PAPER 7

Efficient Sewage Treatment for Middle East Climates using Waste Stabilisation Ponds

by

W.J. Maidment and P.A.R. Scott

Scott Wilson Kirkpatrick & Partners
UK

HISTORICAL BACKGROUND

When man began living in organised communities the safe disposal of excreted wastes became necessary. Some early civilisations saw the benefit of water-borne sewerage system but it was not until the advent of the industrial revolution in Europe and its influence on the universal introduction of piped water supplies to the increasing urban population that the disposal of large quantities of waste to river systems occurred. This led to gross population of the receiving waters and the outbreaks of disease from the use of these waters became ever more commonplace. It was public concern, in the UK, that led to the appointment of a number of Commissions to review and make recommendations for the alleviation of the problem. This resulted in the establishment of 'sewage farms' in many towns, but it was the reports of the Royal Commission on Sewage Disposal, sitting from 1898 to 1915, that formed the basis of much of the present-day UK sewage-treatment practice and resulted in the now famous Royal Commission Standards for effluent quality. In the USA sewage treatment fared little better particularly since receiving waters and land areas were especially large. However, by the early 1900's nuisance and health conditions were such that there was an increasing demand for more effective waste-water treatment.

The high cost of land in Europe and the USA and the impracticability of acquiring ever larger areas for sewage treatment led to the search for more intensive forms of treatment with the resulting evolution of present-day sewage-treatment methods. These methods were developed for the industrialised north with its generally temperate cool climate and include:

Activated sludge;

percolating filters;

oxidation ditches/extended aeration; and

package plants

In the Middle East water-borne sewage systems are a relatively recent innovation and have become possible due to the increase in economic activity in this area, the advent of large-scale desalination systems and the drilling of deep wells equipped with electrically-driven submersible pumps. Prior to this, water usage <u>per capita</u> was low and excreta was rendered harmless by the sterilising action of the sun or sea. With increased economic activity came the construction and extension of the major cities and the general introduction of piped water supplies. This, like Europe in the industrial revolution, required a means of sewage disposal and treatment to prevent nuisance and disease and was achieved by importing western technology and standards. At the same time that western technology was being introduced so was the 20/30 Royal Commission standard for effluents. This has led, in some cases, to the use of technologies not always appropriate to the very different conditions of the region. The substantially higher ambient temperatures throughout the year, the general availability of low-cost desert land, the lack of perennial streams and the inappropriateness of the Royal Commission standards should have led, in many cases, to the introduction and development of systems which reflect the special conditions that appertain in arid areas. It is the contention of the authors that waste-stabilisation ponds are, and have proved to be, a very efficient method of sewage treatment in areas of high ambient temperatures and low land costs, particularly when their efficiency in the removal of faecal pathogens is given due recognition. They should become the first choice in tropical and sub-tropical regions and where land is freely available.

INTRODUCTION TO WASTE STABILISATION PONDS (WSP)

Historically, ponds have been used to relieve existing traditional sewage works by operating virtually as storage reservoirs. Gross overloading of these reservoirs resulted in offensive odours and contributed to the unpopularity of this form of treatment. At Santa Rosa in 1924 it was found, by coincidence, that a sewage-impounding reservoir could work efficiently and be free from nuisance providing that the reservoir or pond was not overloaded. Since then much research has been carried out into the operation of ponds and it is widely accepted that tropical and sub-tropical climates provide an ideal environment for the treatment of sewage by this method.

A typical pond arrangement is shown in Figure 1.

MECHANISM

There are three main categories of sewage-stabilisation ponds, anaerobic, facultative and maturation, usually acting in series (see Figure 14) and each having a specific function. Anaerobic ponds are used for the pretreatment of strong wastes; facultative ponds for the major part of the removal of the BOD; and maturation ponds for the destruction of faecal pathogens.

Anaerobic ponds essentially act as septic tanks. The removal of BOD and suspended solids is due to the settlement of the sewage solids which undergo intense anaerobic digestion. Provided that the volumetric BOD loading is below 0.4 kg/m^3/day and that the waste has a sulphate concentration below 100 mg/litre, then a stable alkaline fermentation with evolution of methane occurs which does not give rise to odour problems. If the BOD loading is too low it is difficult to maintain anaerobic conditions.

Facultative ponds exhibit a combination of anaerobic and aerobic conditions, and can be used to treat raw sewage or settled sewage from anaerobic ponds. The upper layers of the ponds are aerobic and the lower layers anaerobic. The oxygen supply for aerobic conditions is supplied, in the main by the photo-synthetic activity of algae although some is provided by surface aeration from wind action. Aerobic bacteria utilise organic matter and the oxygen produced by algae to produce new bacterial cells, water, carbon dioxide, phosphate, ammonia, etc. Of these major end products, carbon dioxide is very important. Algae utilise carbon dioxide during photosynthesis since there is insufficient available from the atmosphere. This dependence of the bacteria and algae on each other for their existence is called symbiosis.

In the lower anaerobic layers of facultative ponds, anaerobic digestion continues in the absence of oxygen.

Figure 2 illustrates the process of symbiosis and Figure 3 shows the pathways of BOD removal in facultative stabilisation ponds.

Maturation ponds are used subsequently to facultative ponds and are aerobic throughout their depth. Pathogens are destroyed due to the hostile environment - starvation, temperature, ultra-violet radiation and algal concentration. Detention time is the key factor in pathogen destruction but recent research has shown that temperature and algal concentration are also important factors in bacterial-removal rates. Increases in these factors leads to an increase in the removal of faecal bacteria. Thus the high temperatures encountered in the Middle East will enhance the bacterial quality of the final effluent from waste-stabilisation ponds.

EFFLUENT STANDARDS

As previously mentioned, the Royal Commission on Sewage Disposal laid down quality recommendations for sewage effluent and among its recommendations were that BOD should not exceed 20 ppm (or mg/l) at 65°F and that suspended solids should not exceed 30 ppm (or mg/l) where there was at least an eight-fold dilution at the point of disposal. This standard applies to the discharge to rivers in temperate climates but is frequently used in other countries where the conditions are very dissimilar. The criteria for deciding on effluent standards should take into account the proposed method of discharge of the final effluent. If the effluent is to be discharged to an aquifer then bacterial quality is important, or if it is to be used for irrigation then both BOD and bacterial quality are the main criteria. If the discharge is to sea then solids would probably be the main criterion.

In the Middle East where sweet water is a scarce commodity, all the environmental, economic and engineering considerations point to re-use of the final effluent for irrigation.

Ponds can be designed so that the quality of effluent is such that it can be used without any additional treatment for unrestricted irrigation. On the other hand they can be designed so that there is no effluent discharge because all the effluent is lost through seepage and evaporation. However, there are draw-backs in that there will be an accumulation of dissolved salts which may become toxic to algae, the portion which percolates may give rise to groundwater pollution and it is possible that ponds constructed even in sandy soil will become self sealing with time.

Recommended irrigation and discharge standards are given in Table I.

The standard for algal concentrations in effluents to be discharged to rivers is based on the finding that the oxygen content of the receiving water course, where there is one, would deteriorate if the algal concentrations were to exceed 1×10^5 cells/ml. Where effluents are used for irrigation the standards for algal concentrations may require amendment since a high algal concentration may cause clogging of drip irrigators. However, in a well-designed pond system, the effluent algal concentration should be below 1×10^5 cells/ml.

There are no recommended standards for water quality when ponds are used for pisciculture. However, there must be some dissolved oxygen all the time and ammonia concentrations may well prove to be the limiting factor.

Chlorination of final effluents is practised in a number of countries, notably the USA. With well-designed waste-stabilisation ponds, chlorination is neither necessary nor desirable. Figure 4 shows the rapid re-growth of coliforms in an effluent after chlorination. Apart from cost and maintenance considerations, there is a risk of formation of carcinogenic chlorinated hydrocarbons and many faecal bacteria are resistant to chlorine which results in aftergrowth. Very high chlorine concentrations are required to kill viruses, protozoa and helminths.

It should be noted that a well-designed pond system can produce an effluent with less than 100 faecal coliforms per 100 ml which is suitable for unrestricted irrigation (16).

DESIGN CONSIDERATIONS

The main factors that must be taken into account when designing waste-stabilisation ponds are:

Ambient and/or water temperature;

wind velocity and direction;

solar radiation and cloud cover;

strength and quality of waste-water to be treated;

final effluent quality required;

area of land available; and

water losses through percolation and evaporation

In cases where there are industrial discharges to the sewerage system, the nature of the discharges should be established, especially where industrial discharges form a significant portion of the total sewage flow.

