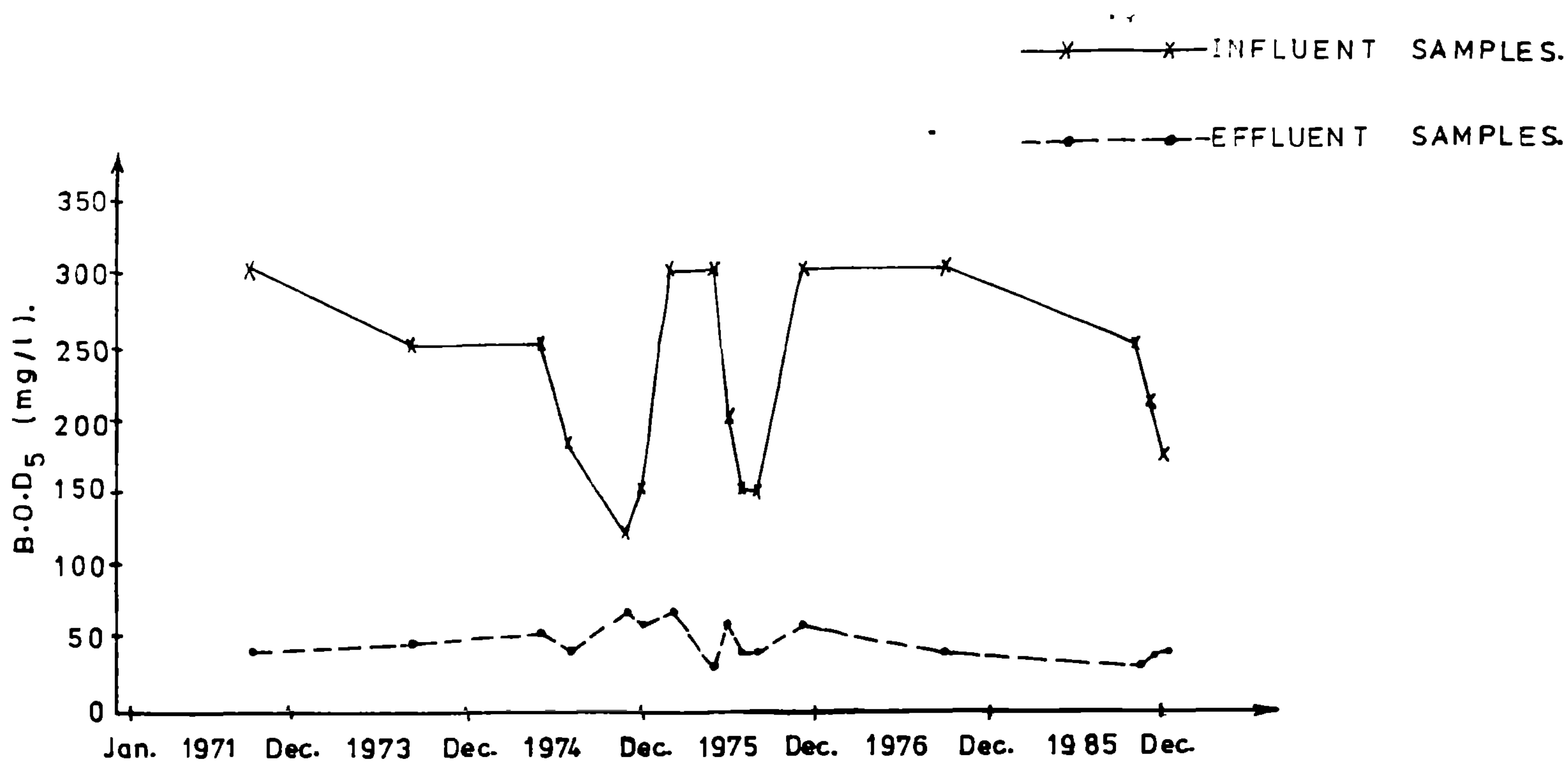

FIGURE 38. B.O.D_5 OF SAMPLES FROM THE CHELSTON PONDS IN LUSAKA WHICH TREAT DOMESTIC SEWAGE.

