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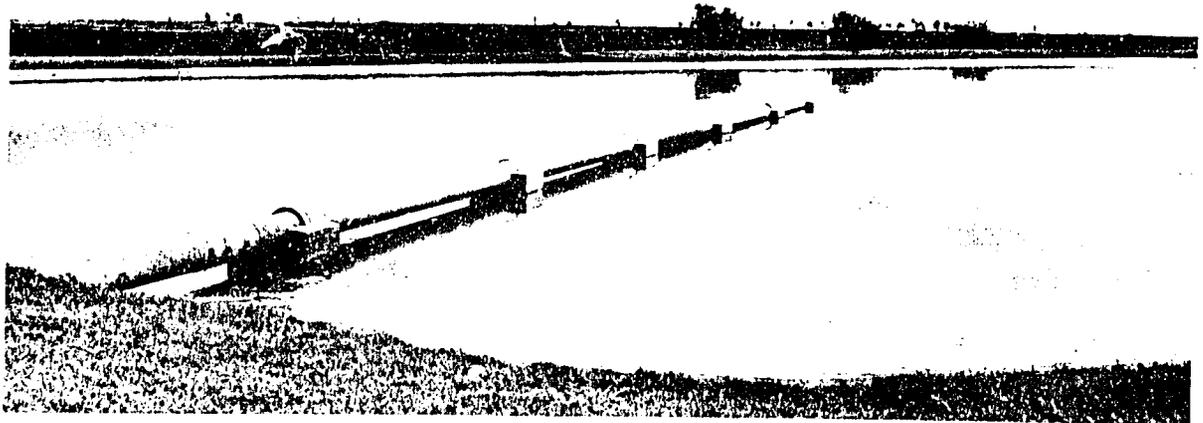
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Prepared for the Agency for International Development

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT
WASHINGTON, D. C. 20410

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302/2/1 Sewage Lagoons

SEWAGE LAGOONS FOR DEVELOPING COUNTRIES

Prepared for

The Agency for International Development

DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

WASHINGTON, D. C. 20410 .

January 1966

FOREWORD

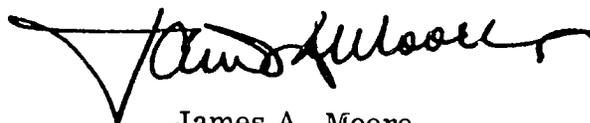
The publications in the Ideas and Methods Exchange Series present ideas and useful experiences that will help urban development and housing advisors of the Agency for International Development in providing technical assistance to developing countries.

This publication on sewage lagoons, which was prepared at the request of A.I.D., is addressed to one of the major problems faced by many developing countries -- that of providing safe and economical means of sewage treatment and disposal.

Sewage lagoons, also called stabilization ponds or oxidation ponds, have been successfully used in the United States and in a number of the developing countries. They are a recognized means of sewage treatment and have two advantages for developing countries: (1) Their construction requires principally land and labor - both local commodities, and (2) they are generally cheaper to install than more conventional treatment plants. Unfortunately, the literature dealing with these facilities is generally of a fragmentary and sometimes highly technical nature.

The authors of this publication, are Thomas Callaway, Housing Advisor, and Berrard Wagner, International Technical Affairs Officer, both of the Department of Housing and Urban Development. In it, they have assembled and summarized pertinent data on sewage lagoons, including their advantages and disadvantages, location, design, construction and maintenance. It therefore should be invaluable to technicians in reaching decisions on types of facilities that may be used and the conditions under which sewage lagoons are practical.

Two things should be emphasized: First, this publication is not a substitute for the services of competent public health personnel and trained sanitary engineers; second, sewage lagoons should not be regarded as a panacea to end, once and for all, the problem of sewage disposal. While significant knowledge exists, additional research remains to be done. Revised versions of this publication will be prepared as additional facts become available. Nevertheless, the information now available is promising enough to warrant dissemination at this time.



James A. Moore
Assistant Administrator

PREFACE

Many cities in developing countries lack acceptable community sewage disposal systems. The failure to provide safe, effective means of disposing of human and other wastes present problems, the seriousness of which cannot be overestimated. This is particularly true in cities with rapidly expanding populations and high densities. In some cases individual households have no facilities at all, or at best, only pit latrines. In other instances, wastes from dwellings, schools, hospitals, commercial and industrial buildings are sometimes discharged into cesspools or into septic tanks with inadequate means of disposing of the effluent. This frequently results in contamination of adjacent areas and of the ground water which finds its way into streams and water supply wells. Even cities with sanitary sewers often do not have satisfactory treating facilities and raw sewage is sometimes discharged into rivers and streams which may also be sources of drinking water for both livestock and humans.

The cost of constructing adequate treatment plants often discourages their installation in cities with limited budgets. However, treatment is possible by means of sewage lagoons which are usually less expensive than more conventional methods.

This publication summarizes the essential information on sewage lagoons in a form readily understood by laymen as well as by specialists. The Agency for International Development, therefore, believes that it will be useful to urban development and housing advisors and a guide to their host country counterparts in reaching decisions and planning for sewage treatment facilities.



Osborne T. Boyd
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INTRODUCTION

Sanitation, particularly the disposal of sewage, has always been a problem to mankind. Wherever man has lived, parasitic disease-causing pathogens have also lived. Sewage has been and still is one of the major sources of disease, especially in areas where proper or effective sanitary measures are lacking. In many parts of the world, especially the developing areas, simple pit privies or latrines are often the only provision for handling human wastes and frequently there are no sanitary facilities at all. Even where sewage systems exist, streams, ponds and nearby wells -- all sources for domestic water supply -- are likely to become contaminated. The lack of better sanitary facilities stems from a lack of knowledge of hygiene and corrective techniques, as well as a dearth of funds necessary for the provision of normal treatment plants. However, a reasonably simple and economic solution for the treatment of sewage exists which requires mainly sufficient land and human effort -- sewage lagoons.

Sewage lagoons, or stabilization ponds, have been constructed in large numbers in the United States and elsewhere; e. g. , Canada, Latin America, Holland, Germany, South Africa, Kenya, Rhodesia, Tanzania, Zambia, and Australia. Only a few failures have resulted, usually from human error in the design stage, involving capacity, leakage, or flow control. The usual objections to such a system which include bad odors, objectionable solids, and poor appearance may usually be overcome by proper location, adequate planning, proper loading and maintenance. Where reasonably priced land is available and when they are properly located, designed and built, lagoons provide efficient, low-cost sanitary domestic sewage treatment.

NATURE OF MATERIALS TO BE TREATED

Sewage lagoons are best suited for treatment and disposal of domestic wastes and some forms of industrial waste. Complex industrial waste originating in dye works, milk processing plants, slaughter houses, etc. sometimes requires special treatment and cannot be readily handled by sewage lagoons alone. Cases are on record of lagoons handling dairy and slaughter house waste, but their design is subject to special consideration.

Physically, normal domestic sewage is approximately 99.9% water, plus small amounts of suspended and dissolved solids in the form of both organic and inorganic matter. Fresh sewage is usually alkaline, tending to acidity with time, as it stabilizes. The strength of sewage depends on the relative per capita quantity of water used by the community and on the amount and nature of industrial wastes, etc., entering the system. In appearance, sewage is generally cloudy and has a slight musty or oily odor.

Chemical characteristics of sewage involve complex organic materials from feces, urine and other wastes, including inorganic material. Nitrogen compounds include proteins, urea, amines and amino acids; non-nitrogenous substances include cellulose, fats and soaps.

BIOLOGY OF SEWAGE

The biology of sewage involves aerobic bacteria utilizing free oxygen and anaerobes which are active in the absence of free oxygen. Though most sewage bacteria live on dead organic matter, a few are parasitic.

Stabilization of sewage is brought about by bacteria and algae. Bacteria digest and oxidize sewage; and algae through photosynthesis, produce oxygen required for aerobic bacterial action. The oxygen cycle of decomposition is complete and continuous, as oxidation forms carbon dioxide, which is used by algae, resulting (under certain conditions) in the creation of additional oxygen. Anaerobic action creates ammonia (a nitrogen compound) which is in turn stabilized by oxidation through aerobic action. The goal of sewage treatment is therefore a natural cycle, achieving stability without the creation of offensive conditions. The amount of oxygen necessary for aerobic decomposition is called Biochemical Oxygen Demand, or B.O.D. The rate of oxygen required is highest during the first 5 or 6 days and declines steadily thereafter. It may accelerate again about the 20th day after which it gradually diminishes over an indefinite period of time.

Objectionable odors may result from the emanation of hydrogen sulfide caused by biochemical action under anaerobic conditions and at pH values (hydrogen ion concentration) below approximately 7.5. However, in ponds having a high dissolved oxygen concentration, the formation of sulphide ions and of free hydrogen sulphide should be prevented and no odors should occur. Satisfaction of the B.O.D. depends on sewage strength and a variety of conditions, including temperature. The higher temperatures in tropical areas are -- in this instance -- an asset in that B.O.D. satisfaction (70% to 90%) can be achieved in a much shorter time than in cooler climates.

ALGAE

Algae are generally one-celled microscopic organisms found in a variety of forms ranging from spheres to rods. Living in the lagoon water, algae use the by-product of bacterial action and the energy of the sun in the process of photosynthesis to produce oxygen, which plays a vital role in the sewage treatment process. Most algae are harmless to humans, but large quantities of certain forms of algae may be harmful to humans and livestock or cause undesirable taste where purified effluent (after further treatment) is to be used for cooking or drinking. (The latter is not recommended, unless reliable tests indicate that the water is safe for drinking purposes.)

Green in color in temperate climates and green-gray in hotter areas, algae usually float below the surface of the pond. During periods of intense sunlight they may rise to the surface and increase their oxygen producing activity. Icing conditions retard algal activity, with a corresponding slowing down of the treatment process, thus necessitating longer liquid retention periods. Algae do not produce oxygen at night, i.e., in the absence of light and sunshine. Also, snow cover over ice will cause a blackout of algal activity and consequently a loss in the production of oxygen.

TREATMENT PROCESS

Lagoons provide a simple but extremely efficient method of treatment in that raw sewage from the collection system is discharged into a shallow "dish" where it is

treated by the same process of oxidation to be found in lakes and streams with the advantages of increased speed owing to controlled conditions and the reduction of pollution of natural waterways. The system involves the retention of sewage in the lagoon until the BOD is adequately satisfied (70% to 90%), after which the effluent is discharged into local streams, or, in a "balanced" system, retained as a medium to support the continuing process at an optimum level. The solids are converted to sludge which settles on the bottom of the pond. Accumulation of sludge is at a very slow rate, estimated by various sources at a fraction of an inch to a maximum of 3-1/2 inches per annum, allowing many years of efficient service from a properly designed lagoon without a drastic reduction in capacity.

However, sewage lagoon effluent (as is the case with the effluent from conventional sewage treatment plants) is not necessarily free of pathogenic organisms and may require additional treatment and/or chlorination. If not chlorinated, its use should be restricted to irrigation of non-edible crops. The degree of contamination should be checked periodically and its use determined accordingly.

It is difficult to arrive at a definition of what constitutes stabilized sewage. The degree of stabilization will, of course, depend upon the use to which the effluent is to be put and on the standards that are applied to achieve such stabilization. The French, in 1950, defined stabilized sewage as follows:

1. The treated water should not contain more than 30 milligrams of suspended matter of all kinds per liter;
2. Before and after 5 days of incubation at 30° centigrade it should not give off any foul or ammoniacal odor and have a negative putrescibility test;
3. It should not contain any substance toxic to fish or harmful to animals living in water into which it is discharged;
4. In 5 days it should not absorb more than 40 milligrams of dissolved oxygen per liter at 18° centigrade (BOD test).

Wherever possible, efforts should be made to engage the services of properly qualified personnel, i. e., public health officials or sanitary engineers, to test the resulting effluent as well as to advise on lagoon planning and design generally.

LAGOON DESIGN

Proper planning is vital in order to eliminate possible future problems and to keep construction operations and maintenance costs to a minimum.

In addition to domestic sewage many types of minor industrial wastes can be handled by normal lagoon systems. A check on the type of industries using the collection system will determine whether or not special treatment facilities must be provided. Once the nature of the sewage is determined, the quantity is the next factor to be arrived at. The quantity estimate is based on the following elements:

Basic liquid waste-water consumption: In communities with central water supply systems, liquid wastes can usually be assumed to be equal to total daily water consumption. In many developing countries this may be assumed to be 20 to 40 gallons

per person per day. However, individual and careful estimates are necessary. Exceptions requiring adjustment of the figure would include subtraction of any large volume of water used for such purposes as irrigation, and the addition of the total volume of water originating from other sources (such as private water supply systems installed by some industries) but discharged into the common collector system.