Methods for the design of ponds are based on, or indirectly based on, the effect of temperature. Generally water temperatures will be about 3°C above ambient temperatures.

Anaerobic ponds

Anaerobic ponds should be designed on the basis of a volumetric organic loading of between 0.1 kg and 0.4 kg $BOD_5/m^3/d$; the lower value being used when the ambient temperatures in the cold season fall to around 12°C; and the higher value when the ambient temperatures are fairly uniform through the year at around 27°C to 30°C. For minimum ambient temperatures between these two extremes, it is suggested that it is reasonable to assume a linear relationship.

The successful operation of anaerobic ponds depends on maintaining the balance between acid-forming bacteria and methanogenic bacteria. In anaerobic digestion sewage soils are broken down in two stages by these two groups of anaerobic bacteria. First, organic compounds are oxidised to acetic acid and other atty acids and then these acids are converted to methane. The methanogenic bacteria are sensitive to acidic conditions and for this reason the pH should be maintained in excess of 6 and preferably around 7.

Temperature is also important since most bacteria have a maximum growth rate at temperatures of between 20°C and 38°C. Temperatures in excess of 15°C are necessary and the rate of digestion increases sevenfold for each 5°C rise. At temperatures below 15°C anaerobic ponds act simply as sludge storage ponds. At the higher temperatures sludge accumulation is minimal and desludging, which should be undertaken when the pond is half full of sludge, is only necessary every 3 to 5 years.

Retention time should normally be between 2 and 5 days and the depth of the ponds should generally be between 3 and 5 metres. Toxic or inhibiting substances which may be discharged from various industrial processes should, in general, be excluded.

The BOD removed from anaerobic ponds varies between 50% and 70% depending on the retention time, 50% being removed when the retention is 1 day and 70% after 5 days. Because of their high BOD removal rate the inclusion of anaerobic ponds which substantially reduce the size of facultative ponds.

Facultative ponds

Facultative ponds depend on the symbiosis between bacteria and algae. Many different methods are available for the design of facultative ponds and they are generally based on empirical formulae, statistical analysis and rules of thumb. The design methods in most common use are:

Global environmental design basis;

Gloyna's empirical formula;

First-order kinetics;

Indian approximate procedure;

Solar-radiation method;

Thirumurthi method; and

McGarry and Pescod Formulae

These various design methods, being based on observed performances, produce different results which may be the result of variations in local conditions. It is quite probable, for example, that, in domestic sewage, differences will occur purely as a result of different diets. However in hot climates temperature-based methods should be used. The choice of design method will depend on the data available and climate. First-order kinetics is becoming accepted as a rational approach to the design of facultative ponds. It assumes that the pond is a completely mixed reactor in which BOD removal follows first-order kinetics. This is shown in the following equation:

$$\frac{L_e}{L_i} = \frac{1}{1+k_1 t^*}$$

where:

L_e = effluent BOD_5, mg/l

L_i = influent BOD_5, mg/l

k_1 = rate constant for first-order removal of BOD, d^{-1}

t^* = rentention time in days

Now the mid depth area of a pond is given by the equation:

$$A = \frac{Qt^*}{D}$$

where:

A = mid-depth area, m²

Q = volumetric flow rate, m³/d

D = pond depth, m

Combining these equations gives:

$$A = \frac{Q}{Dk_1}\left[\frac{L_i}{L_e} - 1\right]$$

To ensure facultative ponds operate satisfactorily L_e should be in the range 50 mg/l - 70 mg/l for ponds 1m - 1.5m deep. The value of k_1 is about 0.3 at 20°C and its variation with temperature is given by:

$$k_1(T) = 0.3\ (1.05)^{T-20}$$

where T is the varied temperature. This should be taken as the mean temperature of the coldest month.

Choosing an L_e of 60 mg/l and substituting for k_1 gives the design area as:

$$A = \frac{Q(L_1-60)}{18D(1.05)^{T-20}}$$

The surface organic loading of the pond should also be calculated using the following equation:

$$\lambda_s = \frac{10L_1Q}{A}$$

where λ_s = BOD_5 surface loading, kg/ha/d
and checked that it does not exceed the permissible loading given by

$$\lambda_s = 20T-120$$

Facultative ponds should not be built in sheltered areas as wind action induces vertical mixing. Mixing plays a significant role by minimising short-circuiting, preventing stagnant areas from forming and by carrying up non-motile algae to the photic zone because algae can only produce oxygen where there is light. Mixing also carries oxygen down to the lower levels of the ponds and prevents the formation of a thermocline. If there is no mixing then the non-motile algae will settle out, the motile algae will move away from the hot surface layer and form a dense layer some 300 mm to 500 mm below the surface. The settled non-motile algae will exert an additional BOD and simultaneously there will be less oxygen produced as there are fewer algae, thus reducing the rate of waste stabilisation.

The sludge layer that forms on the bottom of facultative ponds undergoes anaerobic fermentation with the production of methane. The methane can cause the sludge to rise resulting in the formation of floating mats which prevent the penetration of light into the photic zone. Consequently these mats should be removed. If the ponds are treating effluent from anaerobic ponds this problem should not occur.

Facultative ponds in general should be between 1 m and 1.5 m deep, although they can be deeper to reduce losses through evaporation and, in cold climates, to retain as much as possible of thermal energy of the sewage. A minimum depth of one metre is essential to prevent the growth of vegetation which, if allowed to grow, makes suitable conditions for the breeding of various insects, snails etc.

Maturation ponds

The principal purpose of maturation ponds is the destruction of faecal pathogens since the major part of the BOD has been removed in the anaerobic and/or facultative ponds. They are aerobic throughout their depth. The design of maturation ponds, then, is based on the removal of faecal coliforms and can be satisfactorily represented by a first-order model:

$$N_e = \frac{N_i}{1+K_b t^*}$$

where N_e = number of faecal coliforms per 100 ml of effluent

N_i = number of faecal coliforms per 100 ml of influent

K_b = first order rate constant for faecal coliform decay, d^{-1}

t^* = hydraulic retention time in days

The value of k_b is highly temperature-dependent and is given by:

$$k_{b(T)} = 2.6(1.19)^{T-20}$$

for values of T between 2°C and 21°C and where $K_{b(T)}$ = the value of K_b at T°C(17).

For a number of maturation ponds in series, the concentration of faecal coliforms in the final effluent is given by:

$$N_e = \frac{N_i}{(1+K_{bt_1}{}^*)(1+K_{bt_2}{}^*)\ldots(1+K_{bt_n}{}^*)}$$

where t^*_n = hydraulic retention time in the nth pond in days.

A suitable design value for N_i is 4×10^7 faecal coliforms/100 millilitres.

From this formula it can be shown that a higher faecal coliform removal is achieved by having a number of smaller ponds rather than just one large pond. Additionally, it can be shown that the most efficient system is one in which the maturation ponds have equal retention periods.

Maturation ponds should be between 1 and 1.5 m deep. They can be deeper if the pressure for land is great but should not be less than 1 m in order to prevent the growth of vegetation. Viral and bacterial removal are marginally better in shallow ponds than in deep ponds.

In facultative ponds, algae are numerous partly as conditions are not conducive to the development of algal predators. However in maturation ponds the algal numbers decrease due to the establishment of an extended food chain of protozoa, rotifers, crustacea and fish and to the reduction in concentrations of dissolved nutrients.

POND CONSTRUCTION

Ponds can be of any shape and, sometimes, it is economic to design them to suit the topography of the site. Length-to-breadth ratios should be 2 or 3 to 1 and the long side should be aligned with the prevailing wind to achieve good mixing.

Ponds should be sited away from centres of population preferably at sites where there is sufficient land available to permit extensions to the system. Generally it is recommended that pond systems are at least 500 m away from the nearest residential area and, where anaerobic ponds, are used 1000 m is recommended. However there are many instances where people are living much nearer without suffering any nuisance. Figure 5 shows Gaborone, the capital of Botswana. Three sets of ponds have been constructed to serve different sections of the capital as it has developed. Stage 1 of pond system 3 was designed by Scott Wilson Kirkpatrick & Partners and constructed in 1975. The site was chosen because the majority of the sewage could gravitate to it, it was far enough away from any proposed development, sufficient land was available for duplication and because it was close to a disposal facility - the Segoditshane river.

Generally pond bases should be impermeable, although the sludge does tend to seal the base with time. Sealing the ponds can be achieved using clay, polythene sheeting (suitably protected with sand), bitumen, ashphalt or blinding concrete.