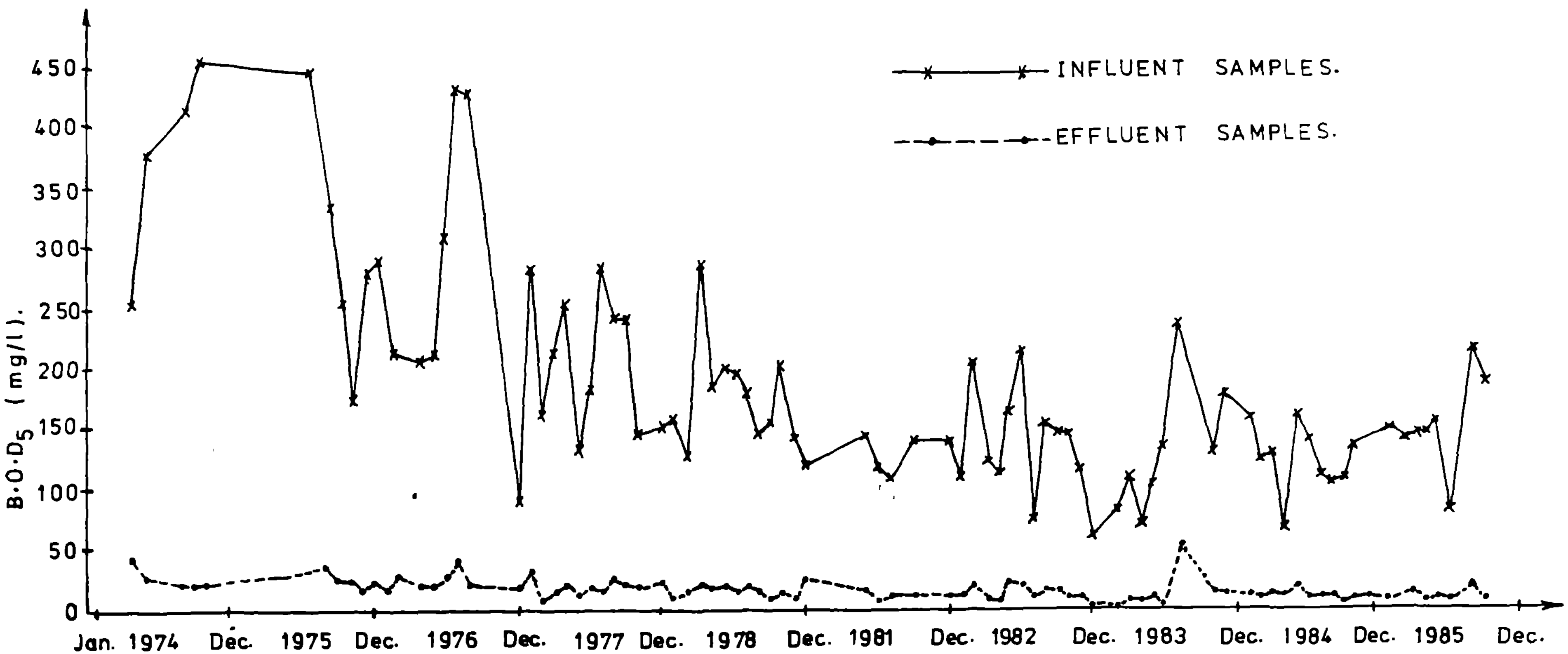

FIGURE 39. B·O·D_5 OF SAMPLES FROM THE NDEKE PONDS IN LUSAKA WHICH TREAT DOMESTIC SEWAGE.