Where a community secures its water supply from individual or communal wells, cisterns, springs, and only part from a central municipal supply, careful studies should be made to allow a reasonably accurate estimate of consumption in terms of gallons per capita per day. This will then be multiplied by the number of persons served by the collector system, to which must be added any additional amounts of waste from other sources. Where a sewer system exists, its actual discharge will, of course, indicate the volume of consumption. However, in most instances only fractional systems may exist, entirely inadequate, and making no allowances for future requirements and expansion.

It may not always be possible to maintain an adequate liquid depth in the lagoon if water consumption is insufficient or fluctuates significantly. For this reason, in areas where severe water shortages occur, it is necessary for a water supply to be added adjacent to the lagoon or lagoons.

Infiltration: Infiltration of water into sewer systems results from poorly constructed and maintained sewer systems, cracked pipes, leaking manholes, pipes below the ground water table and illegal connections; in other words, any water not entering the system from designed or known points. Infiltration may be substantial and often requires an increase in design capacity of the lagoon to allow for the rainy season, although there may be no problem during dry weather.

In the temperate regions, daily average and peak flows should be increased by as much as 30% to allow for wet weather infiltration, while an increase of 50% may be necessary in tropical areas during the rainy season.

In order to insure a minimum design figure for flow in the dry season, no adjustment which would assume increase through infiltration, should be made for this period.

Other factors influencing the volume of water in the lagoon are percolation and evaporation. Though losses through percolation often gradually decline, this factor should be estimated through tests once an actual site is chosen. Evaporation is an extremely variable figure (according to climatic zones) but losses can be estimated for a given region once the surface area of the lagoon(s) is known. Having established daily rates, maximum and minimum seasonal flows at the outfall and losses from the lagoon(s) itself, it is then possible to determine whether or not the water level of a lagoon can be maintained within the designed maximum and minimum depth range.

EVA PORATION

As noted above, evaporation plays an important role in determining the level of water maintained in a lagoon, particularly in tropical areas. The amount of evaporation at a given moment is dependent on the temperature, humidity and wind velocity. As a result, it is difficult to predict with any accuracy the evaporation rate for any short period of time. Fortunately, such losses are only critical on a seasonal basis, for which reasonably accurate averages are known for most regions of the world.

However, in certain areas as much as 20% of the influent may be lost through evaporation.

Lacking any kind of data, evaporation rates may be roughly estimated using tables such as the one below:

Climate	Evaporation in Inches by Month												Total Annual Evaporation
	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Above Equator	Jan.	Feb.	March	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	
Below Equator	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	
Hot	4.0	5.0	6.5	8.0	10.0	12.0	13.0	13.0	11.0	8.5	6.5	5.0	113.0
Moderate	1.0	1.4	2.0	3.0	4.8	6.5	8.5	8.0	6.5	4.6	2.6	1.1	50.0
Cold	0.6 (lowest)	0.7	0.8	1.0	1.3	1.6	2.0 (highest)	1.9	1.8	1.6	1.1	0.7	15.0

Since the figures shown are recorded in relation to seasons in the northern hemisphere, changes must be made for use south of the equator (e.g. possibly the highest loss in December or January, and the lowest in July). A design bell curve could be developed from the above, assuming single rainy and dry seasons. Where two rainy and dry seasons must be reckoned with, a double bell curve would result and the above sequence of figures would be of little use. In any case, there is no substitute for local knowledge. Where no experts are available, local farmers are usually good consultants in outlining seasonal character, though seldom in terms of quantitative figures.

FIELD MEASUREMENT OF EVAPORATION

To obtain accurate local figures, field tests can be made over at least one complete annual cycle, and preferably several. Though these cannot meet immediate needs, they will both facilitate future lagoon design for the region in question and suggest modifications to allow more efficient operation of the original system.

Field measurement of evaporation is done (by the U.S. Weather Bureau) by the use of a metal pan 4 feet in diameter and 10 inches deep. This unit is filled to within 2 inches of its rim and is supported to place the water surface a foot or more above ground level. The drop in water level is measured periodically and the unit is refilled from time to time to the original level. The recorded results are multiplied by 70% to arrive at a theoretical reservoir evaporation rate.

Evaporation volume formula:

The volume of evaporation in gallons (E) for any given time (day, week or month) can be determined by the following formula:

$$E = 27,000 \times (A_S) \times (E_+)$$

Where E + = estimated evaporation in inches for the period of time in question;
 A_S = the lagoon area in acres.

SITE LOCATION

Though availability of land is a controlling factor, sites at lower elevations than the collection system are economically preferable in order to eliminate the need for costly lift stations. Objections on the part of the local inhabitant (usually psychological) can often be overcome by careful explanation, and, if possible, visits to existing lagoon systems. Zoning, or distance restrictions written for traditional waste disposal plants are also a factor, though from a practical point of view a minimum distance of 1/4 mile from a housing area has proven satisfactory. The direction of prevailing winds (during the day and at night time) is also an important factor in locating lagoons with respect to housing.

WIND

The lagoon layout should always be planned so that the direction of the prevailing wind is never along the line of flow thus short-circuiting sewage from inlet to outlet or retarding the normal flow. Obstructions which restrict air movement (including buildings) should be avoided. Wind induces wave action and sub-surface currents which are necessary to stimulate oxidation. However, winds in excess of 30 miles per hour may create wave action which in turn may cause erosion* along the edges of the lagoon. This can be prevented by installation of concrete blocks or slabs at the water-edge (see also "Gradients and Embankments").

In order to assure a clear sweep for winds, seasonal changes in direction and relative speeds should be known. As pointed out above, farmers, fishermen, or others who work outdoors year round are usually excellent sources of general climatic data if local figures are not available. As with evaporation, however, long-term observations should be made to broaden background data for future designs and improvements in primary systems.

Because local wind conditions are affected by a number of factors, including temperature, heights of vegetation, etc., a generalization concerning obstructions in the immediate vicinity of the lagoon is difficult to make. In the average case, however, one might allow a clear distance of 5 to 8 times the height of any groups of trees or bushes from the lagoon. In the case of isolated buildings, a clear sweep equal to the height or width of the structure, whichever is greater, is generally sufficient. In any case, a minimum clear sweep of 300 feet free of all but isolated obstructions should provide adequate wave action.

AERATION

The low cost of lagoon treatment, free of any mechanical aids, is a factor which makes the system a very appealing one -- particularly in developing nations and communities. However, where necessary and economically feasible, various means of artificial aeration can be used to induce circulation and wave action, and thus oxygen absorption. This means can be used to revive systems which for some reason have become anaerobic, or to add capacity to existing facilities where the problem is

* U.S. experience indicates that erosion is not serious until lagoons reach an area of 30 acres or larger.

immediate, or where lack of funds or land delay the construction of additional lagoons. Aeration can also be used to slow or prevent icing-over of lagoons located in colder climates.

Under this method, a blow supplies air to a system of perforated pipes placed on the lagoon bed. The rising air bubbles induce slight circulation and increase absorption of oxygen. Slight foaming may be noted over the pipelines. An American engineering company has installed a system utilizing a 10 h.p. blower which delivers air at the rate of 150 cubic feet per minute. Using 7500 feet of plastic tubing laid parallel and spaced from 10 to 30 feet apart, the system has a potential capacity of 600 homes, or approximately 3000 persons. A similar system is being used with some success in reviving polluted lakes in Sweden. Other systems include agitation of the lagoon surface by water spray.

Where ponds are designed to cause flow of sewage from higher to lower levels, intervening baffles tend to agitate the water, and thus increase aeration. It should be noted, however, that sludge tends to build up on the high side of the baffles. Other attempts to increase aeration include changing levels through the use of a series of steps at the inflow point, or the use of a series of small ponds each lower than the last. These methods have been used when the flow is low due to dry weather, but the value of results cannot be predicted with any degree of accuracy.

The practicality of artificially aerated lagoons, however, should not be over-estimated. An extended aeration process is no substitute for the natural treatment process using algae to provide oxygen. Therefore, wherever possible, lagoons should be designed to function without artificial aeration.

PERCOLATION

The problem of liquid loss by seepage into the soil is twofold. First, there is the danger of polluting nearby water sources if the lagoon bottom is below or too near the water table at any season. Secondly, under severe conditions, the loss of liquid may be great enough to drop the volume of the water retained to a point below that necessary for efficient aerobic operation. Some loss of liquid is to be expected through percolation in any soil, though the volume of such liquid loss depends upon the type of Soil encountered. In Africa, for instance, black cotton, laterite (murrum), and clay soils are best since their percolation factor is small. The following table indicates a rough means of classification of soils by visual and tactile identification. However, the values shown should not be used for design purposes. Instead, percolation tests, as described in the following section should be made:

RELATIVE ABSORPTION TEST TABLE

<u>Time (in minutes) required for water level to drop one inch</u>	<u>Relative absorption rate</u>	<u>Classification of the type of soil</u>
0 - 3	Rapid	Course sand or gravel
3 - 5	Medium	Fine sand or sandy loam
5 - 30	Slow	Clay, loam or clay with sand
30 - 60	Semi-impervious	Dense clay
60 and over	Impervious	Hard pan or rock

Note: The first two types of soil are not suited for lagoon purposes unless water retention is assisted by the installation of a waterproofing skin at the lagoon bottom.

PERCOLATION TEST

Before finally choosing a site, percolation tests should be made to allow an accurate estimate of initial liquid loss, and the relative danger of pollution of any nearby water supply. Tests should be made at the depth of the projected lagoon bed. To this end, it will be necessary to dig a pit large enough to allow convenient working area at the desired level, except where the natural grade is intended as the lagoon bottom. A square hole one foot to a side, is dug to approximately 1'-6" depth, below the proposed level of the lagoon bottom. The test hole is then filled with water to a known depth (usually 6 to 12 inches). After the water has disappeared, the hole is again filled to the same depth, and the time for its absorption noted. This time (in minutes) is divided by the depth in inches to give the time required for the water level to drop one inch. This process is then repeated at several points over the test site particularly where changes in soil character are evident. The resulting factors are then averaged to arrive at a single design factor.

It should be noted that sludge deposits slowly seal the lagoon bottom, reducing losses to a negligible point in relatively impervious soils, and drastically reducing percolation in even the worst cases. For example, experience indicates that an initial loss as high as 6 inches per day may gradually decline to as little as 1/4" to 3/4" per day.

LAGOON DESIGN FORMULAS

No exact science of lagoon design has been developed so far. Early designs required a total pond area of one acre for every 100 to 200 persons while later developments and experience led to much higher loadings. In Africa, lagoons are operating satisfactorily today with total pond areas of one acre for every 600 to 1,000 persons. However, such "rules of thumb" can be misleading or even dangerous. So many variables enter the picture that each case should be investigated individually.

In designing a lagoon, it is necessary to establish the capacity which is the area of the lagoon times the depth. To arrive at these figures, it is essential to obtain the following basic information:

1. The maximum volume of liquid entering the lagoon which is the sum of the basic liquid waste-water consumption of the community which the lagoon serves, plus liquid entering the system through infiltration, rainfall, etc.
2. Minimum volume of liquid to be retained in the lagoon, which is the basic liquid waste water consumption minus the loss of liquid from the lagoon from seepage and evaporation.
3. The strength of the sewage in terms of BOD per person per day and the loading of the pond in pounds of BOD per acre per day.
4. The retention period necessary for the sewage to reach a BOD reduction of 70% to 90%.

Where sanitary engineers or competent public health officials are available, it is of course advisable to seek their aid in determining BOD rates, loading per acre, etc. Where such information is not available, the following formulas may be used in planning the necessary lagoons.

1. Surface Area

As (acres required) =

Population served x pounds of 5-day BOD per person per day (0.12 to 0.20)^{1/}
Design BOD loading pounds per acre per day (20 or more)

Note: In the State of Missouri (USA), BOD loadings of up to 68 pounds of 5-day day (20°C) BOD per acre have been successfully employed. In some areas and under certain conditions up to -- or over -- 100 pounds may be feasible. In Nairobi, Kenya, BOD loadings of 54 pounds were found to work out satisfactorily, and 200 to 250 pounds were used in two-pond systems.

^{1/} This formula was suggested by the Public Health Service, United States Department of Health, Education and Welfare.

In Pretoria, for instance, 145 pounds BOD per acre per day were adopted in the primary pond of a multiple-pond system, amounting to an equivalent of 1,200 persons per acre or 50,000 gallons per acre per day. Local climatic conditions greatly influence design and operation and should not be underestimated.

2. Depth

For reasons of economy and efficient operation, the depth of the liquids in lagoons should normally range somewhere between 2 and 6 feet; with minimum depth of 2 to 2-1/2 feet, vegetation is not likely to grow at the bottom of the pond. Shallower ponds (2 to 5 feet) are best in cool climates in order to allow for maximum penetration of sunlight. Because of the higher angle of the sun in tropical climates, deeper sunlight penetration permits deeper ponds (3 to 6 feet). Experience in various parts of Africa indicates that a depth of 4 feet is usually satisfactory.

