THE USE AND PERFORMANCE OF FISH FOR POLISHING EFFLUENT FROM WASTE STABILIZATION POND SYSTEM

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DECLARATION

I hereby declare that this thesis has been composed by myself and that it is a record of my own research work. It has not been accepted in any previous application for a higher degree. All sources of information are specifically acknowledged by means of references.



C. O. ANTHONIO.

C E R T I F I C A T I O N

This project thesis entitled "The Use and Performance of Fish for Polishing Effluent from Waste Stabilization Pond System", by C. O. Anthonio, meets the regulations governing the award of the degree of Master of Science (M.Sc.) of Ahmadu Bello University, and is approved for its contribution to scientific and literary presentation.

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ABSTRACT

This study investigates the performance of fish in ponds for the polishing of effluent from a waste stabilization pond system. Two pilot ponds, each of dimensions 2m x 4m x 1.25m were constructed, to receive the effluent from the maturation ponds of the Ahmadu Bello University waste stabilization pond system. The performance of the ponds in terms of the reduction in T5, 55, Chlorophyll-a, 800 and COO, were assessed when stocked with fish at rates of 5.0, 2.5, 1.25 and 0.0 fishes per m^2. The ponds were operated at a detention time of 5 days throughout the study.

The results show that fish population has significant influence on the performance of the ponds. Suspended solids removal as high as 85.6$ was observed for 5.0 fish/m^2 stocking, while operation at 0 fish/m^2 often resulted in effluent with increased S.S and chlorophyll-a concentration. A maximum COD removal of 40$ **was** obtained in the pond stocked with 2.5fish/m^2 while 5C0D removal as high as 77$ was achieved in the pond with 5.0 fish/m^2. The ponds were able to provide some BOO removal, though the ponds operated at 1.25 and 0.0 fish/m^2 indicated increases in BOO of up to 11.5$ and 10.7$, respectively.

One of the full-scale maturation, ponds feeding the pilot ponds, iuas also used to investigate the rate of growth and productivity of 300 fishes. Average fish growth rate of 0.83g/d. or 0.14g/m^2.d were observed over a period of 6 months of investigation. Bacteriological tests on the guts and flesh of the fishes indicated the presence of coliform bacteria, but absence of sulphite-reducing bacteria.

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ABBREVIATIONS AND NOTATIONS

ABBREVIATIONS

A.B.U.	Ahmadu Bello University
BOD	Biochemical Oxygen Demand
BOD 5	5-day Biochemical Oxygen Demand
TBOD	Total Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
SCOD	Soluble-Chemical Oxygen Demand
TCOD	Total Chemical Oxygen Demand
DO	Dissolved Oxygen
HRAP	High Rate Algae Pond
R.O.E.C.	Reed's Odourless Earth Closet
R.P.M.	Revolutions Per Minute
S.S.	Suspended Solids
T.S.	Total Solids
V.I.P.	Ventilated Improved Pit (Latrines)

NOTATION		UNITS
A	Pond Mid-depth Area	m^2
d	Pond depth	m
I	light intensity at depth, d,	$erg/cm.^2 s$
Io	light intensity at water surface	$erg/cm.^2 s$
k	(reaeration/removal) rate constant, at T.	./day
ko	(reaeration/removal) rate constant, at To.	./day
Na	Concentration of algal cells	mg/cm^3
T	Mean monthly ambient temperature	°C
E	light absorption coeff. of water and algal susp.	cm^2/erg
$	Light absorption coeff. of water	./cm
ΔF	Free engergy change	
ΔH	Enthalphy change	
ΔS	Entropy change	
θ	Temperature reaction coefficient/Arrhenius constant.	

CHAPTER 1

INTRODUCTION

The aim of the International Drinking Water Supply and Sanitation Decade (1981-1990) is that all people be provided, it possible, with safe water and adequate sanitation. The Decade has not only placed the highest priority on these basic human requirements, but has helped to highlight the deplorable conditions of the world's poor, especially in developing countries.

The ability of a society to pay for its needs and the applicaton of knowledge about the transmission of water-based and water-borne diseases, for example, have made it possible in developed countries to provide safe water and to treat wastes efficiently. This, however, is not the case for the majority of rural populations in the developing countries, where it is given low priority. The developing countries are faced with a number of problems, including a poor economy, population explosion and inadequate resources of money, materials and trained manpower - which are serious obstacles to their development. The scarcity or absence of safe water supplies and the use of unsafe water resources undermine rural health. Lack of sanitation facilities raises morbidity and mortality rates, which in turn, depress economic productivity and curtails social development. This vicious cycle continues indefinitely and migration from rural to urban areas is a common result, and further compounds the problems.

Bhalla (1978) and Pacey (1978), observed that a large proportion of technologies imported into developing countries are still much too expensive for the very poor nations and larger proportion of the populace in averagely poor countries. Cost of construction, lack of adequately trained operators, mechanical components and cheap and available power to run the plants are some of the factors responsible for inefficient

operation of most waste-water treatment systems in developing countries. Thus low-cost, appropriate wastewater treatment solutions, which can be suitably upgraded, have to be adopted. Just as important, the developing countries themselves must develop the human resources to operate and maintain the facility after they have been installed, otherwise investment may not yield permanent improvements.

Uncontrolled discharge of wastewater into the environment poses grave dangers to public health and has adverse effects on the environment. Because of these intensive methods of biological wastewater treatment have had to be developed. Conventional treatment systems, common in temperate developed countries, usually involve highly complex chemical engineering processes which are not only extremely expensive to build and operate, but also require the services of highly trained operators, which are often lacking in most developing countries. The waste stabilization pond, however, has been found in developing countries to be an effective and satisfactory method of wastewater treatment, if land is inexpensive, as capital costs are far less than for comparable conventional wastewater treatment processes. Stabilization ponds are easy to design and construct, requiring very little operator control, skilled labour and maintenance, for successful operation. The simplicity of operation and ability to handle a desirable wastewater treatment alternative, particularly in tropical countries where suitable climatic conditions exist.

Algae-laden effluents resulting from wastewater treatment not only have a detrimental effection on the overall performance of stabilization ponds in terms of COD or BOD removal, but significantly influence conditions in receiving waters, such as DO depletion, creating a nuissance condition; and impairing the receiving water quality for reuse. Several reports including, Mangelson and Watters (1972), Serfling and Alstein

(1978), Ferrara and Harleman (1981), and Kilani and Ogunrombi (1984), discuss methods for upgrading and improving the treatment efficiency of waste stabilization pond systems, with particular emphasis on facultative ponds. The use of fish culture in polishing ponds may be of help in reducing indicator microorganisms, plankton and benthic population, and thus improve the effectivensss of a waste stabilization pond system for reducing COD, BOD and removing nutrients from the wastewater. Fish can also serve to reduce the vegetative standing crop and control mosquito and other sufrace water breeding organisms. In addition to the ability of fish to polish effluent from ponds, a number of economic advantages can be gained by utilizing the algae in pond effluent for fish production.

The objectives of the study can be summarized as:

1. To investigate the performance of varied fish stocking in polishing ponds receiving effluents from waste stabilization ponds.
2. To investigate the growth response and productivity of fish feeding on algae and other nutrients in maturation ponds.

CHAPTER 2

LITERATURE REVIEW

2.1 Wastewater Treatment in Developing Countries

The wastewater of a community may be defined as the combination of the liquid or water-carried wastes removed from residences institutions, and commercial and industrial establishments, together with such ground water, surface water and storm water as may be present.

Because of the nature and composition of wastes, wastewater treatment and disposal is vital for several reasons, amongst which are:-

(i) The destruction of the pathogenic or disease causing microorganisms.

(ii) To prevent the pollution of any body of water (surface or groundwater) to which the effluent escapes after discharging.

(iii) To prevent or reduce production of large quantities of malodorous gases which may result during decomposition of accumulated untreated wastewater.

(iv) To convert the waste and wastewater into a readily reusable source, and so conserve both water and nutrients.

It is clear that cost of conventional sewerage systems (which is the standard solution adopted for the sanitary disposal of excreta and wastewater in the high-income, developed countries) make them incompartible with the present per capita income of a majority of the population in developing countries. Besides economic considerations and social acceptability is the need for increased awareness of the importance of sanitation by the authorities concerned. Clearer evidence of health benefits to be expected from funding such projects, since their hopes of financial returns will be smaller is probably a reason why authorities in many developing countries have paid little attention to the problem of excreta disposal. Pacey (1978) reported that taking the developing

countries as a whole, only 15% of rural people, in 1975, were estimated to have adequate excreta disposal facilities. It is in these areas where funds are least available and per capita incomes are lowest. For most of the inhabitants of the rural areas drinking water is often obtained from streams or hand-dug wells, while pit latrines are often the most common excreta disposal method available. Refuse does not pose a serious problem in these areas as the quantity generated is low and is buried or disposed off in a nearby bush.

On considering the widely varying circumstances of developing countries, it becomes clear that no one system is likely to be appropriate to the needs of all communities of developing nations. Iwugo (1981) listed sanitation technologies currently in use in Africa to include the following:-

(a) Pit latrines (on-site and dry system);

(b) Compost toilets (on-site and dry system);

(c) Bucket latrines (on-site and wet system);

(d) Aqua-privies (on-site and wet system);

(e) Septic tanks and soakaways (on-site and wet systems);

(f) Conventional sewerage (off-site and wet system).

Pit latrines remain to date the most widely used technique for excreta disposal in the developing countries, in the urban as well as rural areas. Low cost and good performance, when the number of users are low, make them a suitable system in rural areas. Modifications and improvements to the conventional pit latrine include: the Reed's Odourless Earth Closet (R.O.E.C.); disludgeable pit latrines; and the Ventilated Improved pit (V.I.P.) latrines. All forms of pit latrines are dry systems and like compost latrines are incapable of receiving household sullage. Dry systems

pollute an extreemly restricted area except where intercepted by the water table.

Composting latrines are capable of being built partly or entirely above ground in rocky areas or where highwater tables exist. Composting is the relatively fast process of decomposition of organic matter, such as occurs in garden compost heap: it achieves a relatively high temperature in the early stages of the process. Thus, the principle of the composting latrine may be widely applicable in tropical developing countries, where climatic conditions tend to favour it and the advantage of not requiring water in the transport and digestion of excreta. The multrum toilet, multrum and clivus latrine, modified R.O.E.C. latrine with composting chamber as well as the double vault system are some common types of composting latrines. Composting latrines should perform well in rural areas if proper user - education is provided, (Iwugo, (1981)).

The removal of night soil from individual houses in urban areas using trucks, carts or manually carried buckets, is a system which was widely used in Europe. The bucket latrine system is undoubtedly the worst and most abhorrent form of sanitation in practice, in urban areas of developing countries. Problems associated with the bucket latrine system are that, it can be very unhygenic because of the high probability of spillage during removal and transport; the difficulty of employing scavengers because of the relatively low wage and the social stigma associated with the work and; the considerably high degree of social discipline required among both users and collectors for successful operation of the system.

Aqua-privies are essentially simplified septic tanks located immediately below the squatting plate. A drop-pipe, which extends below the liquid level provides a water seal which reduces odour, fly and mosquitoe nuissance considerably. A vent-pipe should be provided to

exhaust the gaseous products of the anaerobic fermentation occuring in the tank. Disposal of the liquid effluent from the tank, can be achieved by subsurface percolation into the ground via a soakaway or by small-bore sewers connected to waste stabilization ponds. The socio-cultural reluctance of carrying water to the toilet in order to maintain the water seal, where taps are not available near aqua-privy toilets, is a major factor which militates against satisfactory performance of the system (Feachem et. al, (1977), Pacey (1978); and Iwugo, (1981)).