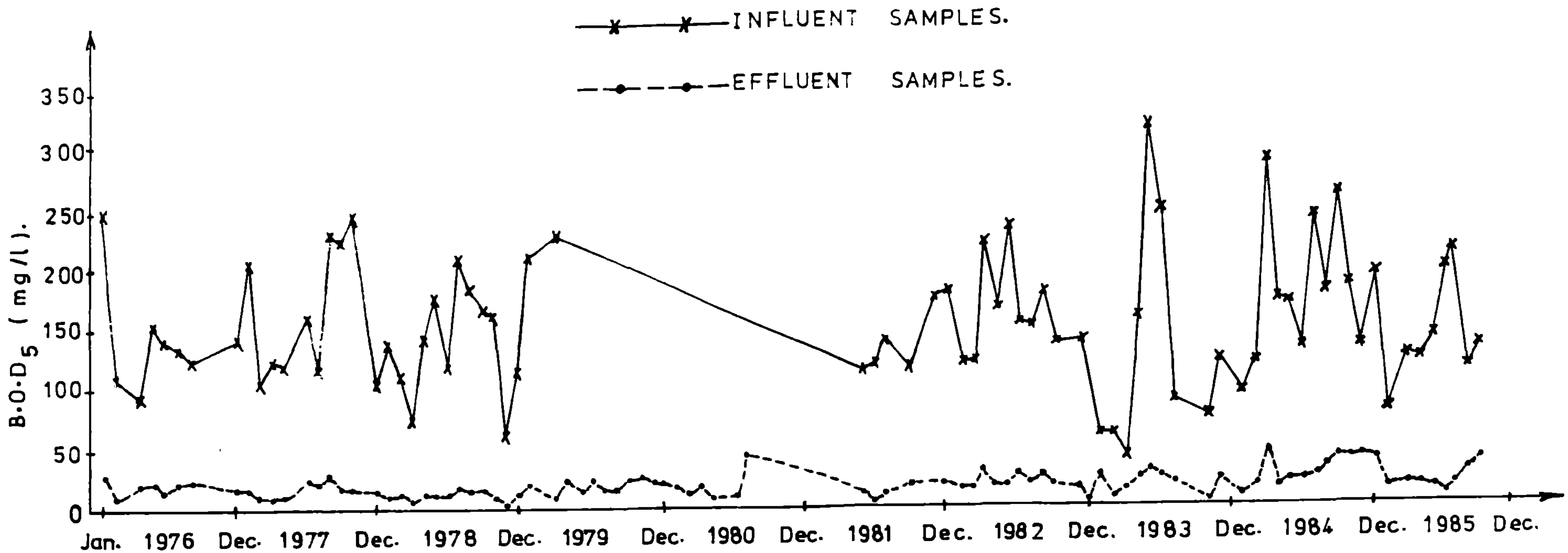

FIGURE 40. $B{\cdot}O{\cdot}D_5$ OF SAMPLES FROM THE MINDOLO PONDS IN KITWE WHICH TREAT DOMESTIC SEWAGE.

3.5. Analysis of the Results.

According to the record of the results as compiled in this report the following are the ranges and the averages of the test results and the removal efficiencies of the selected pond systems;

(a) pH.

For all the selected pond systems the pH values range between 6 and 9. It can be observed from figures 25, 26, 27 and 28 that except for a few times for the Ndeke and the Mindolo Ponds, the effluent pH values are higher than the influent pH values. This should generally be so since the presence of algae in the ponds increases the pH of the wastewater.

(b) Permanganate values, S.S. and $B.O.D_5$.

The ranges for permanganate values, S.S., and $B.O.D_5$ of the influent and effluent samples from all the selected pond systems, together with ranges for the removal efficiencies of the pond systems are shown in table 10.

The averages of the recorded permanganate values, S.S. and $B.O.D_5$ of influent and effluent samples from the selected ponds and the average removal efficiencies of the ponds are shown in table 11. For the selected pond systems the permanganate value reduction ranges from 58% for the Matero Ponds to 65% for the Ndeke Ponds. S.S. reduction ranges from 39% for the Matero Ponds to 82% for the Ndeke Ponds. while removal efficiency for $B.O.D_5$ ranges from 77% for the Chelston Ponds to 91% for the Ndeke ponds.

Table 10. The ranges of permanganate values, S.S. and $B.O.D_5$ for samples from the ponds studied and the ranges of the removal efficiencies of the pond systems.

Ponds.	Matero Ponds	Chelston Ponds	Ndeke Ponds	Mindolo Ponds
Period of results	1974 - 1985	1970 - 1985	1974 - 1985	1976 - 1985
Influent permanganate values	30-95mg/l	45-118mg/l	18-58mg/l	12-52mg/l
Effluent permanganate values	12-40mg/l	8-74mg/l	2-30mg/l	5-22mg/l
% reduction in permanganate values	18-85%	8-91%	12/91%	32-84%
Influent S.S.	83-356mg/l	88-366mg/l	64-421mg/l	89-434mg/l
Effluent S.S.	34-195mg/l	30-216mg/l	14-96mg/l	16-96mg/l
% reduction in S.S.	0-87%	0-75%	36-94%	57-94%
Influent $B.O.D_5$	168-300mg/l	120-300mg/l	61-447mg/l	38-316mg/l
Effluent $B.O.D_5$	20-60mg/l	30-72mg/l	2-54mg/l	1-45mg/l
% reduction in $B.O.D_5$	70-93%	42-90%	83-96%	63-98%

Table 11. The average values for the permanganate values, S.S. and $B.O.D_5$ and the treatment efficiencies of the selected ponds.