Embankments usually have slopes of about 1 in 3 but this can vary depending on the soil conditions. Erosion is prevented by placing precast concrete slabs or rip-rap at top water level. The top of the embankment should be at least 500 mm above top water level and the concrete or stone protection should extend over that portion of the embankment likely to be affected by wave action. The use of precast concrete slabs also serves the additional function of preventing weed growth around the margins thus removing the conditions necessary for the breeding of snails and mosquitoes. In Figure 6 the precast concrete slabs at top water level can clearly be seen during drying out and desludging. Figure 7 shows grass stopping at the water level due to the presence of precast concrete paving slabs and also the formation of a sludge mat which should be removed during normal maintenance operations.

All pond systems should have some form of flow measurement at the inlet and outlet to enable the performance of the system to be checked.

In order to prevent the formation of a sludge bank at the inlet to anaerobic and facultative ponds, the inlet pipe should be taken some distance out from the edge of the embankment. Additionally there can be local deepening of the pond in the area of the inlet which will act as a store for non-degradable solids such as grit and sand which tend to be a major constituent of the sludge banks.

Typical details of inlet arrangements are shown in Figures 8 and 9.

Figure 10 shows what can happen when the raw sewage is discharged directly into a facultative pond at its edge - a sludge bank forms which prevents the influent getting into the pond freely and additionally provides suitable conditions for vegetation to grow which provides a habitat for insect breeding.

There are numerous types of interpond connection and Figures 11 and 12 show two different types that have been used. Refinements can be made, such as providing variable level draw offs and these may well prove worthwhile for large systems which are permanently manned.

The size of the pipework for the interpond connections should be kept to a minimum so as to attenuate peak flows.

For larger systems it is desirable to provide screening and grit-removal facilities and the degree of automation and sophistication of these facilities will depend on the size of the pond system and the availability of skilled or semi-skilled labour.

SLUDGE

In conventional sewage-treatment works, one of the major problems is the treatment and disposal of sludge that is produced daily. It also accounts for a large proportion of the operation and maintenance cost of the works. In stabilisation ponds this is a relatively minor problem, anaerobic ponds requiring desludging every 2 to 5 years, facultative ponds every 20 to 40 years and maturation ponds probably never during the lifetime of the system. The sludge once removed can be dried on sludge-drying beds or in the pond itself and then used as a fertiliser. To assist in sludge removal, facilities for draining down the ponds and for by-passing them should be provided. They do not, however, need to be provided for maturation ponds. If it is intended to allow the sludge to dry in the ponds, then access ramps should be provided to allow vehicular access for the excavation of the dried sludge.

Duplication of ponds and well-laid-out interconnecting pipework will enable desludging to be carried out with the minimum of overloading to the remainder of the ponds in the system. Figure 13 shows a system that has 3 anaerobic ponds in parallel, followed by two facultative ponds in parallel, followed by four maturation ponds in series. The interpond pipework arrangement allows any of the anaerobic or facultative ponds to be taken out of commission for desludging.

UPRATING POND SYSTEMS

Pond systems should be constructed to treat the present and the immediate future flows rather than to the 20- or 30-year design horizon, mainly on economic grounds, but partly because if they are extremely large they will take a substantial time to fill and consequently there will be no effluent available for irrigation for some time.

Pond systems can be extended simply by the addition of a second stream in parallel. This process may be repeated a number of times provided that sufficient land is available. Another alternative is to construct facultative and maturation ponds initially, and when they become overloaded, to construct an anaerobic pond prior to the facultative ponds. These alternatives are illustrated in Figure 14.

Other methods of uprating pond systems include the construction of aerated lagoons after anaerobic ponds but before facultative ponds or the installation of aerators in the facultative pond. Aeration however alters the biological processes as oxygen is supplied by the aerators resulting in the disappearance of algae and the facultative pond now operating more as an activated-sludge system. Another alternative is high-rate ponds which could be used to reduce the loading on facultative ponds. They are very shallow, 20 cm - 40 cm, and the photic zone extends virtually for the full depth of the ponds. The conversion of sewage nutrient to algae is very rapid, and the large amounts of algae is very rapid, and the large amounts of algae produced have to be removed. However, it is the lack of a suitable algal removal system that has limited their use at present.

ALGAL REMOVAL

Algae in the effluent not only increase the concentration of the suspended solids but also increase the BOD value. It has been suggested(2) that up to 62% of the BOD of the effluent from a facultative pond is due to algae. Clearly the removal of algae would have a dramatic influence on the quality of the final effluent. The removal of algae can, as previously stated, be partially achieved by increasing the number of maturation ponds but this does not appear to be very efficient.

Numerous methods of algal removal are available and vary widely in complexity, cost and effectiveness. However, if the effluent is to be used for irrigation, then provided the algae do not clog the irrigation system it can prove advantageous because the algae provide a source of nutrient.

MAINTENANCE

Pond maintenance, apart from desludging, consists mainly of cutting grass around the ponds, the breaking up of algal mats and the removal of any floating debris and scums. Scum should not be removed from anaerobic ponds but it may be necessary to spray the scum with insecticide to prevent the breeding of flies. The use of insecticides is however not generally necessary or recommended as it may inhibit the biological process in the stabilisation ponds. It is worth noting that waste-stablisation ponds do not rely on skilled operators or on a large array of electrical machinery or controls which have to be maintained at a high level for satisfactory operation of the plant. Waste-stabilisation ponds are intrinsically fail-safe in their operation and, provided basic maintenance is carried out, will operate satisfactorily with the minimum of attention.

ECONOMIC AND FINANCIAL COST COMPARISONS

The basic criterion in determining whether a particular method or system of sewage treatment is efficient or not is to make comparisons between the economic costs of each alternative in achieving the same purposes. It should be appreciated that it is not possible to generate an economic model that will apply to all countries and provide the necessary information to make sound judgements. For example land, labour, capital, power and water costs vary from one country to another. However, the World Bank in its Technical Paper Number 7, (1) published an economic cost comparison between four different systems of sewage treatment, viz:

Waste-stabilisation ponds;

aerated lagoons;

oxidation ditches; and

biological filtration,

The basic parameters used in the comparison included:

Contributing population	250,000;
per capita BOD_5	40 g/d;
controlling temperature	20°C;
effluent standard	25 mg/l BOD_5: 10,000 FC/100 ml.

Capital costs included land, earthworks, structures and equipment and recurring costs of power, labour and maintenance. It is not clear whether shadow prices were included in the economic analysis. The result of the World Banks's analysis is shown in the graphs of Figure 15 for discount rates of 5%, 10% and 15% and varying land costs. These graphs indicate that waste-stabilisation ponds would be the least cost alternative when land costs are less than 15 US $/m², 9.7 US $/m² or 5.4 US $/m² for discount rates of 5%, 10% and 15% respectively. In some cases it could prove economic to convey sewage from an area where land is relatively expensive to an area where land costs are minimal (3).

For controlling temperatures above 20°C, waste stabilisation ponds will become even more economic; and it is clear that in situations where land is relatively cheap and temperatures high the economic case for using waste stabilisation ponds becomes very strong. However, each case must be taken on its merits and the judgement and assumptions involved in any economic analysis must be carefully made.

RECENT TRENDS AND DEVELOPMENTS

Research

Waste-stabilisation ponds have recently been the subject of an intense research project undertaken by the Federal University of Paraiba, Brazil, in association with the Universities of Leeds and Liverpool of the UK. The research was carried out at the Experimental Station for the Biological Treatment of Sanitary Sewage in the city of Campina Grande in northwest Brazil and the results of this research were published in July 1983 (16). The results were very encouraging and showed a reduction in BOD and suspended solids from a mean of 240 gm/l and 350 mg/l to 17 mg/l and 45 mg/l respectively for a series of 5 ponds with a total retention time of 28.1 days. The controlling temperature was 26° C, this being the mean mid-depth temperature between June 1977 to May 1979. Good though these figures are the removal of faecal coliforms can only be regarded as remarkable having been reduced from 4.6×10^7/100 ml in the influent to 30/100 ml in the effluent; a reduction of over 6 log units and well below the WHO's guideline for unrestricted irrigation. Impressive results were also recorded for the anaerobic ponds which received raw sewage at 132 g and 311 g BOD/m^3/d; had retention times of 1.9 days and 0.8 days and a mid-depth temperature of 26° C. BOD removal was 76% - 81% and a useful reduction of 1 log unit in faecal coliforms occurred with no odour problems. The overall results of this research are given in Tables II and Tables III respectively.

Further research is planned to test the performance of deeper (2 m - 3 m) ponds with special attention being paid to their efficiency in the removal of bacterial and viral pathogens. Should this research prove successful land requirements could be substantially reduced making ponds an attractive option for the treatment of sewage from large urban centres.