3. Capacity

With the minimum and maximum desired depths established, and using the surface area figures calculated above, the volume of the lagoon is readily found with the formulas below:

$$\begin{array}{l} \text{Minimum lagoon capacity} \\ \text{in cubic feet} \end{array} = \begin{array}{l} (\text{surface area in acres}) \times (\text{minimum depth in feet}) \times \\ 43,560 \end{array}$$

$$\begin{array}{l} \text{Maximum lagoon capacity} \\ \text{in cubic feet} \end{array} = \begin{array}{l} (\text{surface area in acres}) \times (\text{maximum depth in feet}) \times \\ 43,560 \end{array}$$

Because the efficient operation of lagoons depends on maintaining optimum maximum and minimum liquid depths, these must be taken into account in the design of a lagoon. This will require a careful study of local annual temperature and rainfall data. For example, provision must be made to accommodate the maximum infiltration which generally occurs in the rainy season and to maintain an adequate minimum liquid level in the lagoon during the dry season when usually minimum infiltration and maximum evaporation occur during the same period.

RETENTION PERIOD

A minimum retention period must be determined in order to induce the reduction of BOD to a point allowing discharge of effluent into a normal waterway or irrigation system. In the United States, lagoons of the flow-through type, receiving raw sewage, normally employ 60 to 90 days retention. In tropical countries this is likely to be reduced but should not be less than 20 to 25 days.

A practical retention time is based on the rate of flow balanced against an efficient minimum and economically maximum pond size. If the volume of influent is roughly equal to the volume of liquid remaining after percolation and evaporation losses to keep the lagoon level within acceptable minimum and maximum limits, no effluent will result and the system can be termed balanced. As a balanced lagoon system is sometimes desirable, the lagoon size can be planned within reasonably flexible limits to achieve this end. Operating a lagoon as a closed or balanced system during the dry season, and

allowing for effluent at a rate within the desired retention time during the season of rains is one of the several means of operating lagoons in a tropical climate.

Hydraulic retention time can be determined by the following formula:

$$T \text{ maximum} = \frac{7.48 (C \text{ maximum})}{G_m} \quad T \text{ minimum} = \frac{7.48 (C \text{ minimum})}{G_m}$$

Where

- T. max. = maximum retention time (days)
- T. min. = minimum retention time (days)
- C. max. = maximum capacity (cubic feet)
- C. min. = minimum capacity (cubic feet)
- G_m = gallons per day influent
- 7.48 = gallons per cubic foot

The optimum retention time will depend upon organic loading, as well as hydraulic loading. The lower the loading in ponds of 5 day BOD per per acre per day, the greater the volume of liquid. This permits a longer retention period and a correspondingly greater reduction of BOD.

ALTERNATE DESIGN FORMULAS

In addition to the above, the following series of formulas has been developed by the African Housing Board, Lusaka (Zambia) and the Council for Scientific and Industrial Research (CSIR) in Pretoria, South Africa. As well as arriving at a set of design figures, the following set of formulas can be used to predict the effectiveness of a multiple pond system. (Note that gallons used in these formulas are Imperial gallons, one Imperial gallon = 1.2 U.S. gallons = 4.536 litres.)

For design purposes, a given level of BOD contribution per person should be based on actual measurement. Where this is impossible, a figure must be assumed. This figure is variously noted as 0.12 pounds per day to 0.20 pounds per day, depending on such factors as local water consumption and dietary habits of the people.

Sewage strength in terms of BOD can then be arrived at by the formula:

$$\text{Sewage BOD (in mg. per liter BOD)} = \frac{\text{Per person per day BOD in pounds} \times 10^5}{\text{Flow in gallons per person per day}}$$

For instance, for a population of 5,000 persons and an assumed daily flow of 40 gallons per person, the

$$\text{BOD of sewage} = \frac{(.12)}{(40)} \times 100,000 = 300 \text{ mg/litre}$$

Design figures for primary ponds are then calculated by going through the following steps:

Step 1

Derived from an empirical relationship, the maximum pond BOD for aerobic conditions can be found as follows:

$$P \text{ maximum} = \frac{750}{0.6d+8}$$

Where $P \text{ maximum}$ = maximum pond BOD in mg/litre
 d = pond depth in feet

For a 4-foot deep pond, for example, $P \text{ maximum} = \frac{750}{(0.6 \times 4)+8} = 72 \text{ mg/litre}$

If an additional safety factor is required, use: $\frac{600}{0.6d+8}$

(The latter formula has been suggested in the most recent literature from Lusaka and Pretoria, Africa)

Step 2

Retention time in days may be calculated (using $P \text{ maximum}$ found above) through the use of the formula:

$$R = \frac{1}{K} \times \left(\frac{PO}{P \text{ maximum}} - 1 \right) \text{ days}$$

Where R = retention time in days
 PO = known influent strength
 K = velocity constant (assume 0.17)

Note: The value of K is based on few data and may be modified as more data become available;

e.g. with K at 0.17, PO at 300 mg/litre and $P \text{ maximum}$ at 72 mg/litre

$$R = \frac{1}{0.17} \times \left(\frac{300}{72} - 1 \right) = 19 \text{ days}$$

Step 3

Pond volume (in cubic feet) is found as the product of retention time and daily flow;

e.g. Volume = 19 days x 200,000 gallons per day
= 3,800,000 gallons x .13367 = 508,000 cubic feet

Step 4

The required pond area (in acres) is a division of volume by depth;

$$\text{Area} = \frac{\text{Volume}}{\text{Depth}} \text{ (assume vertical sides)}$$

$$\text{e.g. Area} = \frac{508,000}{4} = 127,000 \div 43,560 \text{ square feet} = 3 \text{ acres}$$

Step 5

For comparative purposes and for multiple pond systems, it may be necessary to determine the pond loading per day. To do this, use the influent strength (PO) depth (d), and retention time (R) found above, in the following formula:

$$\text{Loading} = \frac{2.71 \times \text{PO} \times d}{R} \text{ lbs. BOD per acre per day}$$

$$\text{e.g. } \frac{2.71 \times 300 \times 4}{19} = 171 \text{ lbs. BOD per acre per day}$$

Step 6

Assume 3 secondary ponds with 10, 5 and 5-day retention periods. The relative bacteriological quality of the effluent can be checked for one or a series of ponds using the formula below

(The area of each pond is calculated following steps 3 and 4.)

$$N = \frac{N_o}{KR + 1}$$

Where N_o = M.P.N.(most probable number) of fecal bacteria in the influent
 N = M.P.N. of fecal bacteria in effluent
 K = velocity constant (assume 2.0); (This is based on few data and may be modified as more data become available)

R = retention period in days

$$\text{From primary pond } N = \frac{N_o}{2 \times 19 + 1} = \frac{N_o}{39}$$

$$\text{Secondary pond (1)} \quad \frac{N_o}{39} \times \frac{1}{(2 \times 10) + 1} = \frac{N_o}{39} \times \frac{1}{21} = \frac{N_o}{820}$$

$$\text{Secondary pond (2)} \quad \frac{N_o}{39} \times \frac{1}{21} \times \frac{1}{11} = \frac{N_o}{9000}$$

$$\text{Secondary pond (3)} \quad \text{i.e., final effluent} = \frac{N_o}{39} \times \frac{1}{21} \times \frac{1}{11} \times \frac{1}{11} = \frac{N_o}{100,000}$$

Note: Amounts are rounded.

In the second set of formulas, loading in pounds of BOD per acre per day is not the controlling factor in the design of the (primary) pond but rather sewage strength and the maximum BOD required for aerobic conditions. Besides, a multiple pond system is assured in which the first pond is mainly designed for BOD reduction under odor-free conditions, while the second (or any additional) pond functions mainly to improve bacteriological quality of the effluent from the first pond. Designers may do well to work with both sets of formulas and check the results.

A convenient chart showing the relationship between minimum surface area per person and depth of primary pond is shown below. The chart was developed by G. Van Rooyen Marais for the African Housing Board, Northern Rhodesia (now Zambia).

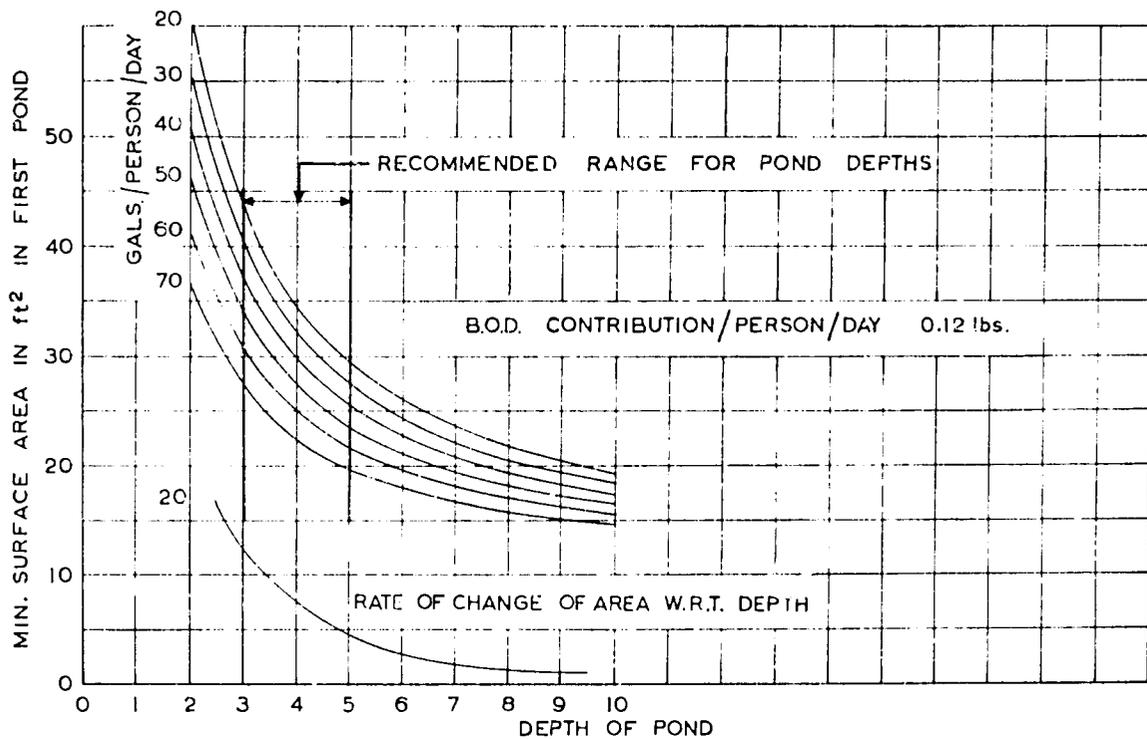


Chart showing relationship between minimum surface area per person and depth of primary pond.

GROUND WATER POLLUTION

Where the water table is well below the floor of the lagoon, the danger of bacterial pollution is slight (although the danger of chemical pollution still remains). Where the lagoon bottom is in or near the aquifer (water bearing strata) pollution can travel hundreds or, in the case of such elements as detergents, even thousands of feet. If a higher site is not available, areas near, or seasonally in, a water bearing strata can be rendered useful by applying an impervious skin of some sort to prevent passage of liquid from the pond into the surrounding soil.

The simplest and least costly method of increasing the impermeability of soils is by compaction. Where available, heavy equipment used in constructing the dykes is

useful in compacting the soil. The "sheep's foot" roller may find a useful and literal substitute through the repeated driving across the site of herds of sheep, goats or cattle.

Resistance to percolation loss can also be economically increased by adding to the top layer of soil some locally available earth with water resistant qualities such as clay. The soils should be thoroughly mixed to a depth of a foot or more by spading with possibly a thin, well compacted layer of the heavier soil forming the top skin.

SKINS AND LININGS OTHER THAN EARTH

Unfortunately, the economic factor will rule out the use of processed materials in the lining of lagoons for many developing areas. However, where such materials are readily available, skins can be formed which make even the worst soil types useful for lagoon sites.

1. *Bentonite.* This is a clay, expands when wet and fills the voids in coarse soils. It may be used as a skin 1 or 2 inches deep, or mixed with other soils in a 5 to 10 percent mix, depending on the characteristics of the local soil. In very loose soils, the value of bentonite may be reduced by diffusion. If it is locally available, it may be an economical solution. However, the price (in the U.S.) of commercial bentonite is approximately \$15 to \$20 per ton.
2. *Soil Cement.* Of the processed skins, soil cement is one of the least expensive and in many respects the best means of long term prevention of percolation. Cement is mixed in place with a layer of soil 6 to 12 inches thick. Thorough, methodical spading and tamping, using a fairly dry mix to prevent leaching, gives a satisfactory result. The proportion of cement to earth should be determined on the site, depending on the nature of the soil. However, it will probably range between 4 and 8 percent. For extremely poor conditions, such as gravel, it will be necessary to import soil from another area. Among the advantages of soil cement are its resistance to erosion, and the fact that it is one of the few soil mixtures allowing work (such as sludge removal) without damage to the skin.
3. *Asphalts.* Spray type asphalts are used extensively in the U.S. at a relatively low cost of 7 to 27 cents per square yard.
 - (a) Asphalt cutbacks are effective when applied to sands, silts, and other fine gravel soils. Mechanical or hand sprays can be used, the latter requiring slightly more material and at least 1 week of curing. Penetration is less than one inch.
 - (b) Thin-film emulsions are best when applied to fine grained soils. Penetration is good and gives temporary protection while sludge is forming its own barriers.
 - (c) Cut asphalt types are more durable, but must be applied mechanically at a high temperature by skilled personnel. Costs in the U.S. range from 25 cents to a dollar per square yard.