Septic tank systems are the most widely used water-borne sanitation systems in Africa, where they have been found to perform relatively well in many urban areas. The septic tank consists of a large tank placed beneath the ground level in close proximity to the house from which it receives influent of kitchen, cleansing and toilet wastewaters. Most of the solids in the waste settle in the tank as sludge and digest on its bottom. The effluent leaves by overflow into a subterranean pipe or trench system which distributes it for percolation into the soil. Other than the high costs, a major defect in the system lies in the design and operation of the effluent disposal component (i.e. the drain-field trenches or soakaways).

Although waste disposal systems such as pit latrines are usually cheaper, it does not follow that they will always be the best choice whenever low-cost rural sanitation is considered. Construction of sanitation facilities when not well planned will result in wasteful of resources and even harmful to community health due to inefficient operation. With the present drive for rapid industrialization by governments in developing countries, the adoption of the sewerage system is likely to be accelerated, particularly in urban areas.

Conventional sewerage consists of a network of underground pipers (sewers) which transport both toilet-flush water and other household

sullage to locations where they can be treated or safely disposed. In Africa only a few towns and cities are served by conventional sewerage and a majority of these are combined sewerage systems. In many tropical countries rainfall occurs seasonally and often with extremely high intensity. It may therefore be rational to install a seperate sewerage system rather than to provide a large combined sewer whose capacity is not fully utilized or have sufficiently high flow velocities to transport excreta in the dry seasons.

The treatment of sewage is often classified as pretreatment, primary treatment, secondary treatment, and tertiary treatment. Pretreatment processes include, grinding for solids size reduction, screening for solids removal, flow equalization and/or oil seperation. Primary treatment are often by the use of physical devices for the removal of suspended solids. Secondary treatment generally involves a biological process for removal of organic substances through biological oxidation. The biological process can be activated sludge, trickling filter, rotating biological contactor, waste stabilization ponds, oxidation ditch, or an anaerobic biological treatment process. Tertiary treatment are necessary when particular contaminants must be removed to meet effluent standards, or to prepare the water for reuse. The objectives of tertiary treatment can be to remove phosphrous, nitrogen, residual organics, colour, suspended or dissolved solids.

2.2 Upgrading of Pond Effluents

Improved waste treatment plant performance have to be undertaken to meet emerging stringent effluent discharge criteria and to restore and maintain the biological, chemical, and physical quality of receiving waters. In the U.S.A. the Environmental Protection Agency (E.P.A.)

embarked upon a research and development program designed to identify design criteria and technology to upgrade the effluent quality of oxidation ponds. Lewis (1978), identifies some of the objectives as including:-

(i) Low cost suspended solids removal processes;

(ii) Design guidelines for discharging oxidation pond effluent to the land;

(iii) Disinfection guidelines and demonstration of applicable disinfection methods;

(iv) Development and demonstration of nutrient control technology;

(v) Evaluation of utilizing the seperated suspended solids in the pond effluent as a useful product, such as a supplement for animal feed;

(vi) Relationship of pond design to an upgrading of pond performance;

Effluents from stabilization ponds can be upgraded by anyone of several add-on devices, some of which are discussed below.

2.2.1 Algae Removal Techniques

The effluent from stabilization ponds, may exert a harmful effect on downstream aquatic ecosystems. Nutrients tied up as algal biomass may be released causing delayed eutrophication problems, as well as influencing overall pond performance in terms of BOD or COD removal. Extensive growth of algae may cause allergies or other clinical problems to animals or men that come into close contact with the algae by swimming in the receiving water, ingesting the water, or breathing an aerosol of these algae. This is especially a problem where there are large masses of decaying algae, can lead to taste and odour problems. The removal of particulate matter from waste stabilization pond effluent is thus necessary to prevent downstream pollution of surface waters and meet disposal standards.

The criteria for selection of a technique would involve such factors as: ease of operation; minimum maintenance and cost; dependability of operation; and efficiency of particulate removal. The several algae removal methods that have been studied and proposed include (Middlebrooks et. al, (1974)): Centrifugation, Microstraining, Coagulation - Flocculation - Sedimentation, In-pond removal systems, Dissolved Air Flotation, and Filtration.

The ranges of solid removal efficiencies of various methods reported in the literature are shown in Table 2.1.

Table 2.1 - Performance of Various Algae Removal Metohds

Algae Removal Methods	% Solids Removal
Centrifugation	50 - 95
Microstraining	30 - 40
Coagulation-flocculation-sedimentation	80 - 90
Inpond removal systems	40 - 80
Dissolved air flotation	80 - 95
Filtration	14 - 80

Most authors (Middlebooks et. al, (1974) and Kilani (1983) generally believe that the high costs of equipment and power (energy) coupled with complicated maintenance problems involved in the centrifugation process discredit its use as a means of improving the quality of effluents from ponds which are already noted for their advantage of low operating expense and simplicity.

Microstraining is reported to be possibly the most often tried technique but one which has consistently failed. Thus abundant records of poor performance constitute the most common criticism of microstrainers.

Since the smallest size microstrainer is 23pm (Middlebrooks, et. al.(1974), algae species such as Chlorella and Scenedesmus commonly found in stabilization ponds, tend to pass through microstrainers, since they are often smaller than 20pm, (Kilani (1983)). Even if microstrainers have been successful they cannot be recommended on the ground of their sophistication which often results in serious maintenance problems.

The Coagulation Flocculation - Sedimentation method which involves the addition of chemicals to pond effluents to modify the algal surface charge and provide a matrix for bridging between algal cells, allowing aggregation of the algae into flocs that can be removed by sedimentation has the following setbacks: difficulty involved in controlling the process, cost of chemicals and limitation of the choice of chemicals to only a few and sludge handling problems. Thus for the same reason why effluent disinfection could not be recommended for developing countries, the coagulation - flocculation - sedimentation technique is not a cost-effective method of algae removal in these regions.

Low algae concentrations in pond effluents have been achieved (Kilani (1983)), by adding coagulants to the last cell of a series of seasonal retention lagoons. However, since a considerable quantity of chemicals would be required for in-pond precipitation in the tropics where the absence of severe climatic cycles results in a lack of suitable periods of low algae concentration in the ponds, this technique again has the problem of considerable cost and possible shortage of chemicals and can therefore not be recommended.

Generally, autoflocculation, which is a natural seperation process of precipitation and settling of algae in a pond when the pH of the pond's contents rise to very high levels is not a very practical alternative for

algae removal (Middlebrooks et. al, (1974)), since there is very little the designer can do to influence its occurence.

In-pond removal systems contrast with other algae removal methods in that they involve a modification of pond construction or operation to enable pond effluent itself to attain the required suspended solids level rather than involve the use of additional tertiary processes to polish pond effluents. The three most common in-pond removal methods are: in-pond chemical precipitation, autoflocculation and fish ponding.

The only plausible criticism of the use of fish ponds for algal removal concen the aesthetic, health or legal prlblems that may often arise with the consumption of the grown fish. Various pathogenic organisms such as Salmonella, Poliovirus, Cox Sackie virus, Shigella, Vibrio Chlorela and Enteropathogenic Viral Hepatitis have been implicated in sewage grown fish (Kilani (1983)). It could appear that keeping the fish from fish ponds in clean water for about 48 hours, or more, before marketing and cooking the fish sufficiently before eating will help to ally any fear of disease transmission by the fish, although more work still needs to be done in this area.

The major problem with the dissolved air flotation (DAF) is the great discrepancy often observed between the results of laboratory bench scale tests and pilot studies (Kilani (1983)). Moreover dissolved air flotation has the disadvantage of requiring air dissolution equipment, making it generally very costly and complex to operate and can therefore not be a suitable system to be coupled with stabilization ponds.

Although the results of algae removal from pond effluents by direct sand filtration (use of rapid sand filters) have been very poor, due to the small size of green algae and the low affinity algae have for sand (Middle-

brooks et. al, (1974)), studies with intermittent sand filters have been reported to yield some encouraging algae removal reulsts. Kilani (1983), however, reported that studies conducted on intermittent sand filters have, so far, been contained to low influent suspended solids concentrations of about 46mg/l or less and pointed out that to ascertain whether intermittent sand filtration alone could efficiently remove algae from algal laden pond effluents, it is necessary to access the impact of higher suspended solids (such as 75 to 150mg/l) on the performance and length of run of filters. Intermittent sand filtration has the disadvantage of requiring occassional interruption in operation while clogged top sand layer is replaced by fresh or previously washed sand.

2-2.2 Disintection of Effluents

The most popular chemical used for water and effluent disinfection is chlorine, thus the term chlorination has been used interchangeably with effluent disinfection. Other chemicals that could be disinfectants include bromine, iodine, potassium permanganate, chlorine dioxide and ozone. Experience with these chemicals in wastewater disinfection is however, very limited.

Opinions are still varied concerning the effects of chlorination of pond effluents. Kilani (1983) reported that many investigators believe that high concentrations of algae commonly found in pond effluents result in increase in chlorine demand. A chlorine dose of 20-30 mg/l at 30-45 minutes contact time or a dose of 8mg/l at 30 minutes contact effective disinfection of algae-laden effluents, were mentioned. Earlier investigations are reported to show that only 2.65-3.0 mg/l of chlorine demand was exerted by pond effluents after 20 minutes of contact. The increase in chlorine demand was attributed to oxidation by the dissolve organic compounds

released from destroyed algal cells. Views about the effect of chlorination on the BOD5 or COD of pond effluents are more diverse than those on the effect of algae on the about of chlorine required. Kilani (1983), mentioned increases in BOD5 at higher chlorine doses and attributed this to the destruction of algae cells at these doses. Effluent BOD5 increased from 20 to 129mg/l for a chlorine dose increase of 2 to 64mg/l. BOD5 reduction from 24 to 25mg/l and suspended solids reduction from 110 to 40mg/l obtained from a chlorine contact pond dosed at 12mg/l and having a retention time of 13.5hours, were also mentioned. It was recommended that a combination of low chlorine doses and long contact periods is required to prevent increeases in BOD5 of the effluent.

The uncertainty surrounding the effectiveness of chlorination in reducing BOD or COD of pond effluents and the complication involved in the design of chlorine contact tanks, make the consideration of chlorinating pond effluents secondary to the use of series maturation ponds which could be easily designed for effective removal of pathogenic organisms.

Also the problems with reliable supply of chlorine in developing countries give some of the other techniques some edge over chlorination of effluents as a measure of reducing algae concentration in effluents. Moreover, chlorinated effluents often have adverse efects on aquatic life (Feachem et. al., (1977) and Middlebrooks et.al, (1982)) and there is also a growing concern about the toxic effects of organochlorine (chlorinated hydrocarbons) in domestic water supply (Tebbutt (1977)). Many of the organo-chlorines resulting from the chlorination of organic-containing water (e.g. treated effluents) are suspected to be carcinogenic.