Developments

The Amman Water and Sewerage Authority in Jordan has recently started work on 180 hectares of waste-stabilisation ponds to relieve the loading on the Ain Ghazal treatment plant. Energy conservation was an important factor in the adoption of a waste-stabilisation pond solution and was preferred to the building of a new treatment works which would have cost as much as the waste-stabilisation ponds and consumed far more power. The ponds have been designed to treat 68,000 m^3/d of partially-treated sewage at a tendered cost of 16.25 million Jordanian Dinar (44.32 million US \$) and are located 40 km from Amman. Consideration is being given to reducing the level of conventional treatment given at the Ain Ghazal works, to fish farming the ponds and to the re-use of pond effluent for irrigation (3).

It is often thought that ponds are only used in hot climates and that there is no place for them in cold climates. A recent report, (23), suggests that apart from septic tanks, ponds are the most widely used and economic process for the treatment of wastewater in Canada. A number of different practices have evolved in the design, construction and operation of ponds in cold climates because of the wide variations in seasonal performance. This generally has resulted in retention times being much larger, being measured in months rather than days, intermittent discharges and draw-off points located below ice cover level.

Standards

In recent years there has been considerable discussion over whether algae should or should not be included in the assessment of effluent quality. A consensus is growing that in general algal cells should be excluded from total-solids limitations as there is ample technical data available to demonstrate (9) that waste-stabilization-pond effluent solids can augment rather than damage fisheries, making the removal of solids a questionable process as far as water quality is concerned.

CONCLUDING COMMENTS

Waste-stabilisation ponds are ideally suited for use in the Middle East. In most areas the skies are clear for the major part of the year, with high mean temperatures.

The design of pond systems can be such that the quality of the final effluent is suitable for unrestricted irrigation without the need for chlorination. Effluent standards should be based on the concentration of faecal coliforms and on BOD, the determination of which should be carried out on filtered samples.

Pond systems are cheap to construct, easy to extend, require no power and very little maintenance. They require desludging at very infrequent intervals whereas sludge treatment and disposal is a major element in conventional sewage treatment systems. Problems with wind-blown sand can be reduced or eliminated by the construction of sand fences or by sand stabilisation. This can be effected by encouraging vegetation to grow, irrigated using the final effluent.

Contrary to popular belief, pond systems, when operated reasonably well, produce less odours than conventional systems partly because of the quiescent conditions. Conventional aeration methods not only produce a sweet odour when operated correctly, but also produce aerosols which can be detrimental to the health of the sewage-treatment-works operators.

Anaerobic ponds, provided they are not overloaded, that the sulphate concentration is below 100 mg/l and that waste temperature is in excess of 15° C will operate very efficiently and be odour-free.

The performance of large pond systems could be improved by the incorporation of mechanical equipment - such as automatic screens, macerators and detritus tanks. In addition, the possibility of having variable level draw-offs linked to a detection system enabling the best-quality water to be passed on to the next pond may be feasible.

Pond systems should be developed in such a way that full use is made of the waste products carried in the sewage. An integrated system may well contain provision for algal harvesting, pisciculture and irrigation using the final effluent.

REFERENCES

1. Arthur, J.P. World Bank Technical Paper Number 7. Notes on the Design and Operation of Waste Stabilisation Ponds in Warm Climates of Developing Countries. Urban Development Technical Paper Number 6. World Bank, Washington, D.C. U.S.A. July 1982.

2. Bradley, R.M. BOD removal efficiencies in two stabilisation lagoons in series in Malaysia. Wat. Pollut. Control, 1983, 82 (1), 114

3. Charnock, A. Amman adopts lagoon solution. World Water, 1983, Sept.

4. Chiow, L. T., Maheswaran, A, and Yew, L.F. Oxidation ponds, Wardieburn Housing Estate, Kuala Lumpur - Design and Operating Experiences.

5. Ellis, K. Aerated Lagoons for the Treatment of Industrial Wastewaters in Developing Countries. 6th WEDC Conference: 1980, March.

6. Feacham, R., McGarry, M. and Mara, D. Water, Wastes and Health in Hot Climates. Wiley 1977.

7. Fraser, J. I. The design of waste stabilisation ponds. 6th WEDC Conference, 1980, March.

8. Gloyna, E.F. Waste Stabilisation Ponds. WHO 1971.

9. Gloyna, E.F. and Tischler, L.F. Recommendations for regulatory modifications: the use of waste stabilisation pond systems. Journ. Water Pollution Control Federation, 1981, Nov., 53, (11).

10. Kilbermatton, J. M., Julius De A.S., and Gunnerson, C.G. Appropriate Sanitation Alternatives: A Technical and Economic Appraisal. World Bank, 1978.

11. Loedolff, C.J. The mosquito problem in oxidation ponds. C.S.I.R. reprint W. R. No. 150.

12. Lumbers, J.P. Waste Stabilisation Ponds: Design Considerations and Methods. Journ I.P.H.E. 1979, 7, (2), 70-78.

13. Mara, D. Sewage treatment in hot countries. Overseas Building Notes. Building Research Establishment. 1977, June.

14. Mara; D. Proposed design for oxidation ponds in hot climates. Proc. A.S.C.E. 1975; April; 101; (EE2).

15. Mara; D. Sewage Treatment in Hot Climates; Wiley 1976.

16. Mara; D.; Pearson; H.; and Silva; S.A.; Brazilian stabilisation-pond research suggests low-cost urban applications. World Water; 1983; July.

17. Marais; G.V.R. Faecal Baterial Kinetics in Stabilisation Ponds. Proc A.S.C.E. 1974; Feb.; 100; (EE1).

18. Meiring; P.G.J.; Drews; R.J.L.C.; Van Eck; H; and Stander; G.J. A guide to the use of pond systems in South Africa for the purification of raw and partially treated sewage. South African Council for Scientific and Industrial Research; 1968; Jan.

19. Pescod; M.B. Investigation of rational effluent stream standards for tropical countries. Asian Institute of Technology; Bangkok; 1974.

20. Polprasert; C.; and Rajput; V.S. Study of chlorine disinfection of pond effluent. (Asian Institute of Technology). Water Research; 1984; 18; (5); 513-518.

21. Van Eck. H. Theory of stabilisation ponds and its implication on their design and operation. C.S.I.R. Reprint; R.W. No. 132.

22. Van Eck. H. Sewage stabilisation ponds - a critical review. Trans. South African Institution of Civ. Eng. 1958; July; 8; (7); July 1958.