Ponds	Matero Ponds	Chelston Ponds	Ndeke Ponds	Mindolo Ponds
Period of results	1974 - 1985	1970 - 1985	1974 - 1985	1976 - 1985
Influent permanganate value	57mg/L	80mg/l	37mg/l	34mg/l
Effluent permanganate value	24mg/l	32mg/l	13mg/l	13mg/l
% reduction for permanganate values	58%	60%	65%	62%
Influent S.S.	196mg/l	214mg/l	214mg/l	220mg/l
Effluent S.S.	120mg/l	120mg/l	38mg/l	43mg/l
% reduction for S.S.	39%	44%	82%	80%
Influent $B.O.D_5$	225mg/l	225mg/l	177mg/l	152mg/l
Effluent $B.O.D_5$	31mg/l	52mg/l	16mg/l	18mg/l
% reduction for $B.O.D._5$	86%	77%	91%	88%

The pH values for all the selected waste stabilization ponds satisfy the Zambian Standards for pH of 6-10 for influent wastewater and 6-9 for the treated wastewater which is discharged from the ponds. For all the ponds which were studied the effluent permanganate values are lower than the influent permanganate values.

The Matero and the chelston Ponds do not satisfy the Zambian Standards for S.S. of effluent from treatment plants of 50mg/l. For the Matero and the Chelston Ponds it has also been noticed that S.S. values for effluent samples are sometimes higher than S.S. values for influent samples. This is generally true for hot and dry seasons when there is an increase in algal growth in ponds which in turn increases the suspended matter in the effluent from ponds. On the other hand the S.S. values of the effluent samples from the Ndeke and the Mindolo Ponds satisfy the Zambian Standard for effluent S.S. of 50mg/l. The high degree of S.S. removal from the Ndeke and Mindolo Ponds could be as a result of proper operation and maintenance of the ponds, especially desludging of the ponds.

The removal efficiencies for E.Coli are quite impressive. The average values range from 99,80% to 99,90% for the Ndeke Ponds and 99,82% - 99,95% for the Mindolo Ponds. However the effluent quality for E.Coli for the ponds does not satisfy the recommended limit of 5000 cells/100ml, if the assumption that E.Coli counts are almost equal to faecal coliform counts holds.

Apart from the Chelston Ponds, all the selected ponds treat sewage and satisfy the Zambian Standard for $B.O.D_5$ of 33mg/l.

4. DISCUSSIONS

The selected waste stabilization ponds provide good treatment in terms of pH, permanganate values and to a great extent $B.O.D_5$ reduction. Apart from the Chelston Ponds the other ponds treats sewage which satisfy the Zambian Standard for $B.O.D_5$ of 33mg/l. It should however be noted that bacteria reduction for these ponds does not satisfy the level recommended by Mara (1976) of 5000 cells/100ml in the effluent. The results from the calculations for bacteria counts in the effluent from the ponds, refer to table 6, show that even the design values are higher than the recommended level of 5000 cells/100ml. The test results show even higher values of bacteria counts in the effluent from the ponds which could be resulting from overloading the ponds.

In order to improve the bacteriological quality of the effluent from the selected ponds, there should be extensions to the ponds. The designs of waste stabilization ponds in Zambia should in future take into account the bacteria reduction. Another method which could be used in order to improve the effluent quality would be to chlorimate the effluent from the ponds. The arrangement of the pond units also matters where bacteria reduction is of concern. An example for this is the arrangement of the Mindolo Ponds. If the two parallel primary ponds in each line of the Mindolo Ponds could be arranged in series then the effluent faecal bacteria could be $1,0x10^3$-$1,3x10^3$/100ml.

It should be noted that bacteria reduction is very important for health and economic reasons. If the water is polluted with pathogenic organisms then there is a high possibility of out break of epidemics caused by the faecal bacteria like cholera or typhoid.