2-2.3 Effluent Reuse

Increasing shortage and inadequate quantity of water supply in most

countries of the world has led to a growing interest in the subject of wastewater reuse. Indirect reuse of effluents has been long practiced by withdrawing effluents discharged into rivers as water supply downstream or through seepage of the effluents discharged on land into the ground water. Direct reuse of reclaimed wastewater for several applications such as industrial processing, irrigation and recreation has also become a common practice. However, direct reuse of reclaimed waters for drinking purposes or public water supply is still generally unacceptable or objectionable (Tebbutt (1977)) although there are scattered records of some areas of the world where this is being practiced. Kilani (1983), mentioned the practice in Windhoek, the capital of Namibia which is noted to be the first city in the world to practice large scale wastewater reuse for drinking purposes.

In 1971, the American Water Works Association (Kilani (1983)) issued a policy statement regarding the use of reclaimed wastewaters as public water supply source, which in parts, states:-

> "The Association encourages and supports increased use of reclaimed wastewaters for beneficial purposes such as industrial cooling and processing, irrigation of crops, recreation and, within the limits of historical practice, ground water recharge. However, the Association is of the opinion that current scientific knowledge and technology in the field of wastewater treatment is not advanced sufficiently to permit direct use of treated wastewaters as a source of public water supply, and it notes with concern current proposals to increase significantly both indirect and direct use of treated wastewaters for such purposes. The Association believes that the use of reclaimed wastewater for public watersupply purposes should be deferred until research and development demonstrates that such use will not be detrimental to the health of the public and will not affect adversely the wholesomeness and potability of water supplies for domestic use".

This policy statement still represents, to a greater extent, the general current view of effluent reuse.

A review of the history of wastewater treatment indicates that wastewater irrigation was originally developed in the early nineteenth century as a system of both treatment and disposal. In any land disposal consideration, due regard must be given to; quantity and quality of

wastewater available, method of application including rates and annual quantities; characteristics of the strata in the soil profile and ground water levels; elapsed time between application and withdrawal based on rate of groundwater flow; distance between point of application and collectors; and anticipated quality of the reclaimed water.

Feechem et al (1977) and Pacey (1978), are of the view that if excreta are used as fertilizer, or crops irrigated with sewage effluent, some people may become infected when they eat the crops. In addition, because some parasites can penetrate the skin, farm workers may be at risk while working on land irrigated with wastewater. In view of these enviromental and health hazards, it is essential to impose restrictions on wastewater irrigation. The irrigated crop must be limited to kinds which must be cooked prior to consumption, such as yam and egg plants, but not vegetables, as advocated by Diamant (1979). However, the risks to health can be completely eliminated if irrigation with wastewater effluents is limited to industrial or cash crops rather than edible crops and ornamental facilities such as fields and race tracks.

2-3 Potential of Biological Systems

Both the conventional lagoon and higher technology treatment processes are often designed for the purpose of sewage stabilization and disposal into aquatic ecosystems. With such factors as increasing population densities, it is becoming obvious that what might appear to be a satisfactory disposal solution for one community becomes an environmental degradation problem for its neighbours. This problem together with the increasing need for water and fertilizer, leads to the inescapable conclusion that wastewater must be dealth with as are resource to be managed rather than a problem to be disposed off. Taking this perspective,

wastewater treatment processes for the future must be designed to operate as managed ecosystems with controlled harvesting of nutrients and planning reuse of the water either directly or indirectly by "downstream" communities.

It is, therefore, worthwhile that agricultural, aquacultural, and silvicultural alternatives for wastewater treatment and reuse be evaluated and encouraged as a treatment mechanism. The possibility of high protein yields through algae production in ponds, or human excreta-fed ponds in which algae proliferate have been used as shrimp and fish culture ponds in Asia for centuries (Feachem et, al, (1977); and Pacey (1978)). As properly stated by Serfling and Alsten (1978), "wastewater must first be 'treated' and the reuse of by-product resulting from the treatment processes should be viewed as added advantage". What is proposed is a process in which aquatic plants and animals are intentionally stocked and harvested as part of a managed ecosystem for the purpose of removing wastewater nutrients and/or pollutants. The harvested by-products offer a source of food if they are to be used for any direct human consumption or benefit, but must not lower the quality of the "treated" wastewater, but infact make some further improvement.

2-3.1 High-Rate Algae Pond (HRAP)

Most of the algae grown in waste stabilization ponds are capable of synthesizing amino acid, a charactertic not exploited by conventional stabilization ponds, which are designed for minimum maintenance rather than for protein production.

The high-rate algae pond (HRAP) is a system developed to provide a maximum yield of algae and a reduction of wastewater organics (Serfling and Alsten, (1978); and Young et al, (1980)). Under proper conditions algae

can be highly productive and rapidly assimilate and convert wastewater nutrients into a more publicly acceptable form, while producing oxygen in the process. Under fluctuating conditions of Solar input, temperature, nutrient loading, and concentrations of toxic substances - the algae die, decay and release the nutrients back to the water. Because of the inherent instability and the need to develop satisfactory harvesting technology, as that is both economic and efficient, the algal pond system may not be very suitable for developing countries.

2-3.2 Aquatic Plants

Floating aquatic macrophytic plants such as water hyacinths (*Fichhornia arassipes*) or duckweeds (*Lemna Spp.*, or *Spirodella Spp.*) offer the following advantages over suspended algae for treating wastewater (Serfling and Alsten, (1978):

(i) The plants are very stable and hardy organisms that can tolerate widely fluctuating nutrient loading rates, solar input, water and air temperature changes, fluctuations in water chemistry, and are not affected by toxic compounds (heavy metals, chlorinated hydrocarbons, wastewaters.

(ii) Floating aquatic macrophytes reduce the high level of effluent suspended solids and BOD caused by algae cells, because the sunlight penetration through the plant fronds is insufficient in most situations to allow significant phytoplankton growth.

(iii) Water hyacinths and duckweed have been observed to be fast growing and exhibit high productivity.

(iv) The large size of the floating aquatic macrophytes make their removal relatively easy in comparison to unicellular algae.

(v) The plants offer high protein animal feed, conversion to fertilizer, and conversion to methane gas or methanol. Water hyacinths grown in waste

stabilization ponds typically average 20% protein, while duckweeds have been shown to average over 40% protein.

(vi) They produce tertiary effluent treatment with little capital or operating costs. These controlled aquatic plant processes do not require the expensive energy, chemicals, construction or maintenance cost that is typically utilized by conventional high technology advanced wastewater treatment systems. However, in spite of the numerous advantages, water hyacinths have been found to be extremely hardy under warm, humid conditions and may not be suitable for cold climates. In many locations, particularly in rural areas where they can grow in potable water supply sources, aquatic macrophytes are considered a nuissance weed and many environmental factors must be taken into consideration before their use.

2-3.3 Fish and Aquatic Animals

Several reports (Mara, (1976); Feachem et. al, (1977); and Pacey (1978) advocate the use of fish and higher aquatic vertebrates as an effective means of utilizing the plankton and bottom fauna often found in waste stabilization ponds. The presence of aquatic vertebrates can provide "polishing" as well as more biological balance to the aquatic system. The high protein content and short generation time of these forms of life also give rise to the production of exceptionally large quantities of high quality protein in relatively small volume of liquid - constituting a good source of food. The stocking of algae-eating and/or bottom feeding fish in maturation ponds, which normally contain a sufficient concentration of dissolved oxygen, as well as the short generation time of both bacteria and protozoa gives rise to an intense production of organisms high in protein content. Thus serving not only as a source of protein but offer good economic return to offset cost of treatment and utilization of the water

resources. Fish growth and survival can also provide an early warning signal of toxic discharge, and also help in eradicating mosquito, by selecting appropriate fish species which feed directlym or indirectly on mosquito - a serious malaris vector in the tropics.

2-3.3.1 Selection and Stocking of Fish

Fish species to be stocked are selected in relation to their ability to:

- Survive in the maturation pond environment;
- Feed on plankton and algae types available;
- Feed on bottom deposits and surface floating matter (such as mosquito larvae);
- Sensivity to ammonia, dissolved salts, heavy metals and other toxic substances;
- Temperature of the pond system;
- Cultural acceptance; and
- marked value as a form of economic return.

Some of the species commonly used include the following:

(a) Carp

The success of carp (Cyprinus Carpio) culture is largely due to the relative ease with which carp can be made to sprawn in captivity and hardiness at all life stages - from egg to adult (Krishnamoorth, et. al, (1975); Noble, (1975)). They can adapt themselves to low level of oxygen, rough handling and both acid and alkaline waters. Huet, (1972) observed that they have low food requirements and grow to a large size before reaching sexual maturity. Their eating habits are omnivorous, the natural food of young carp being zooplankton, and in later life bottom invertebrates. Other foods consumed by carps include algae, small fish,

earthworms and other terrestrial invertebrates and various kinds of detritus, particularly decaying plant matter.

(b) Tilapia

Tilapia can be divided into two well-defined groups, as "guarders" or "brooders" on the basis of their breeding methods. Although principally herbivoures they are occassionally omnivorous, being able to convert plant material into animal protein. Most of the "brooders" are microphagous which feed on fine particulate matter from the bottom deposits of a pond or upon phyloplankton in the overlying water. Huet, (1972) reported their ability to exploit the miccroscopic algae which naturally in the pond. Doubts about the ability of these fish to use blue-green algae, often the dominant phytoplankton in some wastewater treatment ponds, have been dispelled. Payne, (1975) noted that researchers were able to show that, S. NILOTICUS, can assimilate up to 70-75% of the carbon from 14C-labelled blue-green algae - there is no reason that other tilapias cannot do the same.

Most of the "guarders" by contrast, feed upon the leaves of herbaceous plants. T. mosambica eats filamentous algae, a principal habitat for many species of mosquito larvae, thus is often used as in combination with insectivorous species as an agent of malaria control (Balrin (1984)).

(c) Catfish

Catfish, Clarius, or mudfish as they are appropriately called have accessory breathing organs attached to their gills. They can live out of water for several hours or in damp muddy places for months (Huet), (1972) These fish are popular for cultivation because they grow rapidly and also because they give a high production, are sturdy and resistant.

Clarias Feeding habits are varied. They feed on weeds, plankton, decomposing organic matter, insect larvae, snails, crustacea, worms and small fish. As well as having teeth, Clarias have fine gill rakers with

which they are able to filter plankton from the water. The oily flesh of cat fish is greatly relished by most local people either in a fresh condition or after smoking, thus ensuring a reasonable price. However, in some parts of Sokoto State of Nigeria, where it is known locally as "Kullumi", it is not culturally accepted for some reasons probably having to do with the feelers and its dark colour (Faruk and Bala, (1984)).

Literature Survey indicates a wide range of stocking, usually expressed in number of fish per square metre of surface area. The stocking of ponds seeks to determine the optimum quantity of fish to be released in such a way as to obtain the highest quantitative and qualitative production under the most economic conditions.

Noble (1975), found that some fish farms in Europe have shown an optimal density of 0.2 to 0.4 fish/m2, but are being artificially fed to as much as 1.5 fish/m2 in sewage effluents. Kirishnamoothi et. al, (1975) used stok of 1.6 fish/m2, Noble (1975), reportedly stocked enclosures at 0.40 to 3.0 fish per square metre.

The limit to stocking of fish varies according to the species, and for each species according to the age and size of the individual fish as well as the nature of study being undertaken. Huet (1972), found that a fish stocking which is clearly toohigh, first of all leads to weakening the fish which are insufficiently fed. Secondly, the rate of loss is definitly higher among the weakened fish. Growth limitations also results from competition for minimum life space. In this respect the size of the pond can influence the maximum size of the fish, which can grow larger in larger ponds.