- (d) Asphalt concretes would only be used in extreme conditions due to high cost (in the U.S. 50 cents to 1 dollar and fifty cents a square yard). A 2 inch layer is laid hot, using a 6% to 8% low penetration asphalt mix.
- (e) Asphalt saturated and felt covered mastic core mats are produced for reservoir and pond lining, but again are high (in the U.S. 60 cents to one dollar and fifty cents per square yard). These can be exposed or earth covered.

4. *Synthetics.* A variety of plastic materials are now produced which can be used to line sewage lagoons.

- (a) Polyethylene, though easily pierced and subject to slow deterioration when exposed to sunlight, can serve as a useful lining at a cost of 7 cents to 30 cents a square yard (in the United States). A carefully applied earth cover is necessary for protection.
- (b) Polyvinylchloride (PVC) and PVC-acetate have greater resistance to puncture, but cost 50 cents to 1 dollar a square yard. Earth cover should be used.
- (c) Composites, including PVC-asphalt lined sheets have been developed expressly for sewage lagoon lining to meet objections to other plastics. The cost in the United States is approximately 80 cents per square yard.
- (d) Fiber-glass mats are available and have been successfully used to prevent erosion of lagoon banks.

SERIES OR PARALLEL LAGOONS

Lagoon design is essentially the planning of a shallow, near leakproof pan, placed at the lower end of a waste collection system, and sufficient in volume to retain the effluent therefrom until its character is changed sufficiently to allow its discharge without fear of polluting water supply. Depending upon the nature and volume of the sewage to be treated, a single pond is often adequate for a small installation. Where more than one pond is required, series or parallel systems are used. By definition, series lagoons receive in sequence sewage in advancing stages of treatment, passed from one pond to another, until discharged from the last pond at an acceptable level of purification. In parallel ponds, the effluent is channeled into all ponds simultaneously, receiving the same degree of treatment in each until ready for discharge. The optimum system is that utilizing multiple ponds which can be operated either in series or parallel.

Even though the BOD reduction for a given length of time is not much greater in series ponds than that in parallel or single ponds, the reduction of fecal bacteria is significantly greater. For this reason, the series system is used where a high over-all quality of effluent is desired. An advantage of parallel ponds, on the other hand, is that any cell can be taken out of operation for repair or sludge removal without affecting the operation of the system.

Either series or parallel systems can be designed to handle unusually heavy influent (due to rains, etc.), or to permanently receive a significant increase in total BOD loading for indefinite periods without changing the retention time. For other than flat terrain, a series of smaller units, allowing a minimum of cut and fill is the most economical answer for an installation of fair size. As a result, the best answer is a multi-lagoon system which can operate in both series and in parallel fashion, retaining the advantages of each and allowing maximum flexibility.

African experience indicates that for small installations, a two pond system may work best: a primary pond for treatment of the raw sewage and elimination of odors, and a secondary pond for additional treatment to improve the bacteriological quality of the effluent. The first pond should be designed to handle at least 2/3 to 3/4 of the entire load placed upon the installation. Retention time in the secondary pond depends upon the degree of improvement desired, although experiments (CSIR) have shown that a minimum of 20 days is sufficient for satisfactory results. Further improvement may be achieved by dividing the secondary pond into three cells in series, allocating a 10-day retention period to the first cell and 5-day periods each to the second and third (see example cited under "Alternate Design Formulas"). A two pond system, or multiple pond system, also permits correction of certain failures by recirculation from the secondary (or any additional) pond to the primary pond.

LAGOON SHAPE

Though almost any lagoon shape is possible, the proportions must be such as to allow free play for wind from any direction and be oriented to provide maximum sunlight. Rectangular units with rounded corners and a maximum length to width ratio of 3 to 1 allow both efficiency and greatest simplicity in constructing adjoining units. They are preferred over round or oval shaped units. Extremely irregular shapes are to be avoided as embayed areas may become anaerobic due to insufficient circulation.

GRADIENTS AND EMBANKMENTS

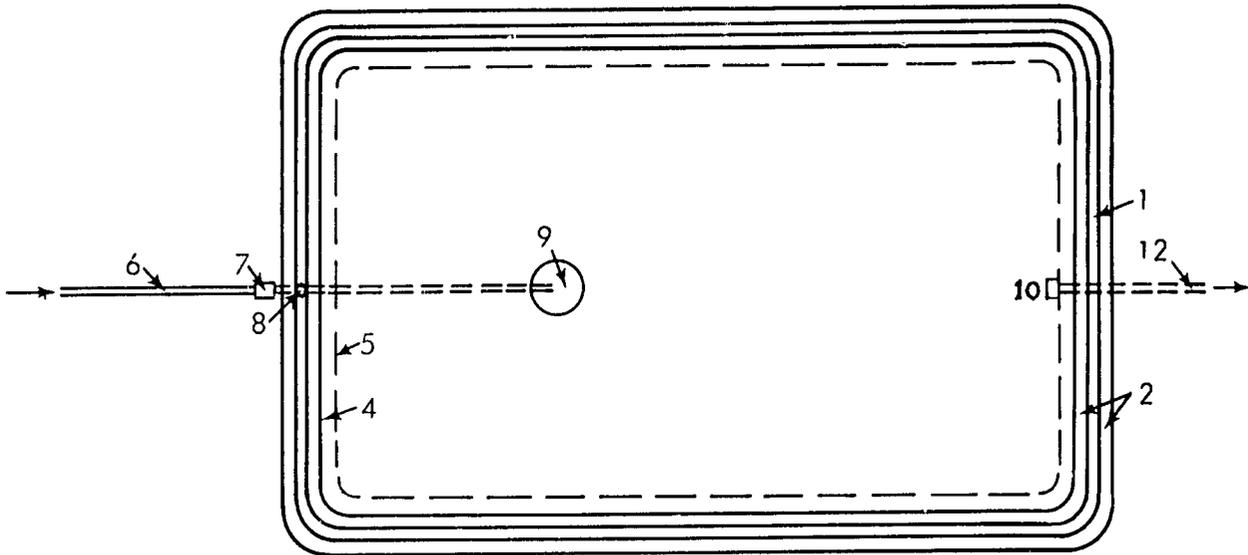
Level beds give the best results. In the area of inlet and outlet minimum slopes (e.g. 1/2 of 1 percent) are advisable unless the area is highly stabilized to prevent erosion.

Dikes serve to contain the liquid, provide reserve capacity, and allow access for inspection and maintenance. The height of the embankments is determined by normal water depth and reserve capacity (approximately 2 feet) plus a foot to allow for additional protection and sludge build up. Thus, with 3 feet of freeboard, the total to the top of the dike would be in the range of 5 to 9 feet above the lagoon floor. In Kenya, a 4 foot liquid depth with a 3 foot freeboard was used successfully.

A slope ratio for the bank of 1:3 to 1:5, vertical to horizontal, gives a range which allows stability and encourages wave action but does not unduly reduce the lagoon capacity. Where icing conditions occur, this slope aids in breaking up such formation when the level of liquid is raised or lowered. The top of the dike should be approximately 8 feet wide to facilitate the use of maintenance equipment.

Economy in construction is greatest when soil cut from the lagoon area is used for the dike. Care should be taken not to use cleared vegetation and debris on the water-side of the dike, but only on its outer third to prevent seepage. Percolation losses can

FIGURE 1
 PLAN OF SEWAGE LAGOON
 (DIAGRAMMATIC)



LEGEND

1. Top of dike 8' wide
2. Embankment
3. Stone slabs or rock border to prevent erosion
4. Water level
5. Bottom edge of dike
6. Inlet pipe
7. Bar screen
8. Manhole
9. Depression in lagoon bed
10. Concrete weir
11. Flashboards to adjust water level
12. Outlet pipe
13. Catwalk

DETAIL OF OUTLET

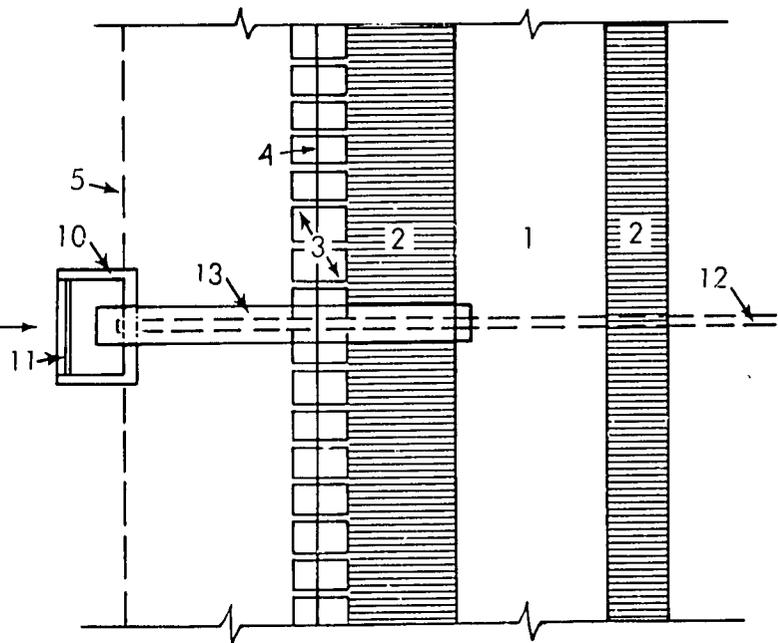
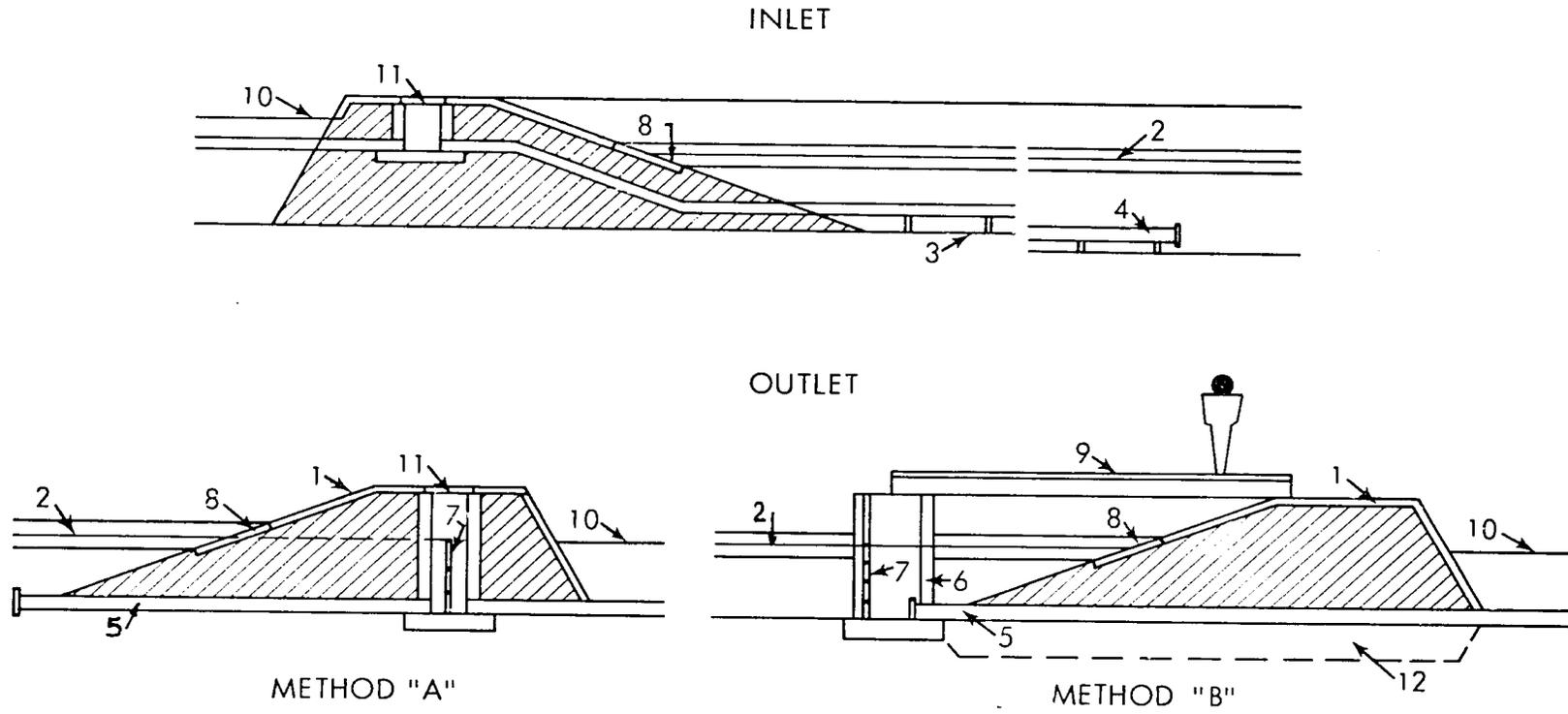