This is generally true where there are people who use the polluted water, as is the case for the Kafue River which is the main water source for Kitwe. The goodness is that the water is treated before use and the intake is upstream of the discharge point of the treated sewage.

Even if the drinking water is treated, the water courses which are polluted are not good for fish breeding. The people are thus deprived of fish which could provide them with a nutritious part of their diet. Economically, the polluted water courses have adverse effects on recreation activities like swimming. It is therefore important to bare in mind that future designs of waste stabilization ponds in Zambia should take into account the bacteria reduction.

In order to improve the performance of ponds on S.S. removal, desludging of the ponds should be done regularly and at design intervals. For algae removal suitable methods should be utilized. To remove algae from these ponds I suggest the provision of troughs across the final ponds as shown in figure 15.

Apart from the improvements on the ponds in order to increase bacteria and S.S removals, there are many other things which should be done on the ponds. Firstly manually cleaned bar screens should be incorperated prior to the ponds in order to eliminate all kinds of floating material. This will eliminate cloths, litter and other big material floating in the wastewater which are not wanted in the ponds. There should also be flow measuring devices which could be used to monitor the flows to the ponds. For ponds in Zambia I suggest that V-notch weirs should be used for flow measurements. Even if these devices only provide instantaneous flow, they have been suggested for use in Zambia because they are cheaper to intall and they are safe in as far as buglary is concerned.

Another improvement to the ponds is their inlet arrangements. The inlets to the ponds result in accumulation of all kinds of material mostly at the inlets. Foul smell originates from the places where there is accumulation of material. A possible way to improve the inlets to these ponds would be construction of multi space channels, which would distribute sewage to a wide area in the primary ponds. Those channels should be above the design pond water level. For all the selected ponds the channels should be at least 20m. long from the edges of the ponds into the ponds. I also suggest that the spaces should be of about 150mm. diameter. There should be a gentle slope along the channel to allow sewage to flow to the ponds. Such type of channel can be seen in figure 41.

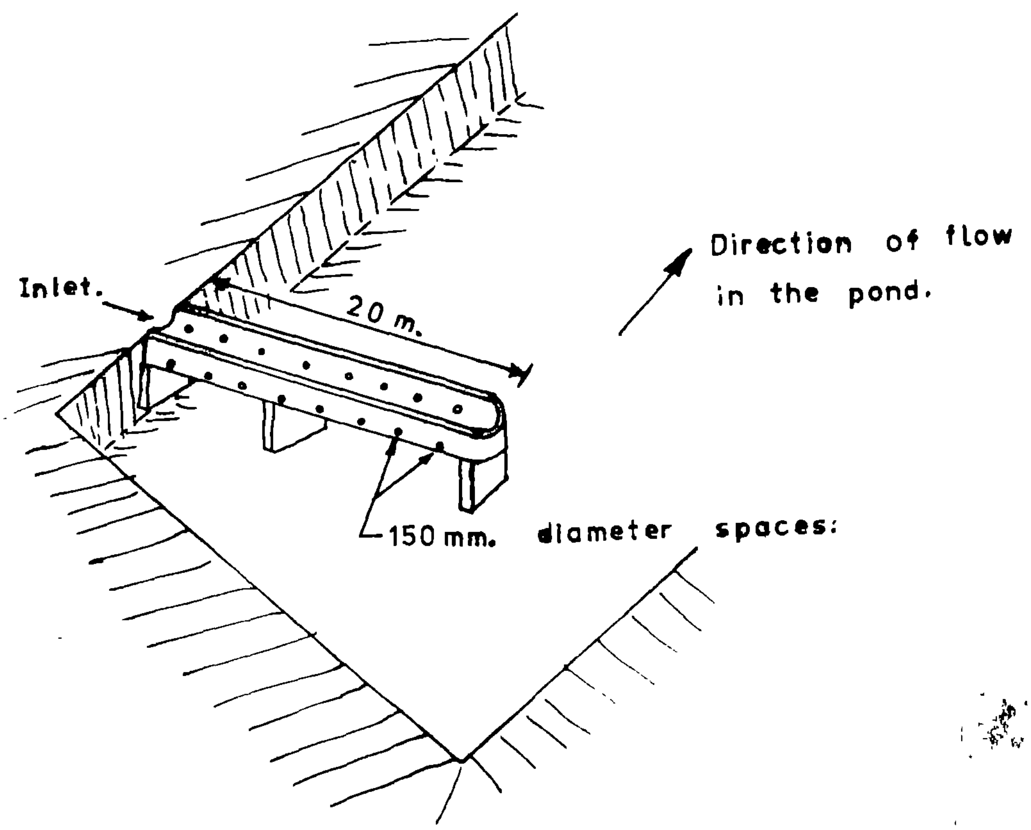

Figure 41. Multi space channel.