Investigations, by Krishnamoorthi et. al, (1975); Noble (1975), as well as routine bioassay test methods (APHA(1965)), indicate the use of

small fingerlings. This is usually to ensure uniformity of test animals with respect to age, size, nutrition as well as response and sensitivity to changes being rather pronounced in these small fish as compared to larger fish would have greater "buffering capacity" to adjust to changes in their environmental conditions.

2-3.3.2. Potential of Fish in Polishing Ponds

Fish can be used to reduce the vegetative standing crop and control mosquitoes. Duckweeds, water hyacinths which atime result in environmental hazards when they grow in ponds are very good sources of food for most fish.

Mosquito fish (Gumbusia affinis) and the guppy (Poccilia reticulata) have been found effective in limiting the number of mosquitoes by feeding on their larvae and pupae. This fish specie in addition to others could help control and prevent the pond system from developing into a mosquito breeding ground, which is often cited as one of the problems of stabilization ponds (Diamant, (1979). Balarin, (1984) reported the use of two tilapias and Pelmotochromis spp. a mallacrophagous fish for bilhazia control.

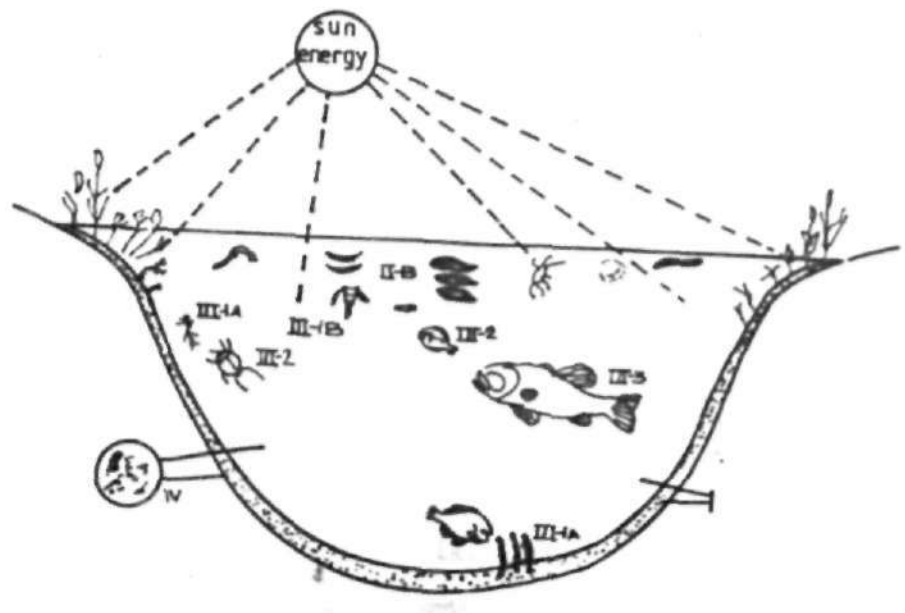
The presence of potentially toxic matter in wastewaters can be monitored by their action on fish as demonstrated by some form of bioassay. The prescribed (Tebbutt, (1977)) measure of acute toxicity is the Median Tolerance Limited (TLm), sometimes referred to as the 50% lethal dose (Lo50). However, the test is insensitive to those levels of effluent that may cause deleterious effects, if exposures are continued for a prolonged period cough frequency of fish is a sensitive, easily measurable physiological characteristic that may provide in formation about sublethal concentrations within the frame of an acute bioassay. In their study, Carlson and Drummond (1978) observed that lower levels of change in cough

increased at all concentrations of all effluents tested. In their investigation exposure to high lethal levels of chlorine increased the rate of the coughing reflex and lead to heavy mucus secretion. Fish cough response is also useful end point for determining whether or not an effluent is of consistent quality over time.

2-3.3.3 The Aquatic Food Chain

An aquatic eco system, such as normally exists in a waste stabilization pond or in a natural waterbody consists of four groups of components: abiotic substances; prodcers; consumers; and decomposers. The producers, and decomposers exist in a relationship called a food chain. A food chain is a sequence of pre-predator interactions in which a portion ofthe chemical energy initially in the protoplasm of the prey in the first interaction is passed on from the protoplasm of are organism to that of another.

Fig 2-1 Pond Ecosystem



Basic Units are:

1 - Abiotic Substances

11 - Producers: A-rooted vegetation, -B- phytoplankton.

111/1 - Primary consumers (herbivores): A - bottomforms; B-Zoo planktons

111/2 - Secondary consumers (carnivores).

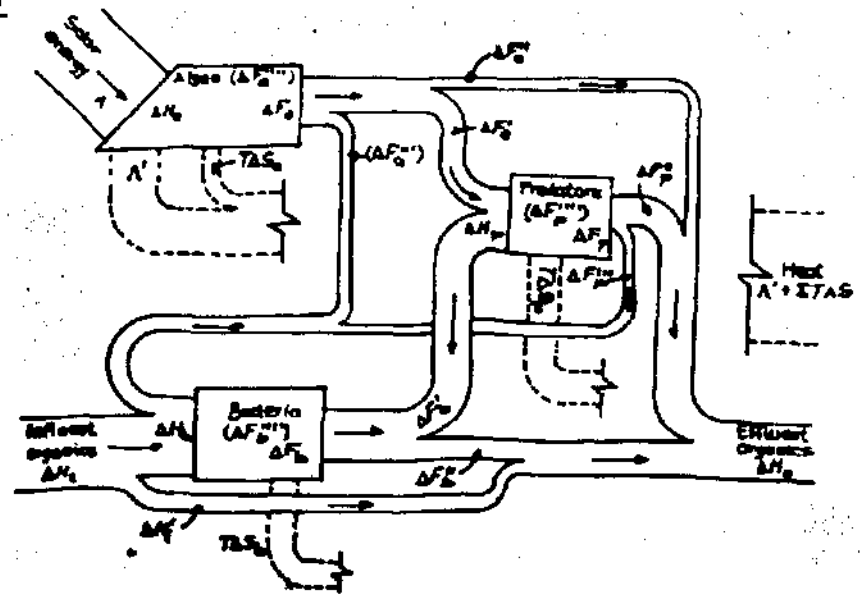
111/3 - Tertiary consumers (Secondary carnivores)

1v - Decomposers (bacteria and fungi of decay)

According to the conservation theory in thermodynamics, the flow of energy through each trophic level (or link in the food chain), (Rich, (1973), equals the sum of the free energy available for growth and maintenance at that level and the entropy lost through respiration.

For example, if a decomposer assimilates an initial energy, AH, (initial enthalpy change) a fraction TAS, (product of Temperature and Entropy change) is lost in respiration while the remainder AF, (free-energy change) is utilized in growth and becomes available for food energy AH2 (final enthalpy change) for the primary predators. A similar energy loss takes place at subsequent levels. Fig 2-2 shows the energy flow through a food web existing in a waste stabilization pond.

Fig. 2-2 Energy Flow Through The Biotic Components of a Stabilization Pond (Rich (1973))



The paths shown in figure 2-2 indicate the flow of energy through the system, the width of path represents the relative rate of energy flow. Most of the energy entering the pond as solar radiation is shown leaving the pond as heat or being incorporated in bacterial and algal cells. Primary and secondary consumers such as fish can be obtained if the pond resources of the food web and pond system are well harnessed and managed.

2-3.3.4 Productivity of Fish in Ponds.

The pinch between declining available agricultural land and the limit on wild fish stocks have caused some food experts to consider aquaculture as a possible source of protein (Balarin, (1984)). Fish is a superior and cheaper source of animal protein. If the favourable amino acid pattern is considered, human beings can utilize almost the entire raw fish. Fish, being cold blooded, take on the temperature of their environment, instead of expending calories to maintain a constant body ?temperature. They also live in an environment that supports them, thus being better feed converters than most land based animals.

Maturation pond effluents which are very rich in nutrients provide a source of intensive protein food production and could be adequately used to grow fish. It would be necessary for the ponds to be fenced, as is usually required, to keep the public and poachers out. No additional maintenance other than those usually required for maturation ponds would be needed as a result of stocking the ponds with fish.

Schroeder, (1975), carried out experiments on the use of wastewater effluents for fish culture, to replace part, or all, of the additional food requirements in commercial aquaculture ponds. In all cases the use of wastewater effluents resulted in large increases in the yield of fish per unit area of pond and sharp decreases in the weight of food which had to be

added to produce a kilogram of fish. Food replacement by wastewater nutrients produce major savings by reducing both costs to the farmer and consumption of valuable grains and fish meal. Phytoplankton and zoo plankton provide the fish with a diet twice as rich in protein as pelleted feeds, containing 25% protein, conventionally used in fish culture. Schroeder (1977), also noted that the high protein diet of wastewater effluents produced fish of low fat content.

Wide ranges productivity (usually expressed as Kg/ha/yr.) are reported in the laterature. Productivity is sensitive to such factors as: competition for food and space; food type and quality; temperature; and other kinds of fish and biota co-inhabiting the pond. In Europe, carp productivities from sewage-fed ponds ranged from 400 to 900 kg./ha/yr., while tilapia productivity was as high as 1000 kg./ha/yr. and even rose to between 2,500 to 3,000 kg/ha/yr., when supplementary food were provided (Feachem et. al, (1977). Payne, (1975) observed that over-stocking by farmers as well as uncontrolled sprawing are responsible for the low level of productivity (about 220 kg/ha/yr.) obtained in many parts of Africa. Increased yields have been observed from polyculture stocking of ponds with fish of different types and different food and environmental requirements. Payne, (1975) noted young carp stocked at 5,000/ha in experimental ponds in Egypt yielded 377 kg/ha., but when stocked with additional 1,250 tilapia/ha, the carp yield rose to 411 kg/ha and the tilapia yield was 300 kg/ha and the tilapia yield was 300 kg/ha. Polyculture productivities as high as 5,000 - 7,000 kg/ha/yr. have been achieved (Feachem et. al, (1977)).

2-3.3.5 Factors Affecting Fish Performance

Fish survival and productivity is sensitive to such factors as dissolved oxygen concentration, presence of toxic compounds, temperature,

presence of non-biodegradable substances which are concentrated in the food chain, substances which impart an undesirable odour and taste to the fish, competition for food and space, food type and quality, and presence of other fish types and biota co-inhabiting the pond.

The varying solubility of gases in water at different temperatures is well known. Temperature tolerances and oxygen requirements of a variety of fish and aquatic organisms have been extensively investigated (Tebbutt, (1977), Nebeker et. al, (1979)). Air supersaturated in water will increase 2.5% for every 1°c rise in temperature.

When the temperature of the wastewater system increases, the resultant temperature may have a deleterious effect on fish populations. A significant change in the $O_2 : N_2$ ratio in air supersaturated water will result in a change in the lethality of that water to fish (Nebeker et. al, (1979). Biological respiration or use of oxygen by algae, higher plants, bacteria and fishes may also cause a change in O2: N2 ratio.

Temperative gradients observed in facultative ponds can produce differences in water density which divide the pond into an upper region (epilimnion) which is warm and continously circulated by the wind, and a lower colder region (hypolimnion) which does not mix with the surface waters. Hypolimnetic anoxia during stratification reduces available habitat for fish, benthos, and all other aerobic animals. The minimum level of DO needed by fish is that required for survival, but much greater concentrations are needed for activity, growth, and reproduction. Minimum tolerance is species specific, dependent on life stage, and affected by interrelated chemical factors (as concentration of carbon dioxide and ammonia. Nevertheless, most species of warm water fish need at least 1.0 mg/l to 3.0 mg/l DO to survive (Huet, (1972); Tebbutt, (1977)). It is likely that destratification would benefit fish populations by increasing

available habitat for fish and other prey organisms - resulting in increased changes of fish growth and survival.