FIGURE 2
SECTION THROUGH SEWAGE LAGOON
(DIAGRAMMATIC)



LEGEND

- | | | |
|--|--|--------------------------------|
| 1. Sod-covered dike | 4. Inlet pipe over depression
(Approx. 30 feet in diameter) | 9. Catwalk |
| 2. Water level
Approx 4 feet with 3 foot
freeboard | 5. Outlet pipe | 10. Finish grade (varies) |
| 3. Lagoon bottom
(Compacted natural grade) | 6. Concrete weir | 11. Manhole |
| | 7. Flashboards to adjust water level | 12. Subgrade key (if required) |
| | 8. Stone slabs or rock to prevent erosion | |

FOUR POND SYSTEM
(DIAGRAM)

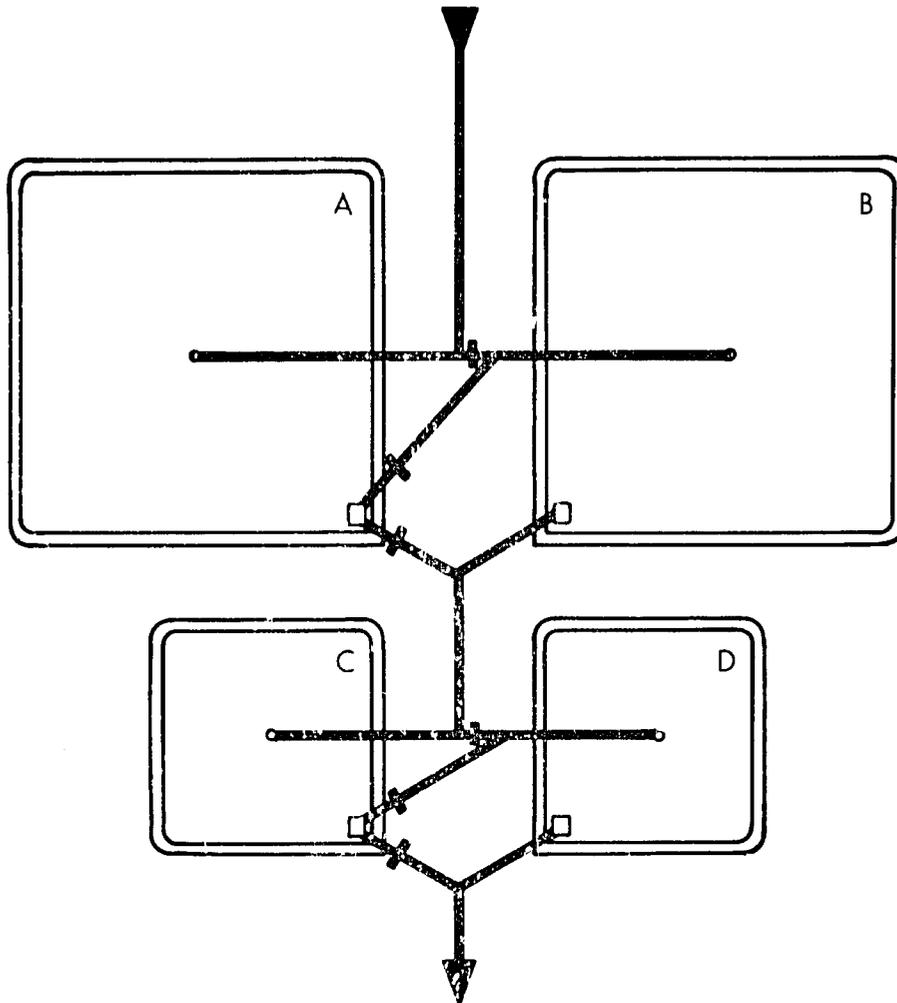


FIGURE 3

Sewage lagoon system consisting of four ponds which can be used either in series or parallel or a combination of both. Influent can be directed to flow into Pond A alone or into Ponds A and B simultaneously. Effluent from Pond A can be directed into Pond B if used in series and effluent from Pond B (or A and B together) into Ponds C and D together or successively. If treated parallel, final effluent will be discharged from Ponds C and D. If treated in series, final effluent will be discharged from Pond D. In addition to normal valves and manholes control valves as shown are necessary for desired flow direction.

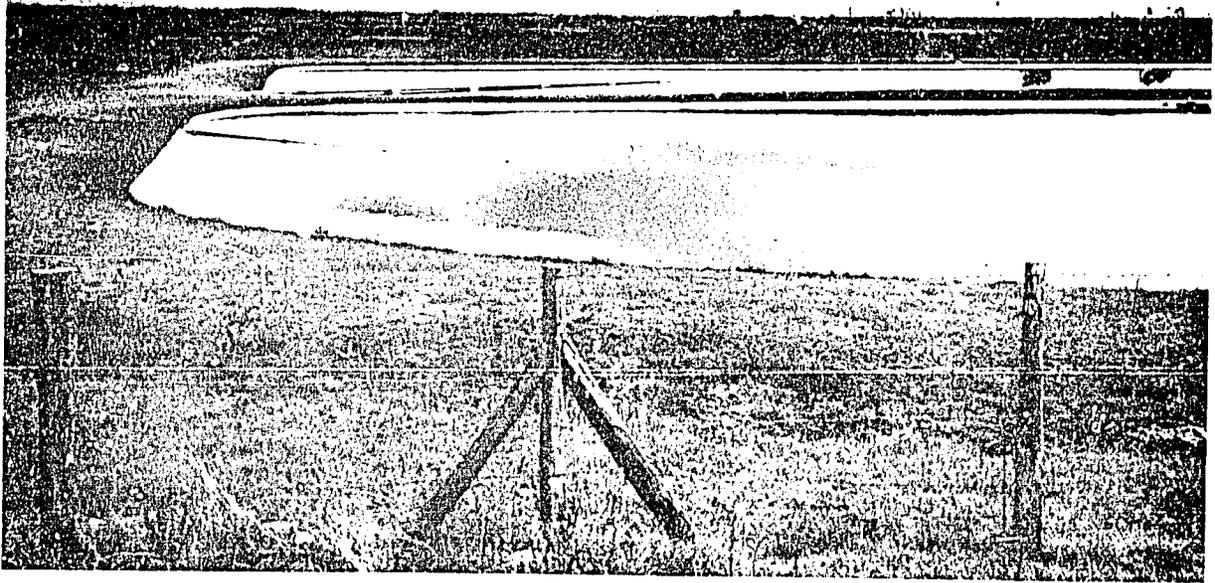


Plate 1. Nairobi Airport Sewage Lagoon (A. H. Taylor, 1960)
View showing two-pond system with inlet pipes.

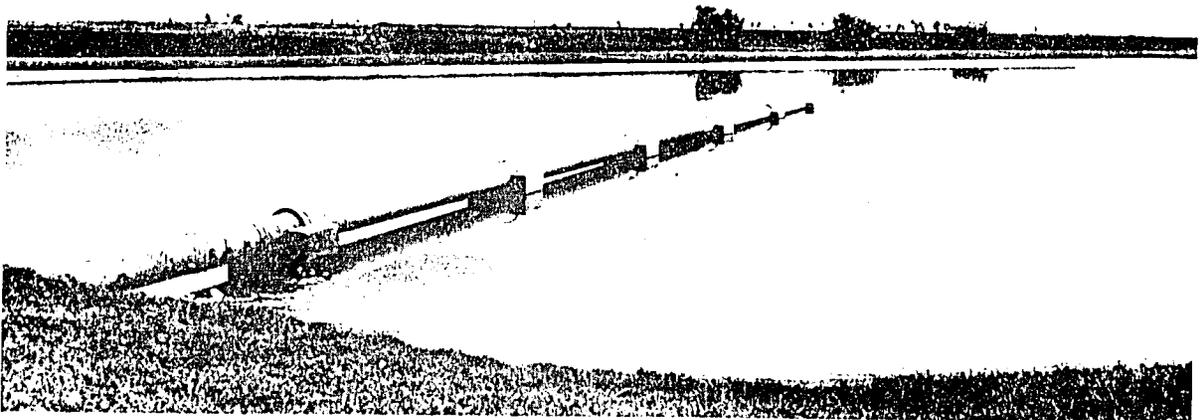
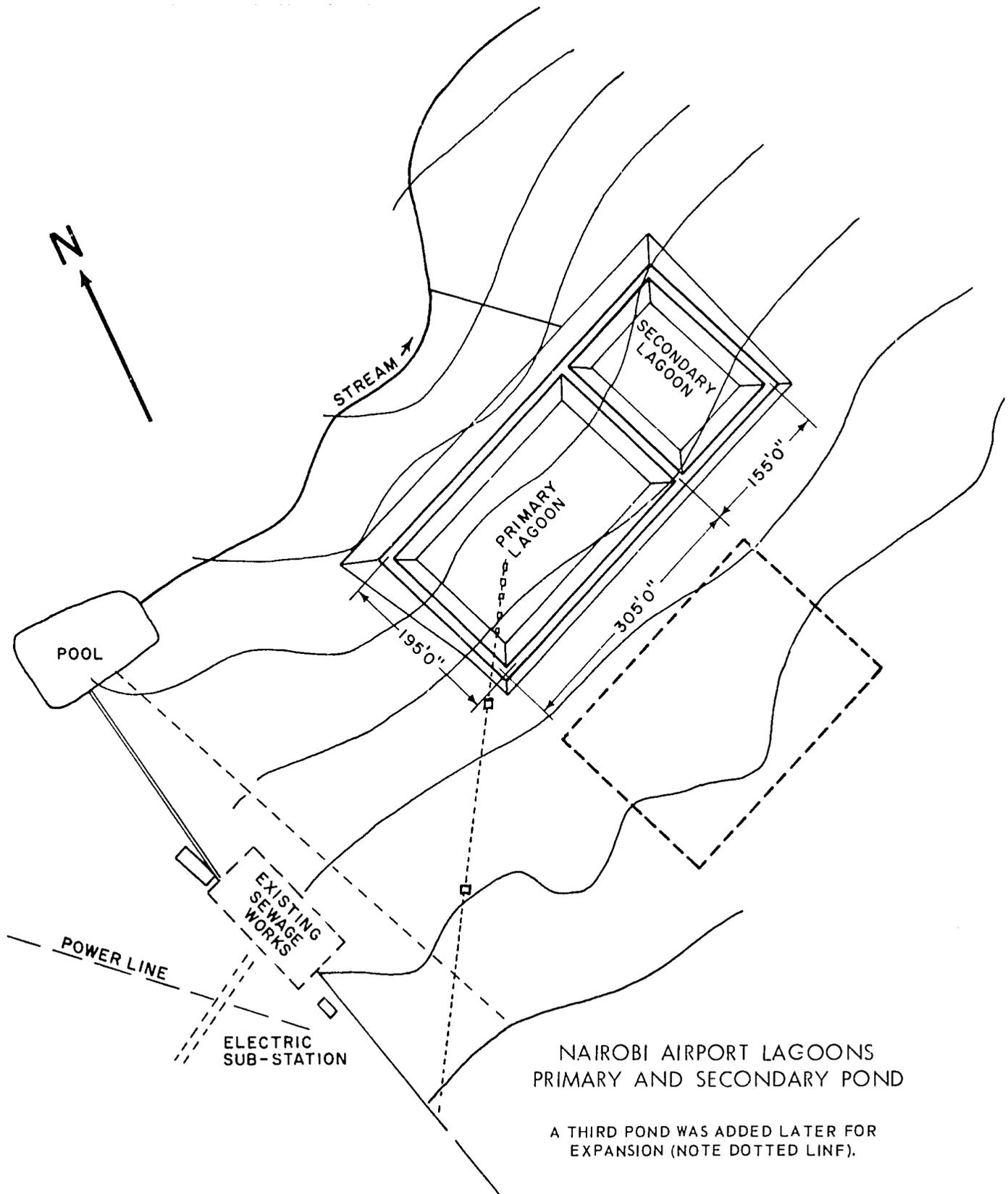


Plate 2. Nairobi Airport Sewage Lagoon.
Detail of inlet pipe



NAIROBI AIRPORT LAGOONS
PRIMARY AND SECONDARY POND

A THIRD POND WAS ADDED LATER FOR
EXPANSION (NOTE DOTTED LINE).