23. Smith; D. Treatment ponds for cold climates - an overview. World Water; 1983; September.

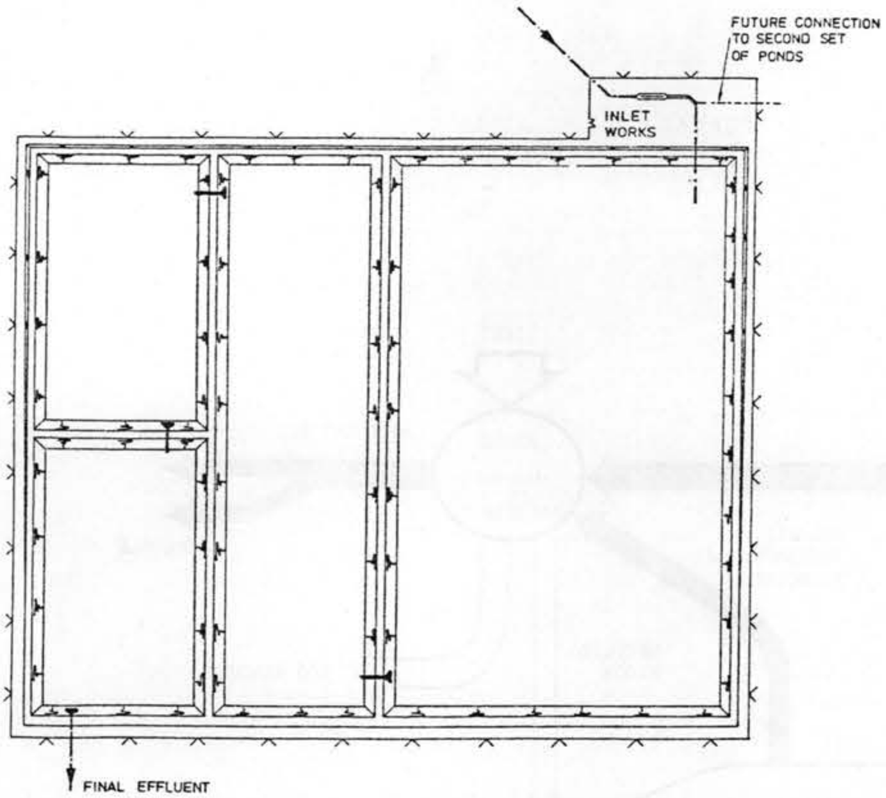

Figure 1. Typical waste-stabilisation-pond arrangement

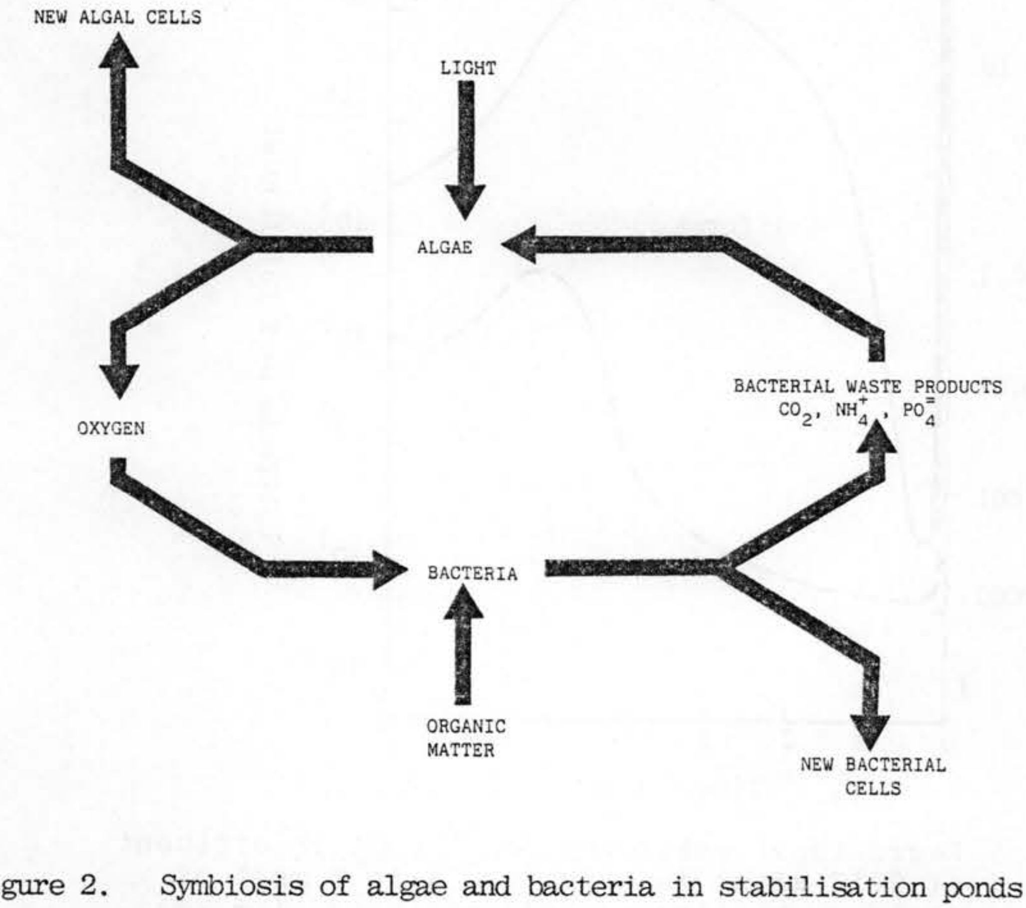

Figure 2. Symbiosis of algae and bacteria in stabilisation ponds

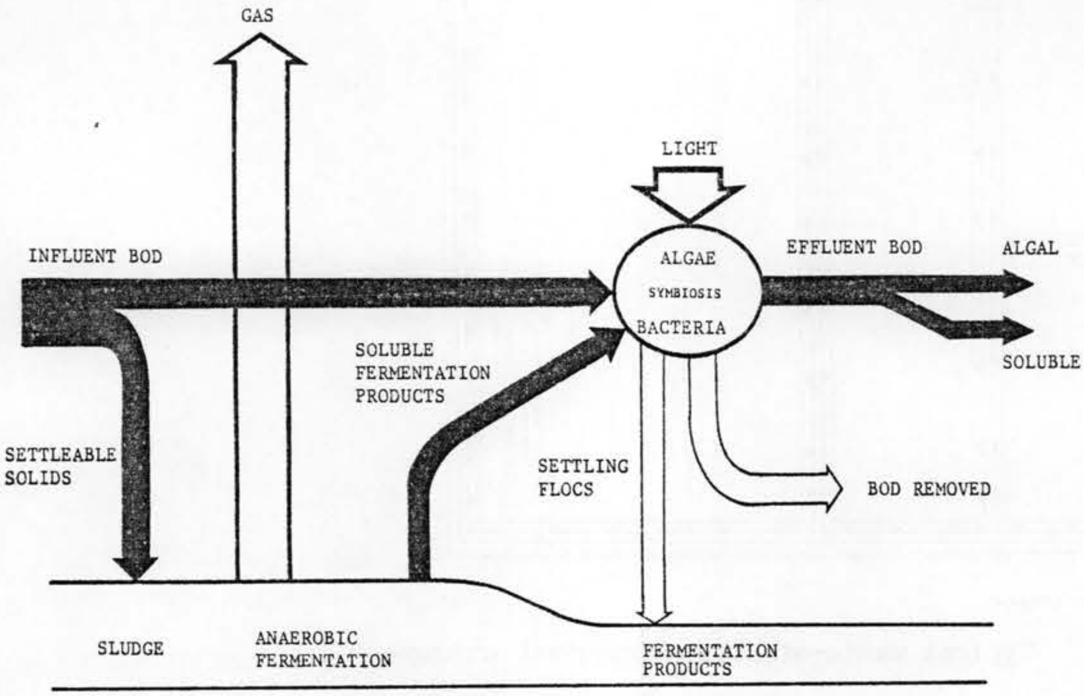

Figure 3. Pathways of BOD removal in facultative ponds

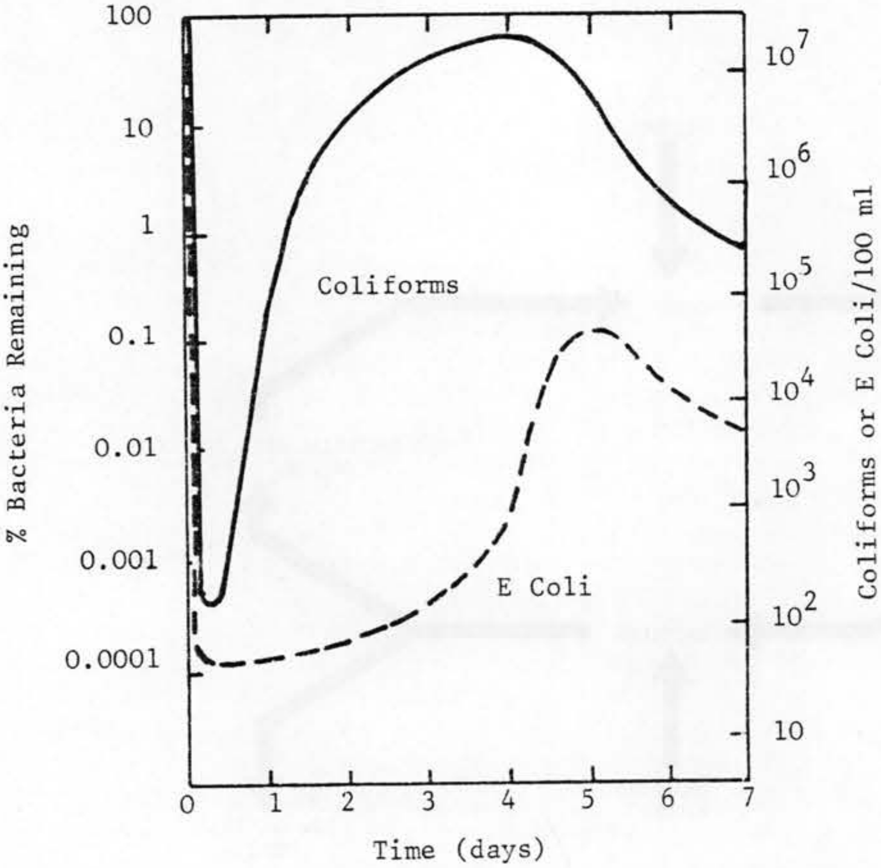

Figure 4. Regrowth of coliforms and E coli in effluent at 20°C after inactivation with 5 mg/l of applied chlorine and no dechlorination (6)