A food chain in the aquatic ecosystem is one of the most important transfer routes of trace heavy metals or radionuclides as well as other undesirable matter by aquatic organisms. Investigations by Patrick and Loutit (1978), have shown that metal levels in fish increased as metal levels in water, sediments and invertebrates increased. As turbificids are infested by many species of fish and other primary and secondary consumers; it seems logical to postulate that metals may be transferred to fish through the worm. Thus completing a food chain, starting with the heterotrophic, sediment-inhibiting bacteria.

The adsorbtion of organic compounds through the gills, skin and digestive track of fish can have an adverse effect upon the flavour of fish flesh. The off-flavour that occurs most frequently may render the fish unmarketable, is often described as "earthy", "musty", or "muddy", (Huet (1972), Feacham et. al. (1977)). At present, the only effective methods of dealing with this problem are to transfer the fish to clean water or wait until the flavour in the pond changes naturally. This is inconvenient and expensive to fish farmers, where the problem exists.

Fish and other microorganisms raised in wastewater have a high probability of becoming contaminated with bacteria, viruses, and toxic chemicals. Appropriate cautions need to be taken when the organisms are harvested and utilized for human and animal consumption. Middlebrooks et. al., (1974) mentioned the effect of the faecal matter excreted by the organisms. According to Diamant (1979), no particular health hazard has been noticed in consuming fish raised in dilute wastewater (i.e. maturation) ponds, because the fish have to be cooked or smoked before being consumed. European fish culture practice recommended (Feachem et. al

(1977) that sewage - grown fish to be sold for human consumption, be kept in clear water (ostensibly unpolluted) for two to four weeks, prior to marketing. The aesthetic problem associated with consuming sewage-grown fish still remains an important criticism of this fish culture technique. Some farmers growing fish in Southeast Asia, for example, are reported (Kilani, (1983)) to often sell them and buy other fish for their home consumption.

CHAPTER 3

WASTE STABILIZATION PONDS

3-1 Definition and Classification

A waste stabilization pond (or lagoon) is a relatively shallow basin contained in an earthen embankment, usually of controlled shape in which wastewater is retained and treated to produce a relatively stable effluent.

The terms waste stabilization ponds, lagoons and oxidation ponds are at times used interchangeably. Ponds are usually classified into classes denoted by some specific prefixes or terms attached to these general descriptive terminologies. Terms such as raw, primary, secondary, tertiary, polishing and maturation have been used to classify ponds according to the nature of the influent wastes or treatment objective. When classified according to the method of oxygen supply - terms like photosynthetic, atmospheric and mechanically aerated have been commonly used. Description of the hydraulic processes in ponds such as continous over flow, intermittent overflow, and non-overflow in classifying ponds have been used. Kilani, (1983) noted that the classification of ponds, despite several attempts by many authorities in the water pollution field, still lacks proper coordination or standardization. To complicate the situation further combinations of the above mentioned prefixes or terms are a times used.

Some of the terminologies used to classify waste stabilization ponds (Lewis, (1978) and Kilani, (1983)) are:

Raw Lagoons - Designed to receive and treat waste without pretreatment.

Polishing Pond - A tertiary pond designed primarily to polish the effluent by reducing settleable solids, faecal organisms, BOD5 and ammonia.

Maturation Pond - A "polishing" pond, where the main objective is the removal of faecal or pathogenic organisms.

Continous Over flow Pond - Refers to pond systems that continously discharges an effluent to a receiving water.

Intermittent Overflow Pond - A pond system that is designed to discharge effluent during specific periods.

Non-overflow Pond - A pond system that is designed for no discharge at all. It is usually designed on the basis of evaporation and seepage being sufficient to counter-balance inflow.

Photosynthetic Ponds - These ponds are designed to rely on photosynthetic oxygenation for a portion of the oxygen needed for waste treatment.

However, waste stabilization ponds can be classified broadly into four major types:-

- Anaerobic,
- Facultative,
- Aerobic, and
- Mechanically aerated ponds.

3-1.1 Anaerobic Ponds

An anaerobic pond is a deep pond in which essentially anaerobic conditions are maintained throughout the entire pond contents. Usually the bottom layers are predominantly anaerobic, the top thin layer is periodcally aerobic. The aerobic top layer is reputed to reduce odour development. Ideally its surface should be unexposed, but in practice it is usually left open.

Anaerobic ponds are commonly used for the treatment of high strength organic wastewaters such as dairy wastes or abattoir wastes. The solids in such wastes, on entering the pond settle to the bottom of the deep pond where they are anaerobically digested, while the partially clarified effluent is usually discharged to another treatment process for further treatment.

Odour problems particularly in heavily loaded anaerobic ponds, may occur. Odour, can however be controlled by reducing loading to a point where a thin aerobic layer develops at the surface. Marais (1970) reported drastic reduction in odour development on recycling from the first or second facultative pond to the influent of the anaerobic pond in the ratio 1:6.

The high efficiency of BOD removal in anaerobic ponds when included in a series of ponds, results in a considerable reduction in land requirements. This has led to the comment by Marais (1970) that,

"Anaerobic pretreatment of effluent is so advantageous that the first consideration in the design of a series of oxidation ponds should always include the possibility of anaerobic pretreatment".

3-1.2 Facultative Ponds

A facultative pond consists essentially of three zones, (Mara, (1976)):

- A surface aerobic zone (or epilimnion), where bacteria and algae exist in a symbiotic relationship.
- An anaerobic bottom zone (or hypolimnion) in which accumulated solids are actively decomposed by anaerobic bacteria.
- An intermediate zone (or mesolimnion) that is partly aerobic and partly anaerobic, in which the decomposition of organic waste is carried out by the facultative bacteria.

Facultative ponds are relatively shallow basins and are designed for long term detention of a wastewater which may or may not have received prior treatment. They are widely used for treating domestic wastewaters. Atimes pond installations that are designed to function as wholly aerobic or wholly anaerobic may actually function as facultative ponds.

3-1.3 Aerobic Ponds

These are treatment facilities that involve the presence of certain bacteria that can only survive in the presence of dissolved oxygen. The oxygen required by aerobic bacteria is provided essentially by photosynthetic activity of the algae, which grow naturally in the pond but often supplemented by surface reaeration. Thus the pond is usually shallow to allow sufficient light penetration for photosynthesis by algae and also to ensure sufficient oxygen distribution from the photosynthetic activity. To ensure aerobic conditions during the night, it must be ascertained that sufficient oxygen reserve is generated during the day by photosynthesis, as algae requires oxygen for metabolism during the night.

3-1.4 Mechanically Aerated Ponds

Such ponds do not rely solely on photosynthetic oxygenation; aeration is supplied by surface mechanical or bubble aerators. Sufficiently high energy input ensures all the settleable solids in the pond are kept in suspension. These ponds may contain algae unless, the detention period is so short and the aeration and mixing are sufficient to allow a high concentration of mixed-liquor suspended solids, inhibiting sunlight penetration and algal growth. If the oxygen transfer rate which is proportional to the difference between the actual and saturated oxygen concentration per unit energy input, may be relatively low, resulting in inefficient energy utilization. Although higher organic loadings can be

applied, in sufficient agitation may result in the formation of an anaerobically decomposing sludge layer at the bottom of the pond, if all the settleable solids cannot be held in suspension.

3-2 Mechanism of Waste Stabilization in Ponds

Low initial and running cost of waste stabilization ponds often results in their being thought of as being rather simple waste treatment systems. From a physical, chemical and biological stand point, however, ponds are complex treatment systems. In order to improve efficiency, obtain better process control and upgrade the performance of existing and new waste stabilization pond systems, an understanding of these complex interactions and treatment processes is essential.

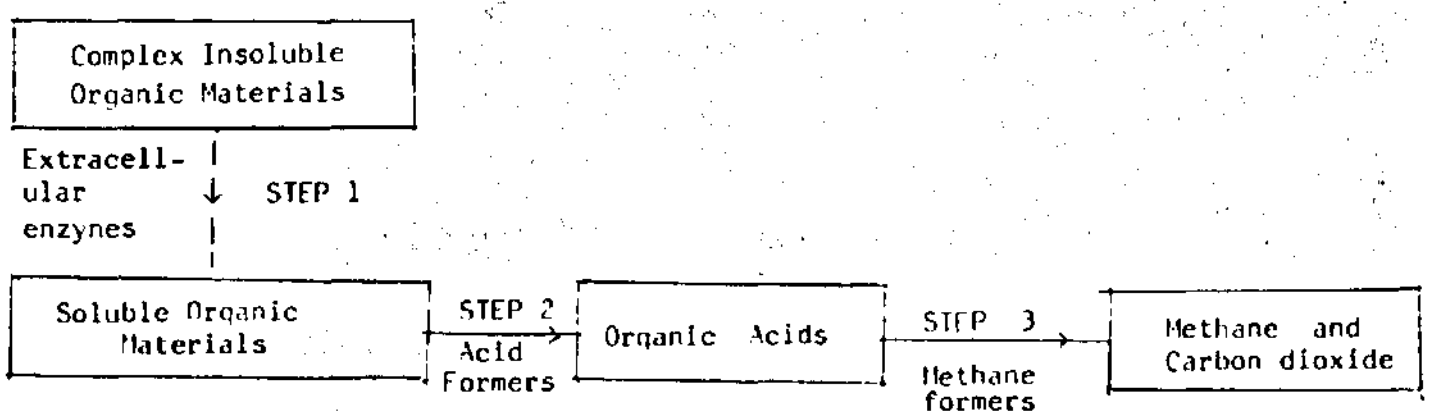
- Oxidation of organic material by aerobic bacteria,
- Nitrification of protein and other nitrogenous material by aerobic bacteria,
- Oxygenation of surface liquids by algae, and
- Reduction of organic material by anaerobic bacteria in bottom deposits and liquids.

In aerobic ponds, only the fist three reactions occur, while only the last reaction occurs in anaerobic ponds. In facultative ponds, being "aerobic - anaerobic" all the above reactions occur.

3-2.1 Anaerobic Treatment Process

In the anaerobic treatment mechanism, stabilization is brought about by a combination of precipitation and the anaerobic decomposition of organic matter to carbon dioxide, methane and other gaseous end procucts. Fig. 3-1 below illustrates the step-wise nature of the treatment process.

Fig. 3-1: The 3-Steps in the Anaerobic Decomposition of Organic Material



Complex insoluble organics, such as fat, proteins and carbohydrates are converted to soluble organics by extracellular enzymes and further to soluble organic acids by a group of bacteria known collectively as acid formers. If conditions are favourable, a second group of bacteria called methane formers convert the organic acids to methane and carbon dioxide. The acid-formers thrive over a rather broad range of environmental conditions, whereas the methane producers are quite sensitive to slight changes in environmental conditions and may not grow under circumstances readily adapted to by the acid formers. This makes the methane forming step to be the rate-determining step.