Plate 3.

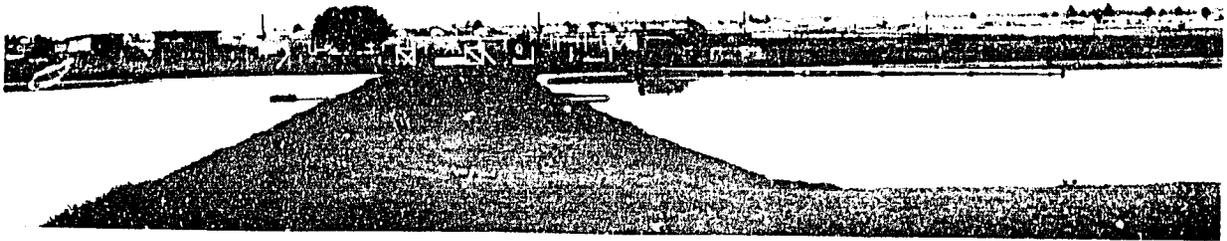


Plate 4. Nairobi Airport Sewage Lagoon. Dike between the two ponds and overflow.

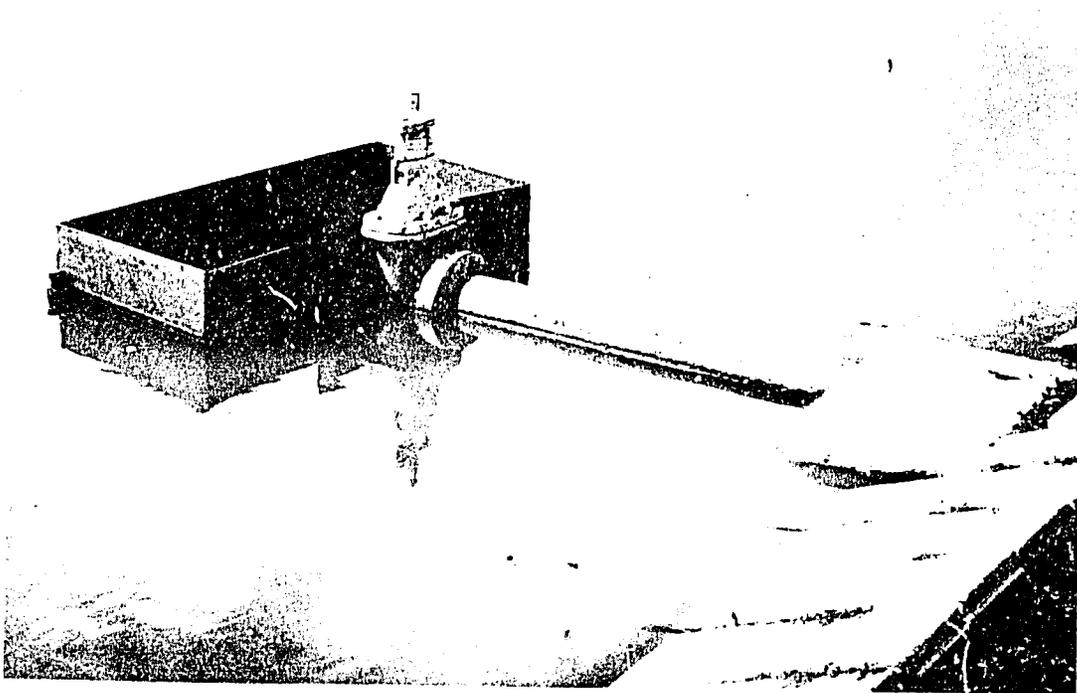


Plate 5. Nairobi Airport Sewage Lagoon. Detail of overflow. (Note precast concrete slabs at pond edge to prevent erosion).

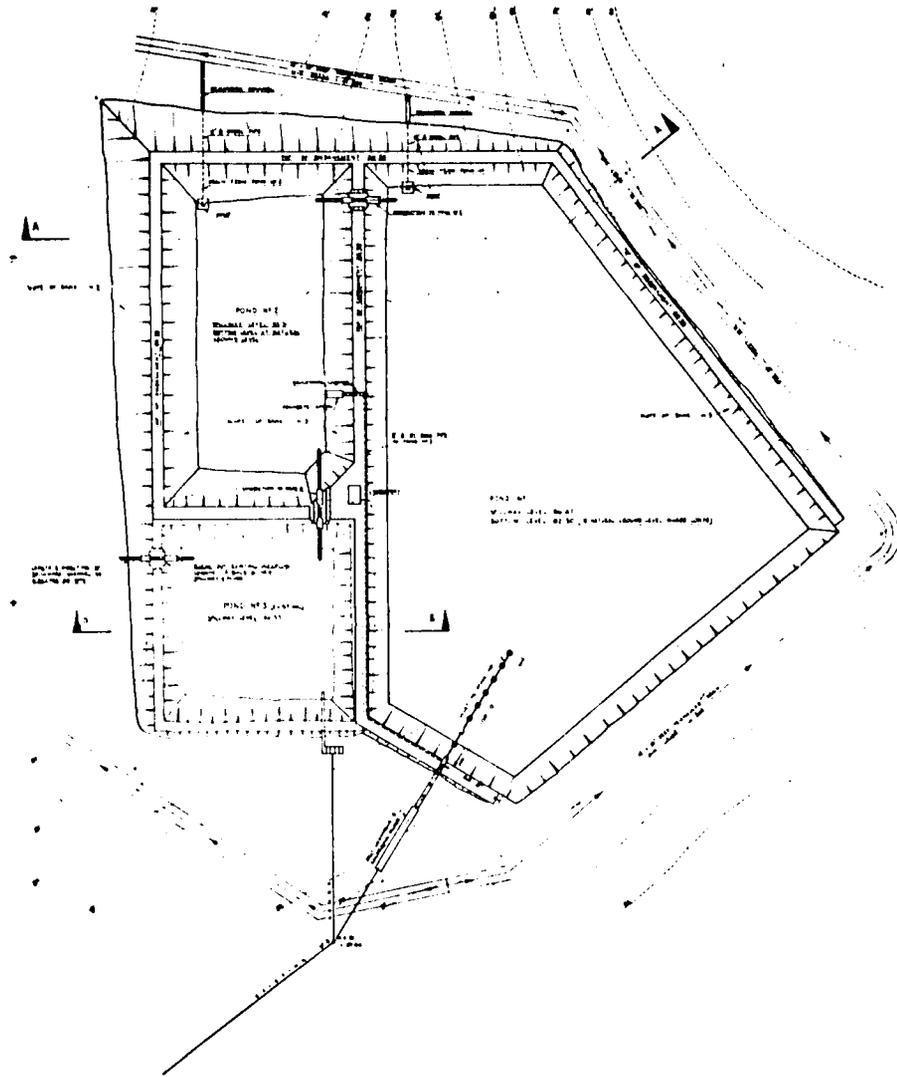


Plate 6. Matero North Stabilisation Ponds
African Housing Board, Lusaka.

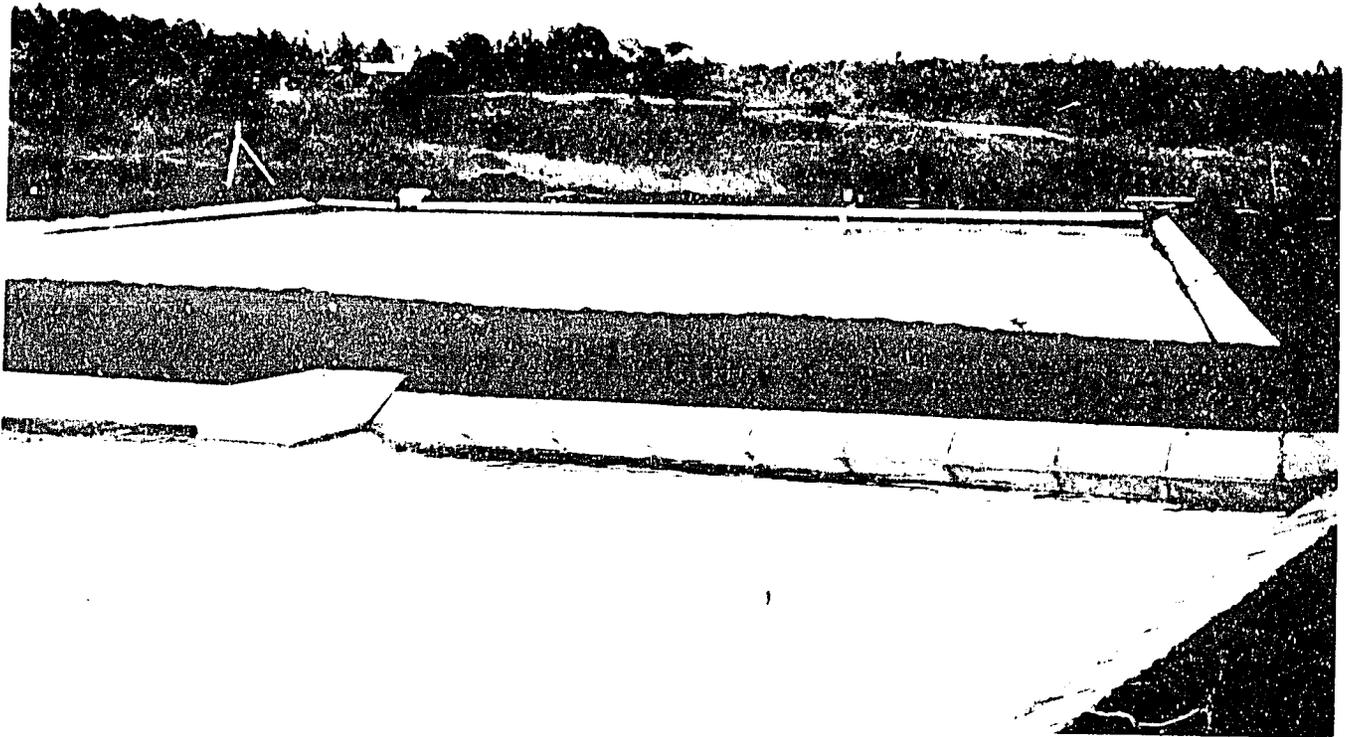


Plate 7. Langata Lagoons Nairobi, Kenya. View of primary and secondary ponds. Note overflow and precast slabs at waters' edge.

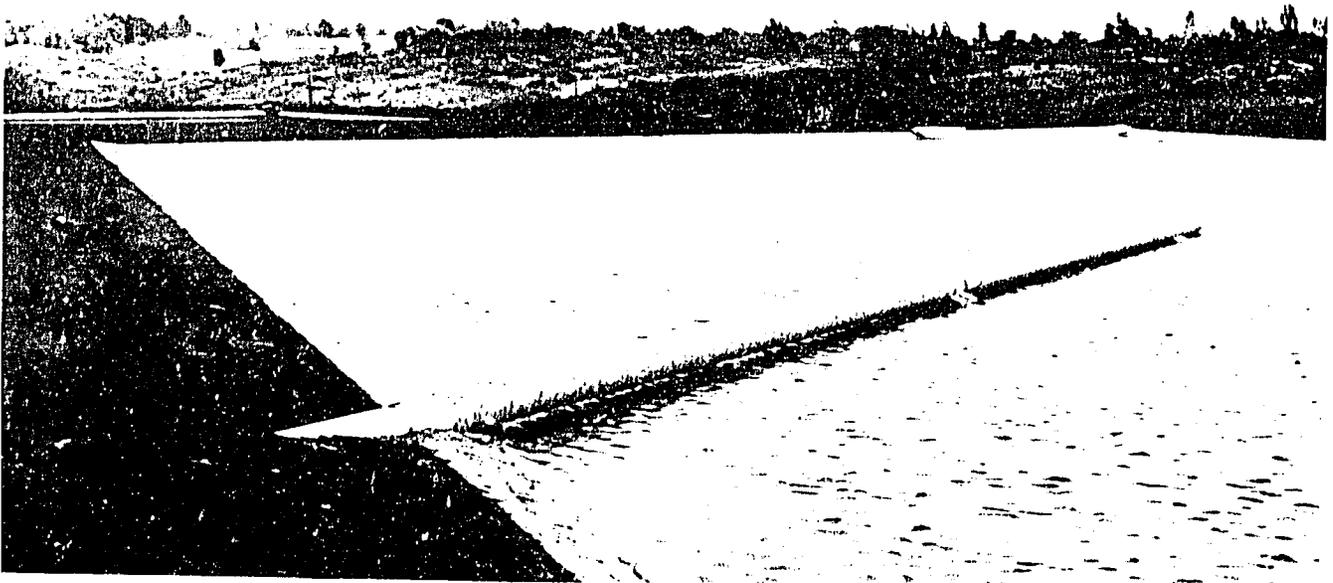


Plate 8. Langata Lagoons Nairobi, Kenya. View of inlet into primary pond. Note barbed wire around pipe to prevent use by children and animals.