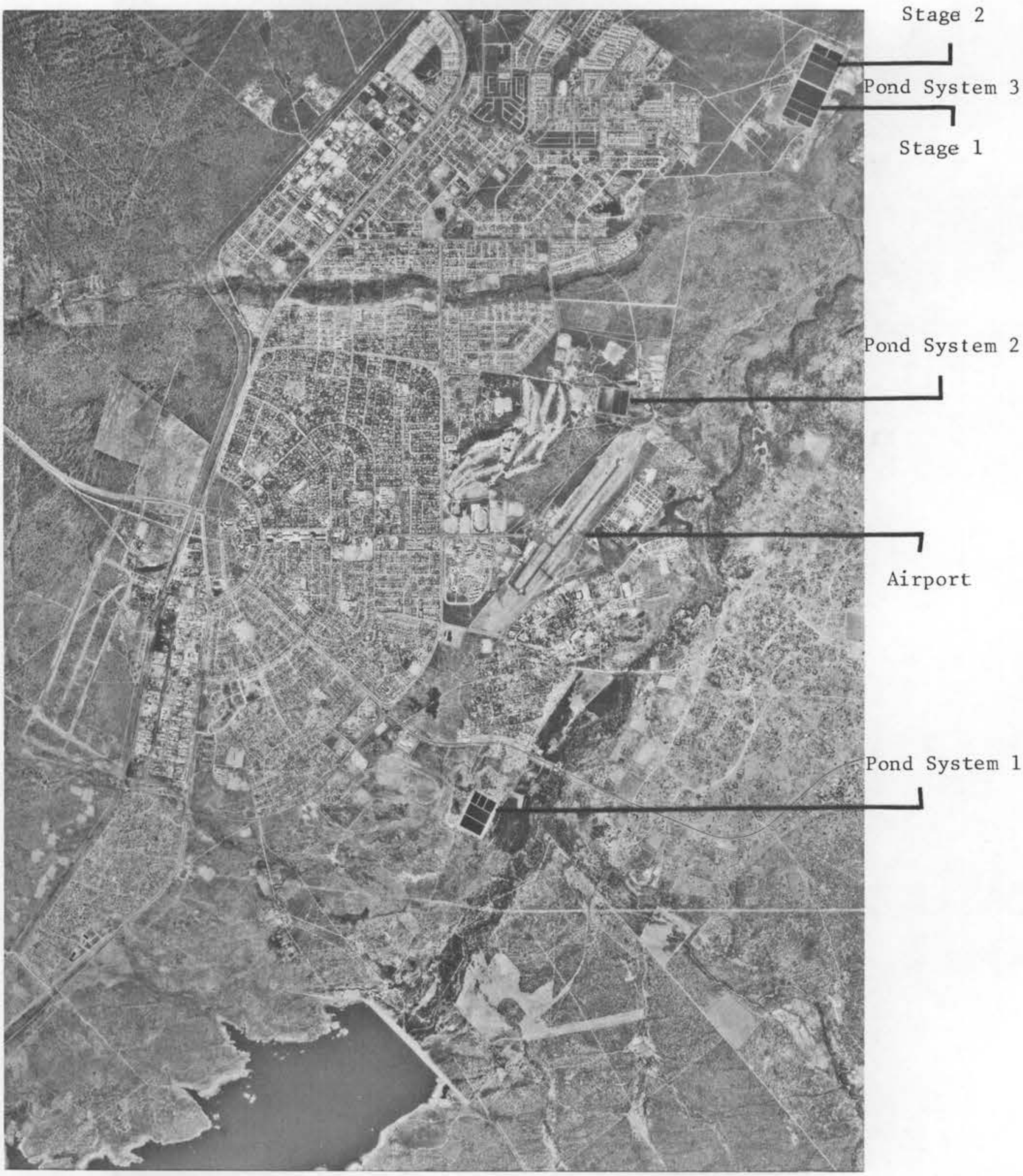

Figure 5. Pond systems, Gaborone, Botswana, July 1982

Figure 6. Embankment protection using precast-concrete slabs and pond drying for sludge removal.

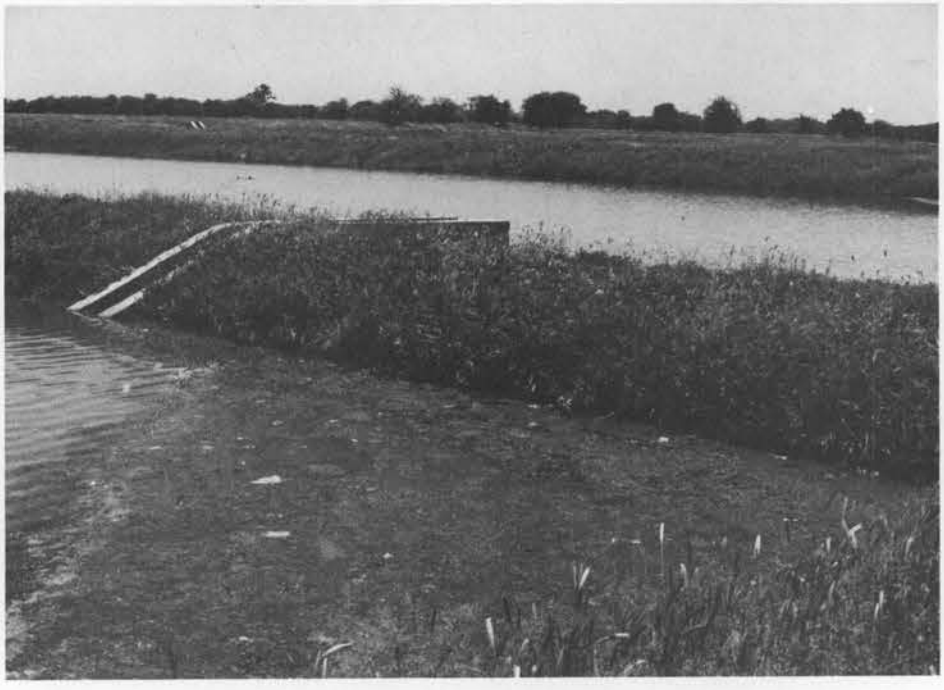

Figure 7. Grass-curtailment and sludge mat.