The authorities of ponds should provide wire fencing around the ponds in order to reduce unauthorised entry to the premises of the ponds. Fencing will also prevent animals from entering in to the ponds as is the case with the Ndeke and the Mindolo Ponds where there are Crocodiles coming from the Kafue River.

All the selected ponds have workers. The workforce on these ponds seem to be suitable for the operation and maintenance activities on the ponds. However it is necessary that the workers should be utilized fully on all the operation and maintenance activities. In addition the authorities of the ponds should provide the workers with the tools and equipment as stated in chapter two.

5. CONCLUSION

Waste stabilization ponds provide a cheap method for sewage treatment for populations up to 10000 as compared to other methods of sewage treatment. The operation and maintenance activities of ponds do not require the sophisticated equipment or professional skills. Waste stabilization ponds however operate well only under particular climate which is of tropical or subtropical type and their land requirement is very high.

Provided waste stabilization ponds are properly designed, constructed and maintained under required climate conditions, they provide effluent of high quality in terms of B.O.D, S.S. and E.Coli. When designing waste stabilization ponds, just as for other sewage treatment methods, it is important to know the required effluent standards for which the ponds, are designed.

Waste stabilization ponds should be constructed, operated and maintained well according to the proper procedures. This results in high treatment efficiency of the ponds. The authorities of the ponds should employ adequate personnel for the ponds and they should provide them with necessary tools and equipment for use on ponds. The personnel should be educated so that they know basic principles of pond operation. the authorites should also monitor the ponds in order to ascertain any deficiencies.

The climatic conditions in Zambia are suitable for waste stabilization pond perofrmance. All the selected ponds do not have anaerobic ponds. They were designed in order to maintain aerobic conditions in ponds. The ponds treat domestic sewage.

The selected ponds were constructed by excavating earth and making embankments. The ponds are not lined. The waste stabilization ponds are owned by the local authorities in Lusaka and in Kitwe. These urban district councils have employed workers to operate and maintain the ponds. These workers are adequate for all the duties on the ponds. The district councils should however provide the workers with the necessary tools and equipment for the operation and maintenance activities as explained in chapter two.

The results of the influent and effluent test samples indicated that the selected ponds perform fairly well with regards to pH, permanganate values and $B.O.D_5$ except for the poor $B.O.D_5$ effluent quality of the Chelston Ponds with respect to the Zambian Standard. In terms of S.S. the Ndeke and Mindolo Ponds give satisfactory effluent quality since the effluent S.S. values are lower than the Zambian Standard. On the other hand the Chelston and Matero Ponds do not satisfy the effluent standard set by the Zambian Standard.

The E.Coli values of the effluent from the selected ponds indicate that the bacteria reduction does not satisfy the effluent value recommended by Mara (1976) of 5000 faecal coliforms/100ml. The treatment efficiencies of the ponds on reduction of E.Coli are however quite high and they are at least 99.80%. The deficiencies of the selected waste stabilization ponds for bacteria reduction has been attributed to the designs which never took into account the bacteriological quality. Another reason for the poor bacteria reduction of the ponds could be the fact that the ponds are overloaded.

In order to improve bacteria reduction of the selected ponds it has been suggested that the authorities should construct more ponds in series. Wherever possible, chlorination of the effluent from ponds should be practised in order to reduce the bacteria in the effluent.

It has also been suggested that the pond arrangement for the Mindolo Ponds should be changed so that the two parallel primary ponds in each line are in series.

Desludging of the ponds and algae removal from the pond effluent should be done in order to improve S.S. removal of the ponds. Manually cleaned bar screens and 'V' notch weirs should be constructed prior to the ponds in order to improve the operation of the ponds. In order to distribute flow over a wider area a multi-space channel should be constructed at the inlet of the primary ponds. This inlet arrangement will reduce accumulation of material at one inlet point. In addidtion, wire fences should be provided around the premises of the waste stabilization ponds.