DANGER HATARI

THESE LAGOONS ARE FILLED
WITH RAW SEWAGE.

JIHADHARI NA MASHIMO
YA MAVI

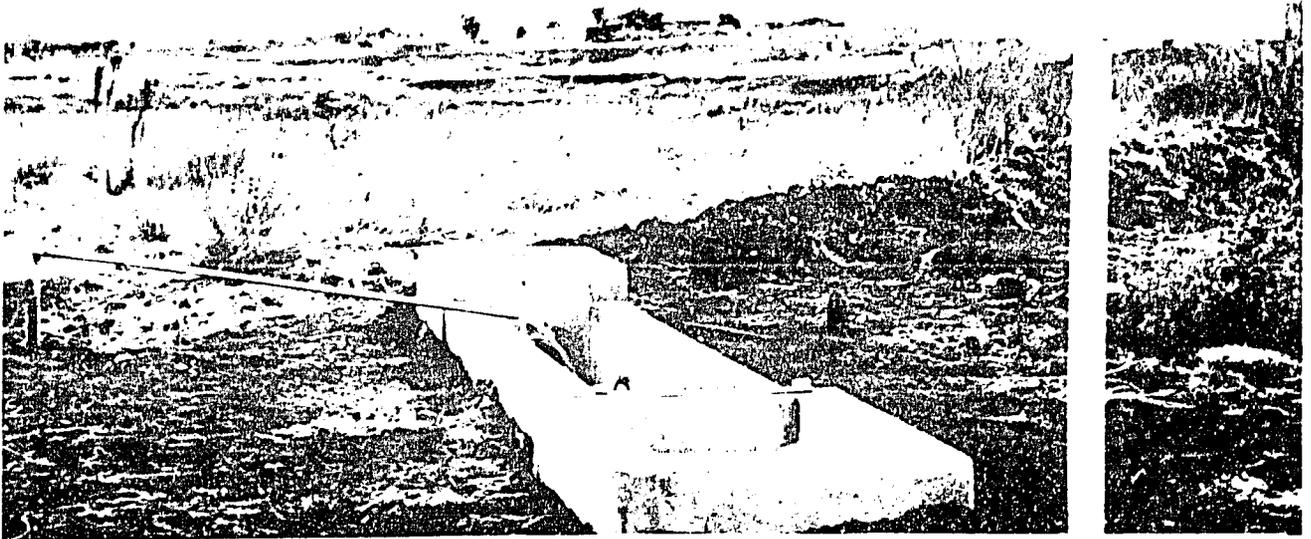


Plate 9. Langata Lagoons Nairobi, Kenya. View of screen chamber.

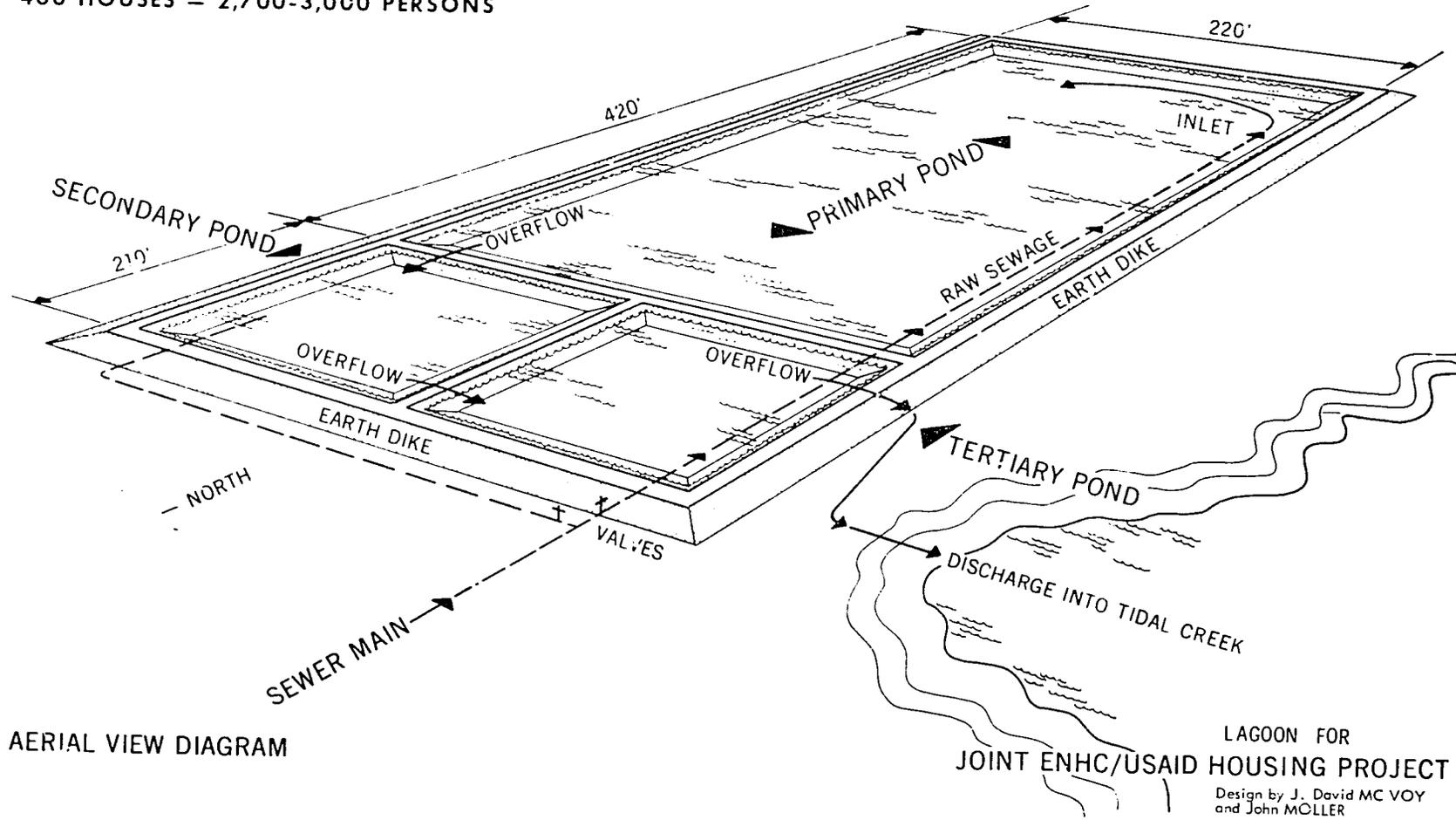
SEWAGE STABILIZATION PONDS

TRANS-AMADI RESIDENTIAL AREA

PORT HARCOURT, NIGERIA

STAGE NO. 2

400 HOUSES — 2,700-3,000 PERSONS



AERIAL VIEW DIAGRAM

LAGOON FOR
JOINT ENHC/USAID HOUSING PROJECT
Design by J. David MC VOY
and John MOLLER

Plate 10. Lagoon for Joint ENHC/USAID Housing Project

be reduced by compaction, the use of soil mixes, or surface skins as described earlier in connection with lagoon bottoms. Organic material should be avoided or at least reduced to an absolute minimum.

Where surface water or erosion might cause slippage, dikes can be started by backfilling a shallow trench (3" to 6") which will act as a keyway. In addition to well-compacted soil, good grass cover is useful in preventing erosion of the embankments. Grasses should be of hardy, local varieties, and have a broad, shallow root system. Erosion at the water-edge can also be prevented by installation of a layer of stones, blocks or concrete slabs (see photographs).

INFLOW AND DISCHARGE AREAS

For small installations, influent lines should discharge at the approximate center of the lagoon. For medium installations, 200 feet from the nearest bank may be sufficient. A shallow dish or saucer shaped depression in the lagoon floor at the end of the influent line will help in keeping sewage solids submerged. The depth of the dish should be about the diameter of the inflow pipe and the diameter of the dish anywhere from 25 to 100 feet. A manhole should be provided where the influent line crosses the dike. Usually, influent should first pass through a simple bar-screen (recommended 1/2" bars approximately 3" to 4" on centers), to remove pieces of paper, cardboard, and other objects. While bar-screens may not be necessary in some countries, they were found essential in others. The resulting increase in maintenance costs is unavoidable, but should present no problem in developing countries.

With a balanced system, where normal operation will not provide effluent, a spillway (concrete or stone faced) in the form of a simple depression in the rim of the lagoon to accommodate overflow under abnormal conditions will suffice. This should be a maximum distance from the inlet point, and placed to discharge into a channel protected from erosion. Where the lagoon is to be drained for cleaning or for sludge utilization, an effluent drain such as those described below should be used. Where the discharge of effluent is normally continual, the outlet should be well below the water surface to avoid drawing off scum but not closer than one foot to the bottom of the lagoon. The outlet (or outlets) should be provided with a drop gate or gate valve to reduce or stop the flow when necessary, thus controlling the liquid depth. A spillway should also be provided for abnormal flow conditions. Spillways, pipe or tunnel outlets should be well clear of the inlet point to prevent drawing off raw sewage or short-circuiting.

An outlet design may be utilized (see sketch method A and B) in which the invert elevation of the pipe is the same as that of the bottom of the pond. The outlet is through a manhole (method A), or surmounted with a concrete U-shaped weir-type structure (method B) slotted at the open side to permit the introduction of flash-boards to control water surface elevation as conditions warrant and, also, to permit drainage of the entire pond for cleaning. A catwalk (method B) from the top of the dike to the top of the weir is desirable for convenience of operation and maintenance.

Where the channels to handle the effluent are inadequate to take care of abnormally large volume, trenches or pits or a herring bone system of trenches may be provided to temporarily retain the water until it can be absorbed or run off in existing channels and thus prevent flooding.

A grit removal chamber should be placed in the main leading to inlet control valves. This can be a single chamber with grates and an open top for easy cleaning.

Two narrow parallel chambers with a diversion gate will allow continued operation while cleaning.

While gravity flow from the collection system is desired for greatest economy, lift stations are sometimes necessary due to non-availability of land in low areas, or in order to keep the lagoon high where surface or near surface-water is a problem.

INITIAL FILLING

Where industrial or commercial wastes are involved, the biochemical treatment process does not start immediately upon filling the lagoon with water and sewage. Natural seeding takes place until the process is established. To allow for dilution and seeding, the lagoon should be partially filled with water before admitting sewage. Similarly, when the lagoon is drained, it may be advisable not to drain it altogether, but retain a fraction of the water for seeding of the next inflow. No seeding is necessary for lagoons handling human wastes only.

After initial filling, a certain length of time (up to 12 weeks) is required for the ponds to settle down. During this time close supervision should be maintained in order to ensure that no fly or mosquito breeding takes place.

ANIMAL LIFE

Secondary ponds have successfully supported a number of varieties of fish which also aid in controlling mosquitoes.

Ducks, geese and water fowl have been known to inhabit the region of lagoons, giving further insect control.

The grazing of domestic animals over the flat areas surrounding the lagoons not only provides food from a (hopefully) lush grass cover, but keeps the height of vegetation to an acceptable level.

PROTECTION

Though the embankments themselves are somewhat of a deterrent to animals and men approaching the lagoon, fences are necessary near built-up areas, especially as a protection to children. Fences 4 to 6 feet in height with an access gate wide enough to allow vehicular access are adequate.

Where valves are in the open they should be locked to prevent tampering. For this reason, as well as protection from the weather, any tools or chemical containers used in connection with the system should be stored in a rain and tamper-proof structure.

MAINTENANCE

A gravity fed lagoon system is simple to service and maintain. Regular periodic checks should be made by someone capable of reading and recording the lagoon depth, extracting samples to check the quality of effluent, and regulating the flow in multiple pond systems. At the same time, inspections should be made of the dikes and the area generally to observe possible leaks, erosion, and (where one exists) to check the grit chamber.

At specific intervals, or to meet periodic problems, maintenance should include clearing of surface clogging (scum) caused by wind action, cleaning bar-screens, oiling valves, cutting grass on the dikes and surrounding area, and controlling weed growth in the lagoons to prevent breeding of mosquitoes. Bar-screens may have to be cleaned (and waste incinerated) daily. Soundings should be made to determine the general level of sludge accumulation and whether or not excessive accumulation is taking place around the inlet points or in any other area where circulation might be retarded.

For maintenance (such as bottom weed cutting) and detailed inspection, a small float or flat-bottomed boat is extremely useful.

A soil sterilant may be used to control undesirable plant growth and therefore mosquito breeding along the water edge of the dikes, but care should be taken not to destroy desirable grass cover above. Furthermore, the danger exists that leaching of chemicals into the lagoon may cause a film which can retard oxidation. Application of soil sterilants should be made prior to filling of the lagoon. Basic maintenance should not require more than one or two workers.