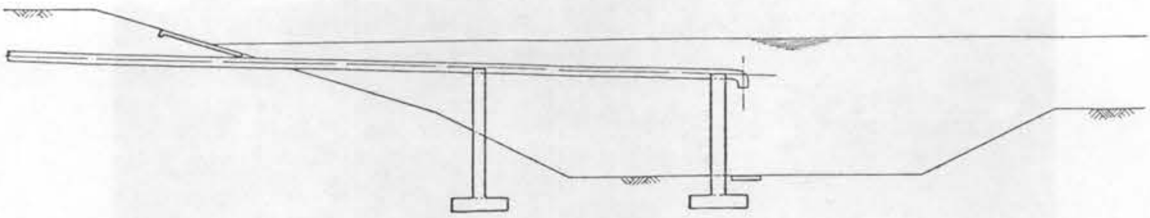

Figure 8. Inlet arrangement 1

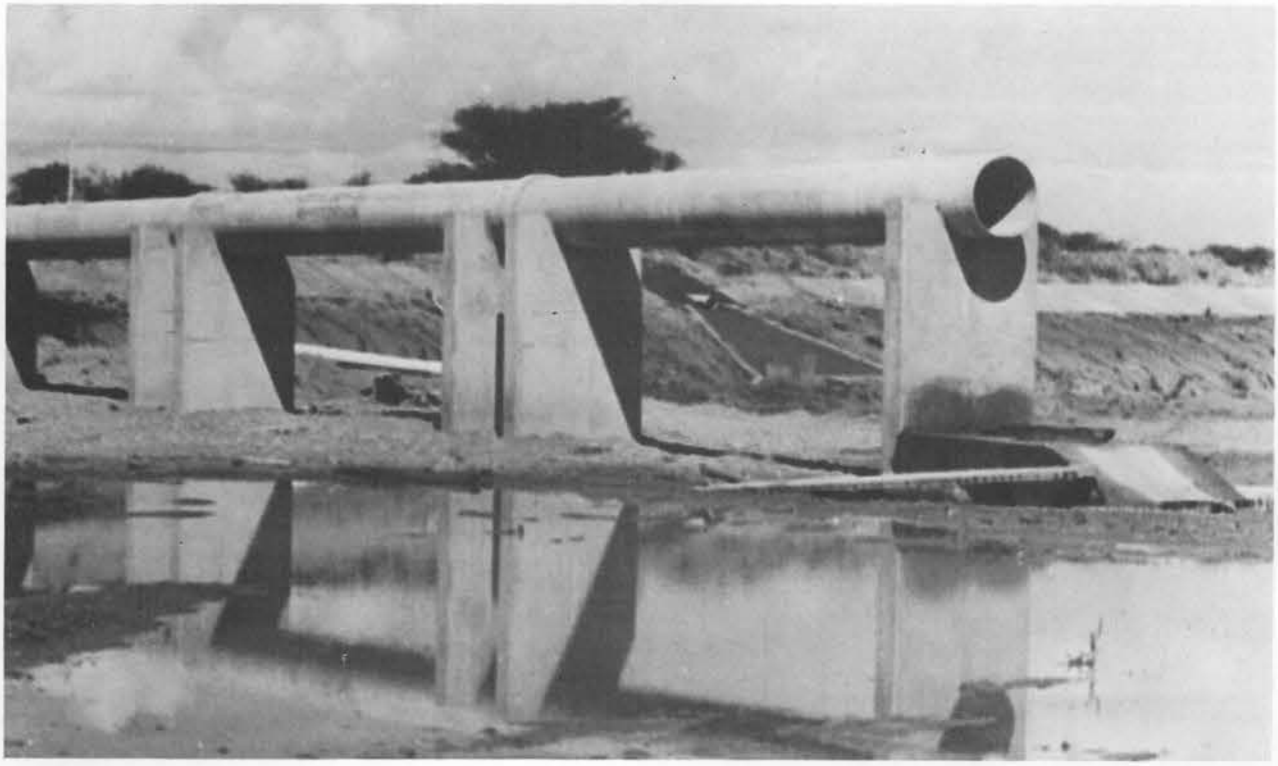

Figure 9. Inlet arrangement 2

Figure 10. Sludge-bank formation

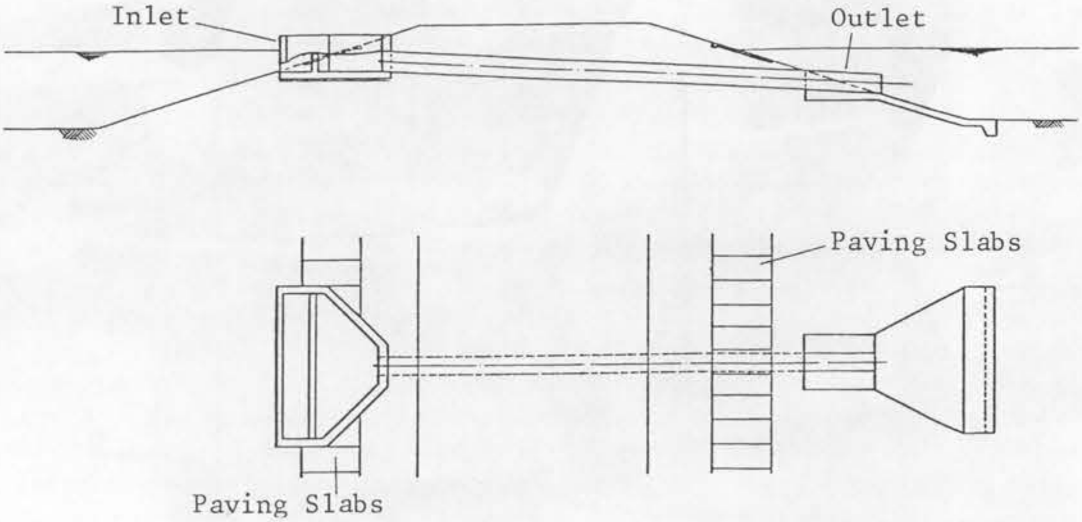

Figure 11. Interpond connection 1.