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	Column 1 Substance	Column 2 Trade Effluent into Public Sewer	Column 3 Sewage and Other Effluent
9.	Chemical Oxygen Demand (COD) (Dichromate method)	1800 mg/L	COD based on the limiting values for organic carbon 60-90 mg O_2/L average for 24 hours
10.	Biochemical Oxygen Demand (B.O.D) (Modified Winkler method and Membrane Electode method)	1200 mg/L	50 mg O_2/L (mean value over a 24 hours period) According to circumstances in relation to the self-cleaning capacity of the waters
11.	Nitrates (NO_3 as introgen (Spectrophoto-metric method and Electrometric method)	80mg/L	The nitrates burden must be reduced as far as possible according to circumstances: Watercourse<50 mg/L; Lakes< 20mg/L
12.	Nitrite (NO_2 as nitrogen/L (Spectro-photometric sulfanilamide)	10.0mg NO_2as N/L	1.0mg NO_2 as N/L
13.	Organic Nitrogen (Spectrophotometric method N-Kjeldhal) (*the % of nutrient elements for degradation of B.O.D. should be 0.4-1% for phosphorous (different for processes using algae))	300mg N/L*	5.0mg/L mean*
14.	Ammonia and Ammonium (Total) (NH_3 as N/L (Nesslerization method and Electrometric method)	50mg/L	The burden of ammonium salts be reduced as far as 10 mg/L (depending upon temperature, pH and salinity)
15.	Cyanides (Spectrophotometric method)	0.5mg/L	0.1 mg/L
16.	Phosphorous (Total) (PO_4 as P/L) (Colorimetric method)	45mg/L	Treatment installation located in the catchment area of lakes: 1mg/L located outside the catchment area: reduce the load of P as low as possible (PO_4< 6mg/L
17.	Sulphates (Turbidimetric method)	500mg/L	The sulphate burden must be reduced as low as possible

APPENDIX A

Extract of the Zambia Standards on Trade Effluent

Table of Standard for Trade and Other Efflents

Column 1 Substance	Column 2 Trade Effluent into Public Sewer	Column 3 Sewage and Other Effluent
A. PHYSICAL		
1. Temperature (Thermometer)	$60^{\circ}C$. After mixing of the waters, the temperature should not exceed $40^{\circ}C$ in the sewer	$40^{\circ}C$ at the point of entry
2. Colour Hazen (Spectrophotometer)	The treatment plant ensure discolouration dyestuffs in the waste water	Must not cause any colouration of the receiving water
3. Odour and Taste (Threshold odour Number)	The odour must not cause any nuisance	Must not cause any deterioration in taste or odour as compared with the natural state
4. Total suspended solids (Gravimetric method)	1200mg/L (Avoid blockage of sewer, effect free flow)	50mg/L. Must not cause formation of sludge or scum in receiving waters
5. Settleable matter sedimentation ml/L (Imhoff funnel)	1.0ml/L in 2 yours (Avoid blockage of sewer, effect free flow)	0.5ml/L in two hours. Must not cause formation of sludge in receiving water
6. Salinity/Residue mg/L (Evaporation and Gravimetric method)	7500mg/L. The salinity must not affect the discharge and treatment or installations or their functioning	3000mg/L. The salinity of waste water must not adversely affect surface water
B. CHEMICAL		
7. pH (10-14 scale) (Electrometric method)	6-10	6-9
8. Dissolved Oxygen mg oxygen/L (Modified Winkler method and Membrane-electrode method)	No requirements	After complete mixing the oxygen content must not be less than 5 mg/L. Extreme temperature may result in lower values.