Kilani (1983) listed some of the environmental factors favouring methane production as:

- temperature control, within $\pm$ 1 - 2°C of operating temperature;
- adequate mixing;
- frequent and sufficient addition of feed solids and nutrients;
- anaerobic conditions;
- maintenance of pH 6.4 - 7.6;
- absence of toxic materials:-

(i) Alkaline and alkaline earth metals (i.e. Na^+, K^+, Ca^{2+}, Mg^{2+}) 1000mg/l

(ii) Free ammonia (NH_3): 150mg/l

(iii) Soluble sulphides (HS^-): 100mg/l

(iv) Heavy metals (Cu^{2+}, Zn^{2+}, Ni^{2+} and Cr^{7+}): 1mg/l

It should be noted that anaerobic metabolism is not as efficient and is also slower than aerobic metabolism in producing cellular protoplasm. The energy mechanism involved in anaerobic metabolism are such that more substrate must be utilized to synthesize a unit mass of cell material than is the case in aerobic metabolism. Complete stabilization of organic matter cannot be achieved anaerobically and it is normally necessary to treat the anaerobic effluent further by aerobic means (Tebutt, (1977)).

3-2.2 Aerobic Treatment Process

Aerobic treatment occurs in the presence of oxygen by certain bacteria that can only survive in the presence of dissolved oxygen. The oxygen, being provided essentially by photosynthetic activity of the algae which grow naturally in the pond, and some by surface reaeration. The pond bacterial utilize this "algal" oxygen and provide themselves with sufficient energy to enable them to synthesize the complex organic wastewater which are needed to build new cells as shown in the following equation:

$$\text{Wastes} + \text{Oxygen} \xrightarrow{\text{Bacteria}} \text{Oxidized Waste} + \text{New Bacteria} \quad \text{3-1.}$$

The ogranic waste materials exist in the form of carbohydrates, proteins, or lipids, with carbohydrates in form of monosaccharides, and

polysaccharrdes constituting the bulk of the organic matter of most biodegradable wastes. The bacterial metabolism is believed to consist of two parts (Mara (1976)):

- Catabolism ("breaking down") for energy and
- Anabolism ("building up") for synthesis.

There is also autolysis which is an important form of catabolism. The following three equations describe these processes seperately:

(a) Catabolism:
$$C_xH_yO_zNS + O_2 \xrightarrow{\text{bacteria}} CO_2 + H_2O + NH_3 + \text{Energy} \quad - \quad 3\text{-}2(a)$$

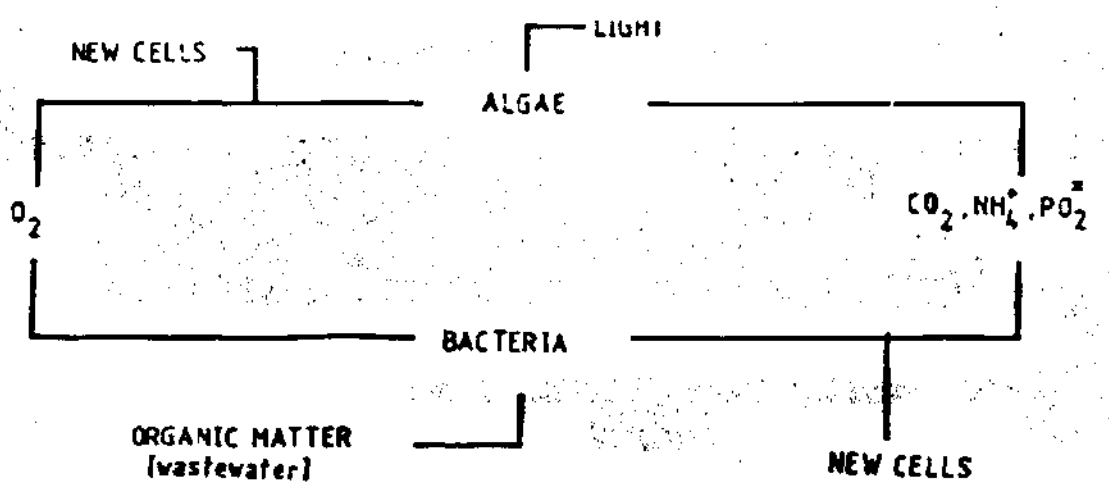
(b) Anabolism:
$$C_xH_yO_zN + \text{Energy} \xrightarrow{\text{bacteria}} C_5H_7NO_2 \text{ (Protoplasm)} \qquad 3\text{-}2(b)$$

(c) Autolysis:
$$C_5H_7NO_2 + 5O_2 \xrightarrow{\text{bacteria}} 5CO_2 + NH_3 + 2H_2O + \text{Energy} \qquad 3\text{-}2(c)$$

About one-third of organic matter is used for catabolic reaction and two-thirds in anabolic reactions. The equation, (3-2(c)), for untolysis does not proceed to completion, since approximately 20-25% of the cell mass is resistant to aerobic degradation.

One of the major end-products of bacterial metabolism is carbon dioxide, which is readily utilized by the algae during photosynthesis. There is thus a "Symbiotic" association of mutual benefit between the algae and bacteria in the pond system, which appears to determine the success of the aerobic treatment mechanism.

Fig 3-2. Symbiosis of Algae and Bacteria in Stabilization



3-3 Factors Influencing Treatment in Ponds

Treatment in waste stabilization pond system relies totally on natural phenomena to stabilize the organic matter in wastes. A thorough knowledge of biological, chemical, natural, and physical factors influencing the natural treatment processs is essential.

3-3.1 Biological Factors

The types and number of microorganisms present in ponds have a significant influence on their performance, since the process of waste stabilization in ponds is by microorganism metabolism.

A wide variety of microorganisms are to be found in the pond-aquatic environment, these include bacteria, algae, protozoa, rotifers, microscopic crusteceans and some higher organisms. Although microorganisms differ widely in many respects, the basic chemical composition of their protoplasm (often refeered to as biomass) is quite uniform.

Of particular importance in waste stabilization pond systems is the photosynthesis that takes place in unicellular plants called algae. The growth and death of such organisms exerts a profound influence on the limited oxygen resources of the pond ecosystem.

Gloyna (1976), mentioned Chlamydomonas, Chlorella, as the most commonly identified green algae, found in ponds. Euglena, a motile algae, is often present in ponds during all seasons, as a result of its high degree of adaptability to most climatic conditions. Blue-green algae common to waste stabilization ponds are Oscillatoria Phormidium, Anacystic, Anabena. Blue-green algae have the ability to form large dense mats on the surface of the water and as a result lower the aesthetic value of the water as well as imparting undesirable taste and odours in water. An important attribute is their ability to use nitrogen in the atmosphere in the absence of adequate amounts of ammonia, nitrate and nitrites in water.

3-3.2. Chemical Factors

The main chemical factors affecting pond performance are: dissolved oxygen, nutrients, pH and toxicity.

(a) Disssolved Oxygen: The presence of dissolved oxygen is essential to maintain the higher forms of biological life in aerobic waste stabilization ponds. Dissolved oxygen concentrations in wastewater discharges also affect the oxygen balance of receiving water bodies. Oxygen is only slightly soluble in water and its solubility depends much on such factors as temperature oxygen partial-pressure in the atmosphere, and strength of the waste, (Tebbutt,(1977), Nebeker et. al, (1979)).

(b) Nutrients - Organic carbon, nitrogen and phosphorus are considered the three most important macronutrients in wastewater required for bacterial growth and metabolism. Other ions of importance in nutrition, but in minute quantities, include magnesium, potassium, calcium, iron, manganese, copper, zinc and cobalt, sometimes referred to as micronutrients. The usual required BOD: Nitrogen and BOD: carbon ratios respectively, are about 100:1 and 20:1 (Gloyna (1976); Mara, (1976); Mara, (1976). Phosphorus has often been observed to be the growth limiting nutrient in aquatic systems, because the ratio of phosphorus to other nutrients in cell material usually exceeds that found in land and water masses of the earth. Phosphorus being a basic constituent of household detergent, is however never lacking in municipal and domestic wastes.

(c) pH- Biochemical reactions in waste stabilization ponds are often influenced by the pH, the optimum range for most biological activities being between pH 6.0 to 9.0 at 25°c. Most bacteria are sensitive to preferring more or less neutral conditions, although, certain species like the sulphur bacteria, for example, can exist in a highly acidic environment. pH has a considerable effect on toxicity as demonstrated

by the behaviour of ammoniun compounds which are relatively innocuous at low pH values. Under alkaline conditions, however, ammonia can be quite harmful to fish. A rise in pH from 7. 4 to 8.0 can halve the toxic concentration of ammonia (Tebbutt, (1978)).

(d) Toxicity - Though minute concentrations of elements are essential for growth of organisms, the presence of some cations including: Cn^{2+}, Pb^{2+}, Ag^{3+}, above certain concentrations can be detrimental to the wastewater treatment system. Their varying degrees of toxicity to microorganism as well as their concentration must be taken into consideration when present in stabilization ponds. Usually depending on the concentration, toxicity may interfere greatly with the enzymatic system of ponds, in terms of reducing metabolic rate. Certain algae, such as blue-green algae may produce substances that may be toxic to aquatic microorganisms and higher animals. Toxicity of blue-green algae (Lewis (1978)),is often being associated to several odourous sulphur compounds including methyl mercaptan, and n-butyl mercaptan.

3-3.3 Natural Factors

These are natural factors which cannot easily be controlled by man, though they may be predicted from previous meteorological data in the particular area required. Some of the natural factors having considerable influence on the operation and performance of waste stabilization ponds include: evaporation, rainfall, sunlight, temperature and wind action.

(a) Evaporation - Evaporation and percolation in ponds with pervious bottoms, provide information about the expected reduction of the incoming flow. Evaporation increases the detention time due to reduction in outflow and reduction in the water depth thus allowing growth of weeds on the embankment slope. The reduction in depth may, however, enhance photosynthetic activity due to increased sunlight penetration.

Intense and severe percolation and evaporation, if not balanced by rainfall, will produce high solids concentration, increased salinity and thus disturb the osmotic balance of the cells of the microorganism in ponds.

(b) *Rainfall* - Similar to evaporation, rainfall has a significant effect on the designed retention time. Rainfall reduces the retention time and causes dilution and reduction in food supply by causing an increased effluent outflow and reduction in temperature of the surface water of ponds, particularly on a hot day, may lead to a layer inversion with anaerobic sludge which normally settle at the bottom, found floating on the surface and at times finds its way to the effluent.

(c) Sunlight - Sunlight is of utmost importance in aerobic and facultative pond systems as sunlight energy is required by algae during photosynthesis.

The greater the degree of light penetration in waste stabilization ponds the greater the utilization efficiency. The energy requirement for photosynthesis can be derived from light having a wavelength of 4,000 to 7,000 A. Light penetration in an algal suspension can be approximated by the Beer-Lambert law (Rich,(1973)):

$$I = Io \exp.\ (-[\$ + E\ Na]d) \qquad -3-1$$

where I- light intensity at given depth, d, ($erg./cm^2.s$)

$\$$,E- light absorption coefficients of water alone, and algal suspension respectively, (./cm) and (cm^2/erg).

Na-Concentration of algal suspension (erg/cm^3).

d-depth below surface (cm).

The efficiency with which algae utilize solar radiation in the environment is approximately 6% (Mara, (1976)). That portion of solar radition that is not utilized in the formation of algal cells is converted to heat.

Hess, (1981) showed that after a certain intensity, the increase in photosynthesis becomes less and less proportional, until it reaches a kind of saturation.