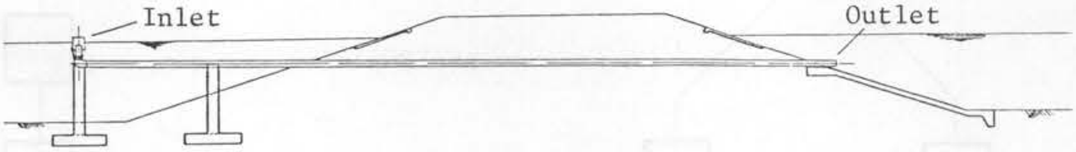

Figure 12. Interpond connection 2

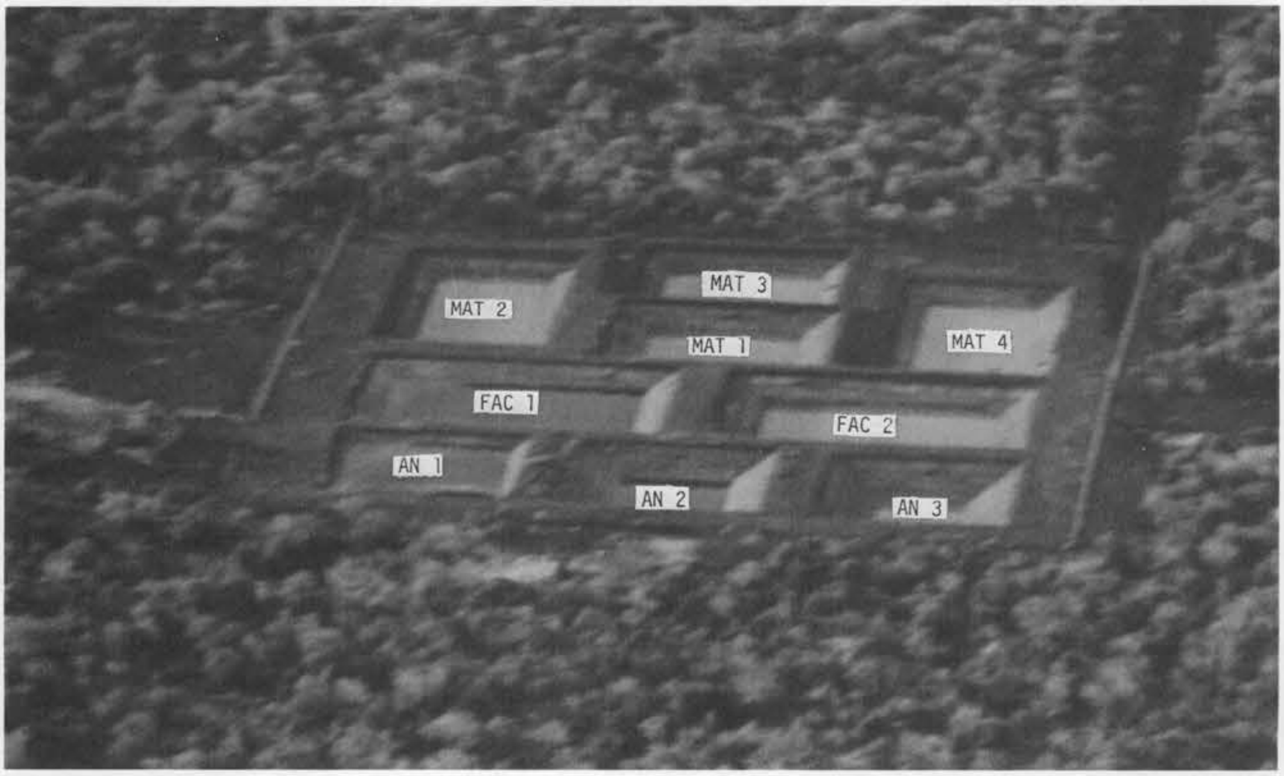

Figure 13. System of anaerobic, facultative and maturation ponds

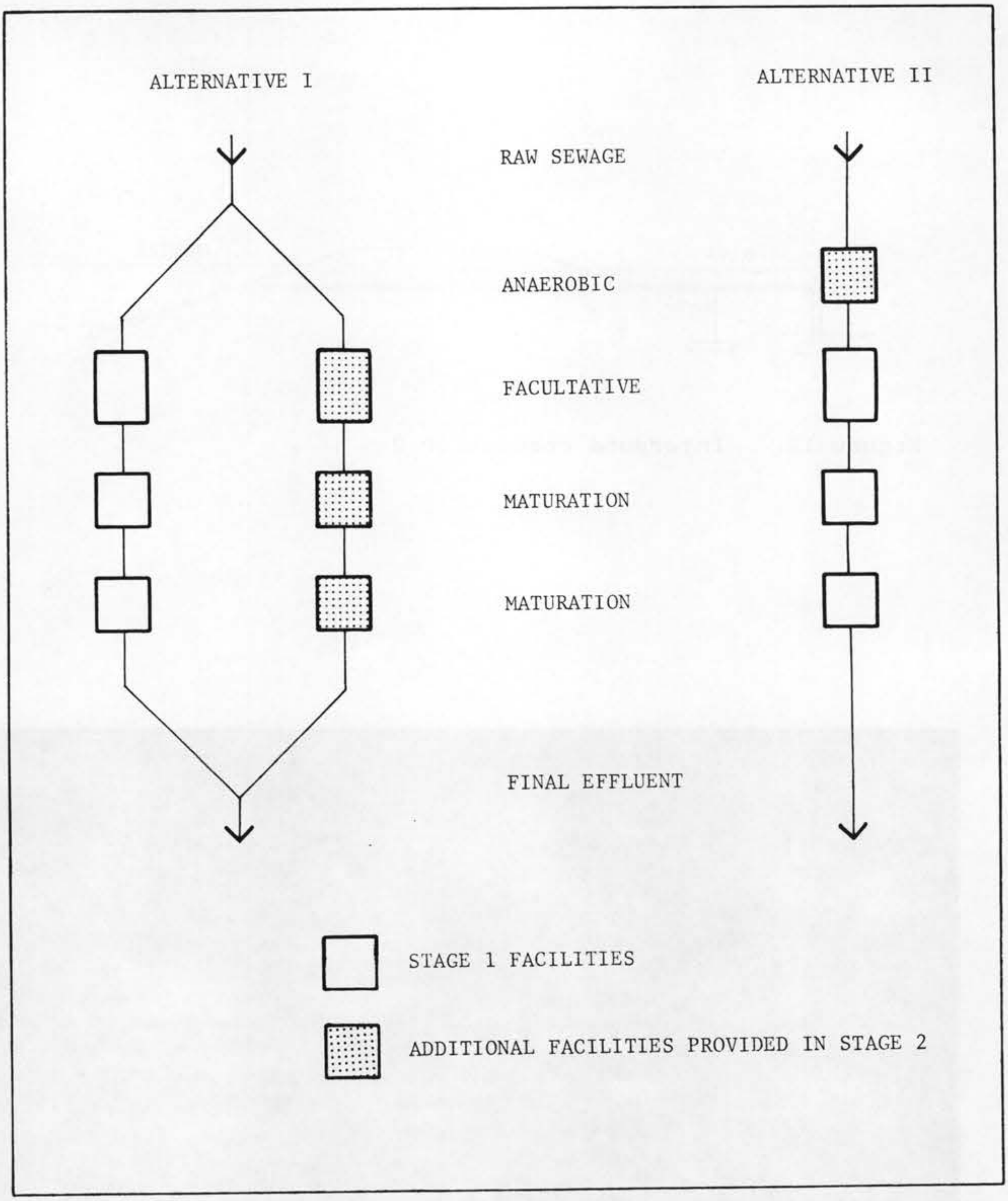

Figure 14. Uprating pond systems

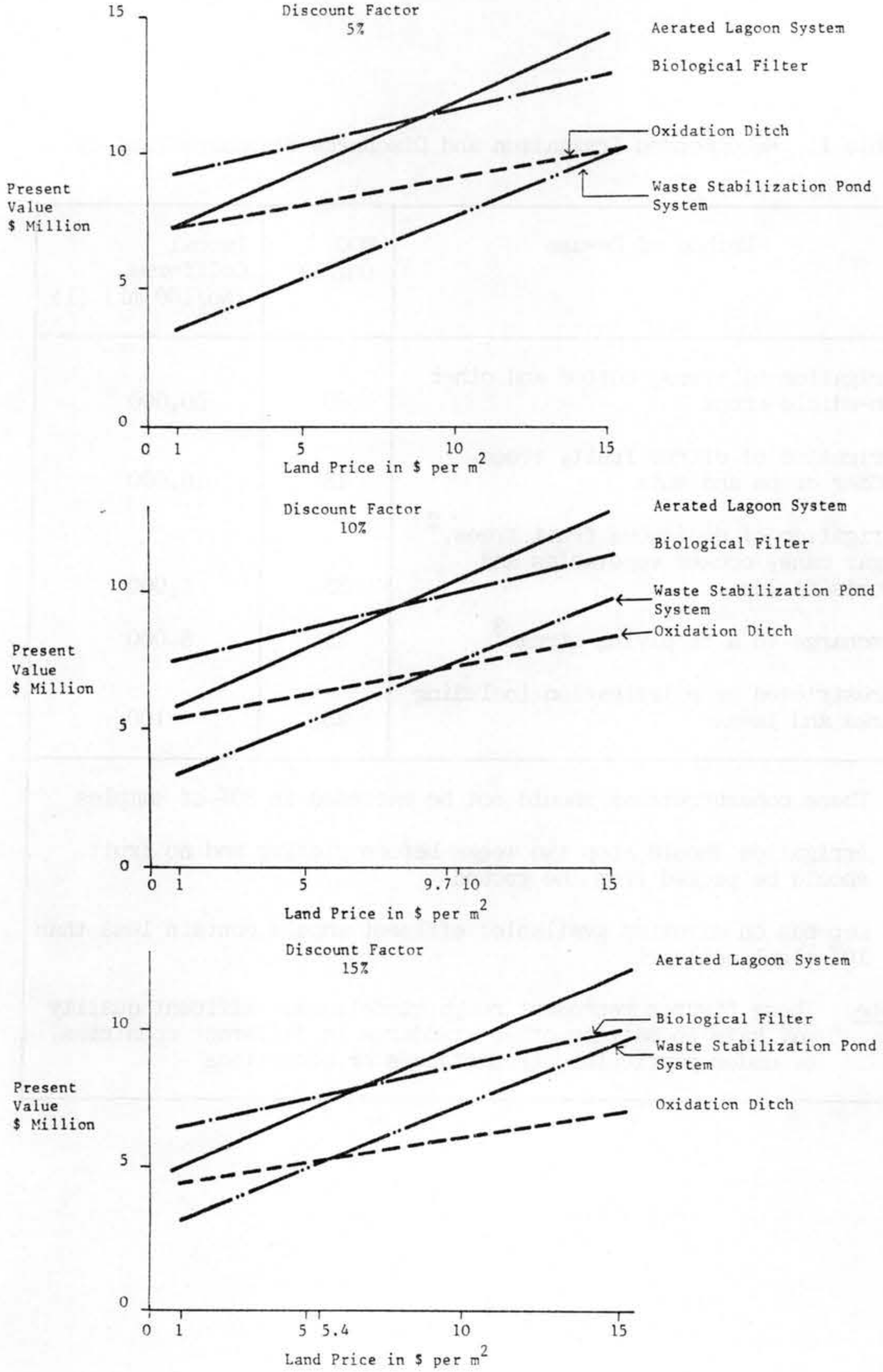

Figure 15. Economic comparisons (1)

Table I. Recommended Irrigation and Discharge Standards (Ref 1)

Method of Re-use	BOD (mg/l)	Faecal Coliforms (No/100 ml) (1)
Irrigation of trees, cotton and other non-edible crops	60	50,000
Irrigation of citrus fruit, trees, fodder crops and nuts	45	10,000
Irrigation of deciduous fruit trees,[2] sugar cane, cooked vegetables and sports fields	35	1,000
Discharge to a receiving stream[3]	25	5,000
Unrestricted crop irrigation including parks and lawns	25	100

1 These concentrations should not be exceeded in 80% of samples

2 Irrigation should stop two weeks before picking and no fruit should be picked from the ground

3 Depends on dilution available; effluent should contain less than 10^5 algal cells/ml

<u>Note</u>: These figures represent rough guidelines. Effluent quality may have to satisfy other standards in different countries, or under particular circumstances or conditions

Table II. Experimental results from a series of 5 ponds (16)

Description	Retention time (days)	BOD (mg/l)	SS (mg/l)	FC (No/100 ml)
Raw Sewage	-	240	305	4.6×10^7
Effluent from Pond 1	6.8	63	56	2.9×10^6
2	5.5	45	74	3.2×10^5
3	5.5	25	61	2.4×10^4
4	5.5	19	43	450
5	5.8	17	45	30

Table III. Experimental results from anaerobic ponds (16)

Description	Retention time (days)	BOD (mg/l)	SS (mg/l)	FC (No/100 ml)
Raw Sewage	-	245	310	4.7×10^7
Effluent from Pond 1*	0.8	59	82	8.1×10^6
2*	0.4	46	64	5.0×10^6
3	1.9	49	57	4.7×10^6

* Ponds 1 and 2 in series