RODENTS AND INSECTS

Control of mosquitoes and other insects as well as rodents, whose burrows may damage the dikes, should be part of the above mentioned periodic maintenance program. Poisons, traps and shooting, and the destruction of burrows as they are found keeps the rodents under control. Poisons must be used with care, however, since domestic animals may be killed where the area is grazed, or where fences are not used. If necessary, sprays and dry mixes can be used to combat mosquitoes, though it is rare for them to appear in large numbers in the area of a well-maintained pond. Here again, oils and chemicals which may form a film on the lagoon should be avoided.

SLUDGE ACCUMULATION

As mentioned under Treatment Process, sludge accumulates very slowly. Its actual rate is difficult to predict since it depends on such factors as pond loading in persons per acre, the amount and nature of industrial waste in the system, the extent to which washing machines, or other water-consuming equipment is used, whether or not grit chambers are used, and, in wealthier areas, the use of garbage grinders.

As sludge is a valuable byproduct for agricultural uses, particularly where fertilizer is scarce or expensive, it may well pay, in a multiple system, to shut down one pond at a time to allow its removal. This may be done after a period of only four or five years initially, and more often thereafter if desired. It might be noted that a five-year accumulation may range from only two or three inches to almost two feet, but that for every inch of depth each acre will yield approximately 3600 cubic feet of sludge. Subject to adequate lagoon design, de-sludging of lagoons in tropical areas may not be required until after 8 to 16 years of use.

When removing sludge, care must be taken not to disturb the earth bed or the sludge which has penetrated to seal it. Where commercial skins of any type are used, even greater care must be taken to prevent puncture.

COST

The cost of constructing and operating sewage lagoons is considerably lower than those required for building and maintaining conventional sewage disposal systems (50% or less for small plants). Experience in the United States indicates per capita construction costs ranging from \$12 to \$14, and operating and maintenance costs from \$0.20 to \$1.00 annually per population equivalent. African experience shows even lower costs, i. e. per capita construction costs of \$5.50 (\$16.80 with sealing of lagoon bottom) and per capita yearly operating costs of \$0.42. Sewage lagoons, compared to conventional disposal systems, seem to be especially economical in the case of smaller communities of 10,000 or less population. However, in view of the necessity for large tracts of land, they are not considered economical for large cities (Australia being an exception).

NIGHT-SOIL TREATMENT IN LAGOONS

In Africa it was shown that night-soil and conservancy tank contents can be disposed of in "sewage" lagoons. In fact, it was found that a concentration of as high as 2,000 people per acre of lagoon would still maintain aerobic conditions. This indicates that lagoons can also be used for disposal of human waste in the absence of an existing sewer system, provided enough water is available to allow the creation of conditions necessary for the oxidation process. Location, design, loading conditions, etc., for such lagoons, however, should not be determined without the assistance of properly qualified technical personnel.

COMMUNITY RELATIONS AND THE LAW

Frequently, when planning sewage lagoons, the feelings of the community are ignored, or not sought, possibly resulting in unnecessary opposition to the system generally. As soon as it is known that a sewage system is planned, and it is determined that lagoons are a practical solution, the public should be informed of both the nature of the project and its advantages. The economy factor will appeal to many who might oppose a new sewage system generally in that lagoons result in substantial cost reductions as compared with the more sophisticated treatment plants—generally in the order of 50 percent or more. Cost, however, is not as important to many as physiological factors involving possible nuisances.

If the lagoon is properly located, designed and built, fears of odors, water pollution, unsightly floating materials, rodents and insects are largely unfounded. Meetings with interested public bodies and the use of local communications media should be a part of what amounts to an educational program to inform, interest, and allay the possible objections of the general public. Pointing out advantages of the system with successful examples in other communities is a useful technique. Community leaders might well be taken on tours of nearby lagoon systems, while larger tours open to anyone, should be organized once the local lagoon is in operation. In this, as with other matters, fear is generated by the unknown, while understanding will usually result in cooperation, or at least acceptance.

Like public opinion, the law plays a decisive but more immediate role in not only where a sewage treatment plant will be built, but whether it will be built at all. Under "Site Location" it was noted that zoning ordinances determine the general area for elements such as sewage disposal systems. Even where zoning laws and health ordinances

condone lagoons, however, concern for the maintenance of property values can become a serious consideration, and may, depending upon the case, result in court action.

Indemnification may be necessary as a result of constructing lagoons in residential areas. Compensation is required for full or partial land takings, as well as for any income loss or nuisances that may occur due to faulty lagoons. Payment for complete parcels of land is normally based on the appraised fair market value. In purchasing partial plots, however, greater compensation may be necessary due to possible reduced income or reduced resale value of the remaining portion.

Four points must be kept in mind concerning possible claims by adjoining property owners and in connection with the purchase of partial parcels of land:

- (1) What accident hazards may result? Injury to children or livestock pose problems but can be overcome by the use of adequate fencing and maintenance.
- (2) What health hazards are involved? Pollution of ground water and domestic water sources by seepage from the lagoon may usually be overcome through careful design, construction and maintenance.
- (3) What nuisances may arise? Unsightly solids, odors and mosquitoes can also be discounted where properly located, designed and maintained lagoons are concerned. Where icing conditions exist, periods of offensive odor in the immediate area may result when the ice breaks up.
- (4) What is the effect of sewage lagoons on the production and resale value of the adjoining parcels of land? Farm operations are naturally affected by any reduction in land area, but no more so by lagoons than from any other use to which the land may be put. Since lagoon construction may affect the possible use-range or resale value of plots in the adjoining area, it is often more economical to buy whole parcels at market value than to pay compensation for possible future loss of income from partial plots. Even when not immediately needed, the excess land is a good investment for the community, and may well be needed for expansion of the system as the area develops.

SELECTED BIBLIOGRAPHY

1. Jewell R. Benson, "How to Prevent Sewage Lagoon Seepage", Ridgewood, N.J. Public Works Journal Corp., Public Works, Vol. 93, No. 3, March 1962.
2. "Design Criteria for Seepage Pits", FHA Completed Studies and Reports Number 22, 1964.
3. Donald L. Floan, "Installing a Sewage Lagoon and Lift Station", Chicago Company, Water and Sewage Work, Vol. 18, No. 8, May 1961.
4. Housing and Home Finance Agency, Federal Housing Administration, "Minimum Design Standards for Community Sewerage Systems", FHA No. 720, Washington, July 1963.
5. O. L. Meyer, "Aeration System", Ridgewood, N. J., Public Works Journal Corp. Public Works, Vol. 93, No. 8, August 1962.
6. Donald A. Mills, "Depth and Loading Rates of Oxidation Ponds", Chicago, Scranton Publishing Company, Water and Sewage Works, Vol. 108, No. 8, 1961.
7. George F. Papenfuss and Mary B. Allen, "General Features of Algae Growth In Sewage Oxidation Ponds", Sacramento, State Water Pollution Control Board Publication, Number 13, 1955.
8. William S. Ratchford, "Sewage Lagoons", Hallowell, Maine, Maine Municipal Association, "The Maine Townsman", Vol. XXIII, No. 6, June 1961.
9. Don Romero, "Nature's Way with Waste", New York 21, National Civic Review, National Municipal League, Vol. XLIX, 1960.
10. Shaw, Meiring, and Van Eck, "Preliminary Results of Research on Raw Sewage Stabilization Ponds", Council for Scientific and Industrial Research, CSIR Special Report No. 189, Pretoria, South Africa, 1962.
11. Ernest W. Steel, "Water Supply and Sewerage", New York, McGraw-Hill Book Company, Inc. 1953.
12. Paul G. W. Walker, "Rotor Aeration of Oxidation Ditches", Chicago, Scranton Publishing Co., Water and Sewage Works, Vol. 109, No. 6, June 1962.
13. William J. Wenzel, "Low Cost Treatment and Disposal Method", New York Engineering News-Record, August 20, 1953.
14. P.T.A. Zeller and F.E. Giesecke, "Secondary Treatment of Sewage in an Artificial Lake", New York Engineering News-Record, Nov. 1963.

15. Ted L. Townsend, "Sewage Lagoons", Appraisal Institute of Canada, Appraisal Institute Magazine, December 1963.
16. D. H. Caldwell, "Sewage Oxidation Ponds, Performance, Operation and Design", Sewage Works Journal 18, 1946.
17. Smallhorst, Walton and Meyers, "Design and Operation of Oxidation Ponds", Public Works, 84, 1953.
18. Towne, Bartsch and Davis, "Raw Sewage Stabilization Ponds in the Dakotas", Sewage and Industrial Wastes, 29, 1957.
19. Ingram, Towne and Horning, "Selected References on Waste Stabilization Ponds", Proceedings on Symposium on Waste Stabilization Lagoons, U.S. PHS, Region VI, Kansas City, Mo., 1960.
20. Bureau Central d'Etudes Pour les Equipements d'Outre-Mer, Service de l'Habitat et Urbanisme, "Etangs et Bassins d'Epuration d'Eaux Usees en Region Tropicale", Bulletins d'Information No. 25, 1963.
21. W. W. Towne, and W. H. Davis, "Sewage Treatment by Raw Sewage Stabilization Ponds", Journal of the Sanitary Engineering Division, ASCE, Paper 1337, August 1957.
22. Van Heuvelen, Smith, and Hopkins, "Waste Stabilization Lagoons", Design Construction and Operating Practices among Missouri Basin States", a Committee Report approved by the Missouri Basin Engineering Health Council, Jan. 21, 1960.
23. Neel, McDermott and Monday, "Experimental Lagooning of Raw Sewage at Fayette, Missouri", Journal Water Pollution Control Federation, June 1961.
24. Ralph Porges, "Waste Stabilization Ponds, Facts and Figures", U. S. Department of Health, Education and Welfare, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.
25. A. H. Taylor, "Sewage Lagoons for Low-Cost Disposal", East Africa Medical Journal, Vol. 37, No. 10, October 1960.
26. E. R. Hermann and E. F. Gloyne, "The Design of Oxidation Ponds", Sanitary Engineering Research Lab., Dept. of Civil Engineering, University of Texas, 1955.
27. A. F. Bartsch, "Biological and Chemical Aspects of Organic Waste Lagoons", U. S. Dept. of Health, Education and Welfare, PHS, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio.
28. Marais and Shaw, "A Rational Theory for the Design of Sewage Stabilization Ponds in Central and Southern Africa", Trans. S. Afr. Inst. Civ. Engineers, Vol. 3, No. 11, Nov. 1961.
29. H. Lister, "Treatment of Sewage with Special Reference to the Use of Stabilization Ponds", Housing Advisory Council, Hatfield Road, Salisbury, Rhodesia.

30. Marais, Shaw, and Asce, "A Rational Theory for the Design of Sewage Stabilization Ponds in Central and South Africa", *The Civil Engineer in S. Africa*, Vol. 3, No. 11, November 1961.
31. Marais, "A Design Chart for a Series of Oxidation Ponds Treating Raw Sewage", *The Civil Engineer in S. Africa*, Vol. 5, No. 9, September 1963.
32. Marais, "A Rational Theory for the Design of Sewage Stabilization Ponds in Tropical and Subtropical Areas", CCTA/WHO Symposium on Hygiene and Sanitation in Relation to Housing, CCTA Publ. No. 84, Niamey 1961.
33. Fair and Geyer, "Water Supply and Waste Water Disposal", John Wiley and Sons, New York, 1957.
34. Meenaghan and Alley, "Evaluation of Waste Stabilization Pond Performance", *Tex. Wat. Pollut. Contr. Assoc.*, 1963.
35. Hodgson, "Stabilization Ponds for a Small African Urban Area", *J. Wat. Pollut. Contr. Fed.*, Jan. 1964.
36. Neel, McDermott, and Monday, "Experimental Lagooning of Raw Sewage at Fayette, Mo.", *J. Wat. Pollut. Contr.*, 1961.
37. Silva, and Papenfuss, "A Systematic Study of the Algae of Sewage Oxidation Ponds", Publ. No. 7, Calif. State Wtr. Pollut. Board, 1953
38. J.L.A. Watson, "Oxidation Ponds and Use of Effluent in Israel", *Proc. Instn. of Civ. Engrs.*, 1962.
39. Parker, Jones, and Taylor, "Purification of Sewage in Lagoons", *Sew. and Ind. Wastes*, 1950.
40. Vincent, Algie, and Marais, "A System of Sanitation for Low-Cost High-Density Housing", Niamey, CCTA Publ. No. 84, 1961.
41. V. A. Shaw, "A System for the Disposal of Night-Soil and Conservancy Tank Contents in Stabilization Ponds", *Public Health*, No. 63, 2, 1963.
42. Van Eck, "Theory of Stabilization Ponds and its Implication on Their Design and Operation", CCTA/WHO Specialist Conference, Pretoria, 1960.
43. Williamson, Arthur E., "Summary Report on Stabilization Ponds and Aerated Lagoons", prepared for Missouri Basin Engineering Health Council, 1964.