(d) Temperature - Temperature may be considered a "catalyst" in most biologial treatment processes, because of its effect on the rate of chemical reactions, reduction in solubility of gases and amplification of taste and odour.

Rich, (1973), found that reaction rates are increased significantly by increases in temperature. The influence of temperature on the reaction rate constant is generally predicted using the following equation:

$$K = Ko\ \theta^{(T-To)} \qquad - 3 - 2$$

where θ - Arrhenins constant

K - rate constant at temperature T

Ko - rate constant at temperature To

In order to ensure stabilization ponds function satisfactorily at all times, it is often designed for the coldest (i.e. worst) condition. This ensures a factor-of-safety whenever higher temperatures prevail.

Temperature may impair the efficiency of facultative ponds as a result of thermal stratification and creation of a thin mesolimnion, "thermocline". This reduces oxygen transfer through the pond system as well as likely result of short-circuiting (Mara, (1976)).

Hess (1981), observed that above 35°C the photosynthesis rate decline rapidly, so as to be practically negligible at 45°C. Hess, (1981), also mentioned the effect of high temperatures in stimulating blue-green algae (cyanophyceae) to grow more intensively and thus replace the more efficient green algae (chlorophyceae) in pond systems. At the same time aerobic bacteria consume a larger amount of oxygen at high temperature thus

resulting in a condition which is likely to produce anaerobic patches at different parts of the pond.

(e) Wind - Wind mixing, particularly in non-mechanically aerated ponds is useful in helping to minimize hydraulic short-circulating and formation of stagnant regions, such as thermal stratification mixing aids transportation of oxygen as well as non-motile algae through the pond. The depth to which wind-induced mixing is felt is largely determined by the distance the wind is in contact with the water (the "fetch"). In order to maximize this effect, ponds should be aligned in such a way that the prevailing wind blows along the whole length, where possible. If the site where the ponds are is subjected to strong winds, waves may result, with occasional erosion of the embankment slopes. Hess (1981), recommended that slope lining or some other protection may be required at the water level in such cases.

3-3.4 Physical Factors

The physical factors affecting pond performance are those which determine the geometry and layout of the stabilization pond system. These parameters include, depth, shape, size and number of ponds and hydraulic flow characteristics.

Depth is a most significant factor as it influences the biological activity of the pond. Whether a given pond will function as an anaerobic or facultative pond depends to a large extent on the depth of the pond. Depths of ponds are usually constant, though intense seeping and evaporation, or some emergency withdrawal, may affect the water level to some extent. Pond depths as low as 0.6m are likely to result in growth of weeds and consequetly mosquito breeding. On the other hand, ponds deeper than 2.0m will have limited penetration of light thus resulting in the pond

being largely anaerobic.

The rectangular shape of ponds have been found to be superior to those of square, circular or irregular geometries. The general belief being that rectangular ponds are more effective in reducing short-circuiting in ponds. Flow patterns in stabilization ponds systems, as affected by shape, presence of dead space, the location and type of inlet and outlets, and the use of baffles have been found to play a significant role in pond efficiency and performance (Mangelson and Watter, (1972); Ferrara and Harleman, (1981)).

The number and layout of ponds have been found to play a significant role in the level of treatment as well as in facilitating pond maintenance in the case of parallel pond systems.

3-4 Useage, Advantages and Disadvantages of Stabilization Ponds

3-4.1 Extent of Pond Useage

Waste stabilization ponds have been recognized for sometime as presenting the sanitary engineer with an alternative method of wastewater treatment, particularly in warm climates. They exhibit some advantages that gives them preference: particularly in developing countries over conventional processes. The stabilization pond system has been found suitable not only in hot climates, but at all latitudes and by both developing and developed countries, for rural and urban wastewater treatment.

Literature has shown use of stabilization pond systems in India, Israel, Australia, West, South, and Central America as well as Britain, (Kilani, (1983)). In most parts of Africa, stabilization ponds have not found wide application, due to lack of policy on wastewater treatment, reuse and effluent quality. However, maturation ponds are generally used throughout South Africa (Marais, (1970)). In the mid-twenties, U.S. cities in California, Texas, and North Dakota were using lagoons as a means of treating municipal sewage, through it was not until several years later that design guideline were developed. Dague (1974), mentioned installations at Maddock, North Dakota, built in 1948, as being the first formally designed lagoon in the United States. The use of stabilization ponds has since spread to many parts of the U.S.A., rising steadily from 45 lagoons in 1945 to over 4,476 in 1971. Dague, (1974), reported that in 1968 lagoons accounted for 34.7% of 9,951 secondary treatment systems. In the state of North Dakota, all treatment of sewage, with the exception of one community is performed in lagoons, (Lewis (1978)).

Although waste stabilization ponds have gained popularity in the treatment of wastewater, continued research still need to be done to improve stabilization pond performance to meet emerging stringent effluent standards.

3-4.2 Advantages and Disadvantages of Stabilization Ponds

Mara (1976), reviewed some advantages of waste stabilization pond systems as including:

(a) Use in achieving any required degree of wastewater purification at the lowest cost and with minimum "skilled" labour. It is the least expensive wastewater treatment system, in terms of capital and running costs, where land is readily available at low cost.

(b) It can treat effectively, a wide variety of industrial and agricultural wastewaters, and can withstand both organic and hydraulic shock loads.

(c) It is considered more efficient in the removal of pathogenic microorganisms than any other biological treatment process.

(d) It is very flexible in operation, and can be easily upgraded to cater for increased loading. Even when the need arises for its relocation, due to urban expansion or alternative land priority requirements, the land can be resold at a much higher price.

(e) It permits the production of protein in the form of algae, in high-rate algal ponds, which enhances fish farming and duck farming as well as effluent re-use for crop irrigation/farming.

The major disadvantages of waste stabilization ponds include:

(a) They require much larger land area than other conventional forms of sewage treatment. The idea of "low capital costs" becomes a mirth where land is expensive.

(b) The effect of climate on the performance of ponds have resulted in seasonal failures in ponds in various temperate regions.

(c) The algae and high concentration of suspended solids may impair the quality of water in receiving streams. Algae die-off and exerting of BOD on receiving streams, green-algae colouration, as well as toxicity in the case of blue-green algae are some of the detrimental effects of pond effluent on receiving streams.

Mara (1976), noted that due to minimum maintenance requirements and its ability to perform satisfactorily, even with some degree of neglect, the common tendency is to neglect its maintenance completely. This may give rise to serious problems of odour nuissance, fly and mosquito breeding as well as undesired vegetation growth.

CHAPTER 4

EXPERIMENTAL INVESTIGATIONS

The experimental investigation consisted of two parts:

- Use of experimental pilot ponds, and
- Use of maturation pond MB-2 of the ABU waste stabilization pond system.

This chapter contains a description of the Ahmadu Bello University (A.B.U.) waste stabilization pond system, the experimental pilot ponds, and sampling procedures and method of analysis.

At the start-up of the experiments no serious operational problems were encountered, but a few minor problems which resulted as the investigation proceeded are fully discussed.

4-4.1 The Waste Stabilization Pond System at ABU

This research work was carried out at the Ahmadu Bello University, Zaria. The stabilization pond sytem is situated at the south-eastern end of the main campus, just downstream of the water reservoir dam, across the Kubani River. The stabilization pond system serves a population of about 12,000 to 15,000; wastewater contributions being from the students hall of residence and the main campus facilities. Wide fluctuations in flow were common. During summer vacations, August to October, and "Christmas breaks", the wastewater flow is always very small when compared to the peak flow occuring when the school is in session. Significant dilution is also commonly observed during the rainy season. Onuoha (1978), estimated a per capita contribution of about 140 l/p.d. which gave a flow of upto $2{,}100 m^3/d$.

The pond system consists of two facultative ponds (FA and FB) and four maturation ponds (MA-1, MA-2, MB-1 and MB-2). The ponds are constructed

and laid out in such a way that they could be operated either as two parallel streams of three units each or all the six ponds in series. A plan of the general layout of the stabilization pond system is shown in Fig. 4-1 and pond capacities and geometry are given in table 4-1 (Onuoha, (1978)).

Table 4-1 Capacity of Ponds at the Ahmadu Bello University Waste Stabilization Pond System

UNIT	LIQUID DEPTH (m)	MID-DEPTH AREA (m2)	VOLUME (m3)	LENGTH:BREADTH RATIO
FA	1.372	10,500	14,400	3:1
FB	1.372	10,500	14,400	3:1
MA-1	0.915	2,000	1,800	2:1
MA-2	0.915	1,900	1,700	2:1
MB-1	0.915	1,900	1,700	3:2
MB-2	0.915	1,800	1,700	3:2

The maturation pond, MB-2 (see plate 4-1) was used in studying fish growth pattern, over a seven months period.

4-1.2 Description of Experimental Pilot Ponds.

Two experimental pilot ponds (A and B) were constructed near maturation pond MB-2 and the effluent outflow channel of the ABU, waste stabilization pond system. The ponds were rectangular, 2m x 4m of the top, and involved escavating to a depth of about 1.25m, with side slopes of about 1:2 (Horizontal: Vertical). A general plan of the experimental pilot ponds are shown in Fig 4-2, and Fig 4-3.

Some of the flow from the two maturation ponds MA-2 and MB-2 through the outflow channel was diverted into the experimental ponds. This

involved the construction of a temporary weir in the 30cm wide effluent channel, and placing a 5cm dia galvanized iron pipe before the overflow weir arrangement. The diversion pipe had an elbow pointed in to the incoming flow, and was submerged 2.5cm below the top of the overflow crest, thus ensuring that any flow over the crested weir implied the diversion pipe was flowing full. A wiremesh was provided at the inlet to the diversion pipe to prevent or minimize flow of floating matter from entering into the experimental ponds. The diversion pipe led to a Tee Junction from where the flow was split equally into each pilot pond in 5cm dia. galvanized inlet pipes, with elbow connections to allow the flows to be delivered into the ponds at a depth of about 0.75m above the pond bottom. Valves were provided to each in let pipe, after the Tee connection to regulate inflow to the experimental ponds.

A liquid depth of about 1.0m was maintained by providing 20cm outflow weirs at this depth through which the effluents discharge into an earth channel that lead to the downstream of the effluent channel of the ABU Pond System. Wire mesh were provided at the weirs to prevent fish from jumping out and being "discharged" with flow. Plates 4-2 and 4-3 show the pilot ponds during operation.

4-2 METHOD OF OPERATION

On the 8th of May, 1985, 404 Fingerlings, consisting essentially of Orechromis niloticus (formerly referred to as Tilapia niloticus) and about 20 Hemichromis fasciatus, were bought from Maska Fish Farm, Funta, in Kaduna State of Nigeria.

The fish fingerlings were stocked into the maturation pond, MB-2 (seeplate 4-1). Throughout this investigation the stabilization pond system

FIG. 4-1 LAYOUT OF WASTE STABILIZATION POND SYSTEM AT ABU, ZARIA.