Substance	Trade Effluent into Public Sewer	Sewage and Other Effluent
18. Sulfite (Iodometric method)	10 mg/L	1 mg/L (Presence of oxygen changes SO_3 to SO_4
19. Sulphide (Iodometric and electrometric method)	1 mg/L	0.1 mg/L (depending on temperature, pH and dissolved O_2
20. Chlorides Cl/L (Silver nitrate and Mercuric nitrate)	1000 mg/L	Choride levels must be as low as possible as < (800mg/L)
21. Active chloride Cl_2/L (Iodometric method)	(0.5-3.0 mg/L)	0.5 mg/L
22. Active Bromine (Br_2/L) (Iodometric method)	(0.5-3.0 mg/L)	0.1 mg/L
23. Flourides F/L (Electrometric method and Colorimetric method with distillation)	< 30mg/L	10 mg/L
C. METALS		
24. Aluminium compounds Atomic Absorption method)	< 20 mg/L	10 mg/L
25. Antimony (Atomic Absorption method)	0.5 mg/L (inhibition of oxidation)	0.5mg/L
26. Arsenic compounds (Atomic Absorption method)	1.0mg/L	1.0 mg/L
27. Barium compounds (water soluble concentration)(Atomic) Absorption method)	1.0 mg/L	0.5mg/L
28. Beryllium salts and compunds (Atomic Absorption method)	0.5 mg/L (inhibition of oxidation)	0.1-0.5 mg/L (according to circumstances)
29. Boron compounds (Spectro photometric method - curcumin method)	<50 mg/L	<10 mg/L
30. Cadmium compounds (Atomic Absorption method)	1.5mg/L	0.5 mg/L

Column 1 Substance	Column 2 Trade Effluent into Public Sewer	Column 3 Sewage and Other Effluent
31. Chromiun Hexavalent Trivalent (Atomic Absorption method)	5.2mg/L	0.1mg/L
32. Cobalt compunds (Atomic Absorption method)	0.5mg/L	0.5mg/L
33. Copper compounds (Atomic Absorption method)	3.0 mg/L	1.0mg/L
34. Iron compounds (Atomic Absorption method)	15.0mg/L	< 2mg/L
35. Lead compounds (Atomic Absorption method)	1.5mg/L	1.5mg/L
36. Magnesium (Atomic Absorption method and Flame photometric method)	< 1000mg/L	< 500.0mg/l
37. Manganese (Atomic Absorption method)	10.0mg/L	< 3.0mg/L
38. Mercury (Atomic Absorption method)	0.01mg/L	0.001mg/L
39. Molybdenum (Atomic Absorption method)	5.0mg/L	0.5-5.0mg/L
40. Nickel (Atomic Absorption method)	2.0mg/L	2.0mg/L
41. Selenium (Atomic Absorption method)	1.0mg/L	0.05mg/L
42. Silver (Atomic Absorption method)	0.1(inbibition of oxidation	0.1mg/L
43. Thallium mg (Atomic Absorption method)	1.0mg/L	< 0.5mg/L
44. Tin compounds (Atomic Absorption method)	2.0mg/L	2.0mg/L
45. Vanadium compounds (Atomic Asorption method)	1.0mg/L	1.0mg/L

	Column 1 Substance	Column 2 Trade Efflunet into Public sewer	Column 3 Sewage and Other Effluent
46.	Zinc compounds (Atomic Absorption method)	25.0mg/L	10.0mg/L
D.	ORGANICS		
47.	Total hydrocarbons (Chromatographic method)	20.0mg/L	10.0mg/L
48.	Oils (Mineral and Crude) (Chromatographic method and Gravimetric method)	100.0mg/L (after installation of oil separators) 20.0mg/L (after installation of demulsifier)	1-2mg/L
49.	Phenols (steam distillable) (Non-steam distilled) (Colorimetric method)	5.0mg/L 1.0 mg/l	0.2mg/L 0.05mg/L
50.	Fats and saponifiable oils (Gravimetric method and Chromatographic method)	No requirement but installation of oil and fat separators	20.0mg/L
51.	Detergents (Anionic) (Atomic Absorption Spectrophometric)	10.0mg/L Alkybenzene sulfonate not permitted	2.0mg (Detergents should contain at least biodegradable compounds)
52.	*Pesticides and PCB'S (Total)(Chromatographic method)	1.0mg/L	0.5mg/L Reduce to a minimum)
53.	Trihaloforms (Chromatographic)	1.0mg/L	0.5mg/L (Reduce to a minimum)
E.	RADIOACTIVE MATERIALS		
54.	Radioactive materials as specified by IAEA	No discharge accepted	Not permitted

*There are approximately 4000 pesticides, herbicides and PCBs. The normal practices as per the works of reference hereinafter mentioned shall be used in respect thereof.

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