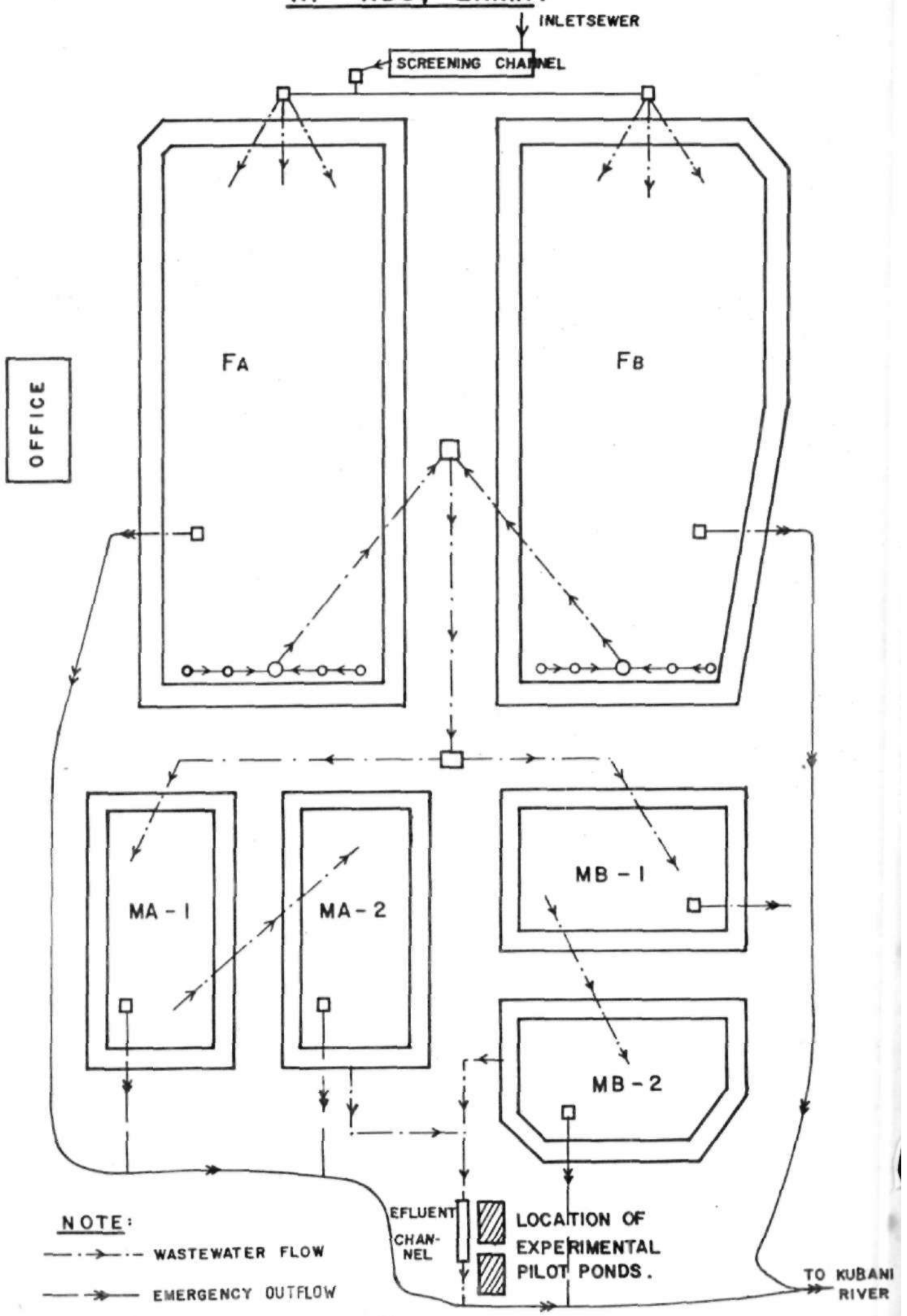


FIG. 4 - 2 LAYOUT OF EXPERIMENTAL PILOT PONDS

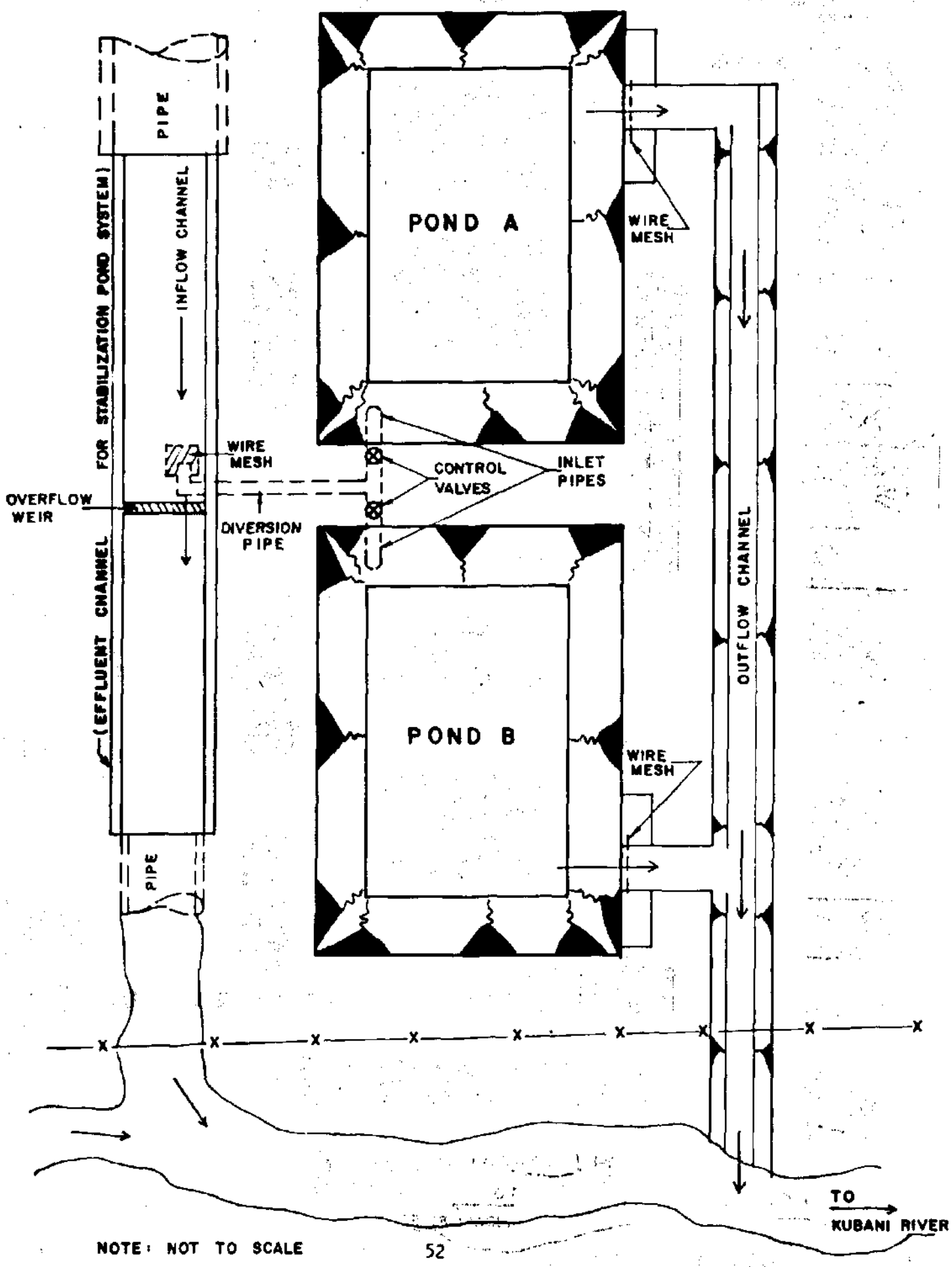
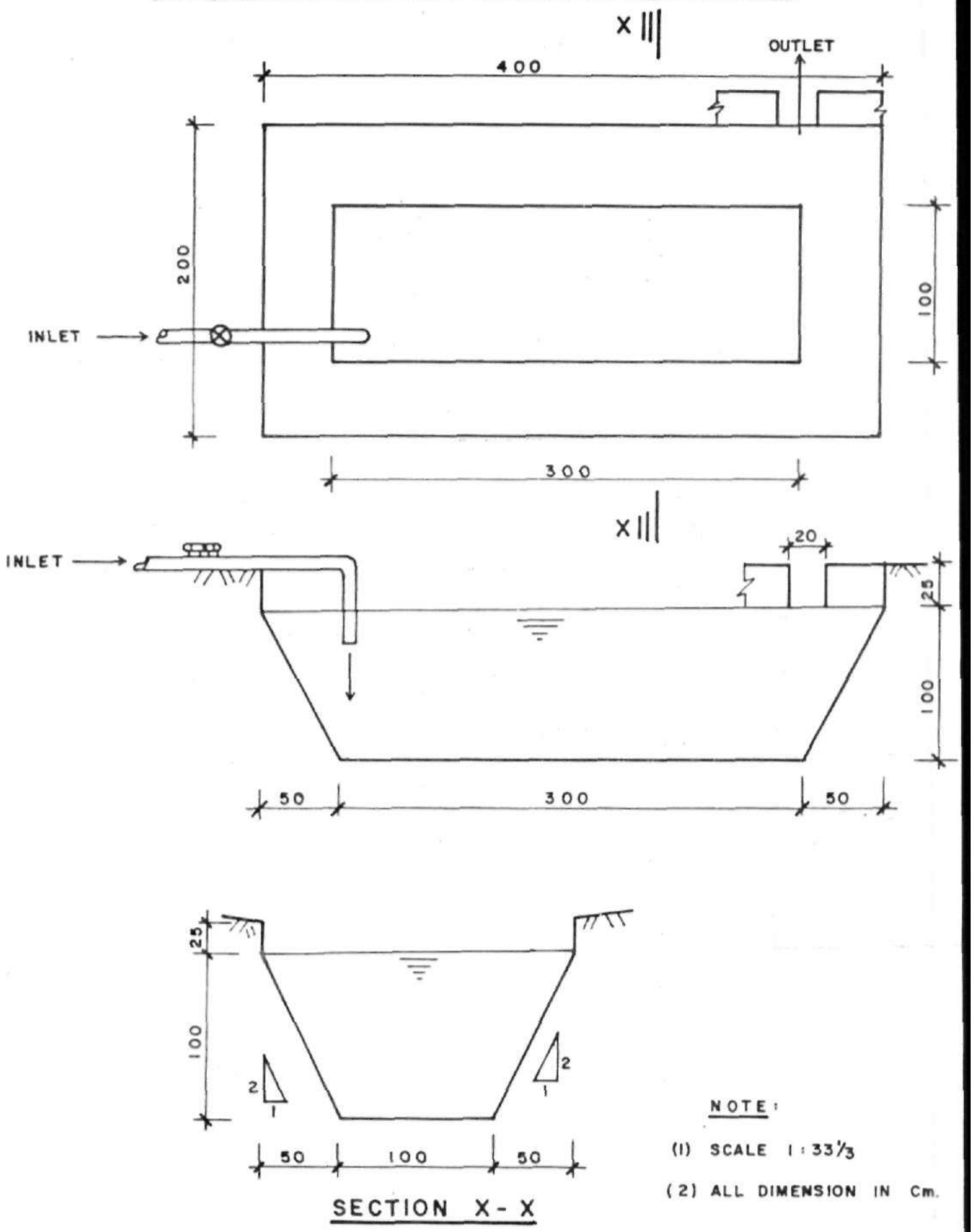


FIG. 4 - 3 EXPERIMENTAL PILOT POND



SECTION X - X

NOTE:

(1) SCALE 1 : 33⅓

(2) ALL DIMENSION IN Cm.

L = 400 L' = 300 W = 200 W'= 100

A = 80 000 A' = 30000

VOLUME = 5 . 5 m^3

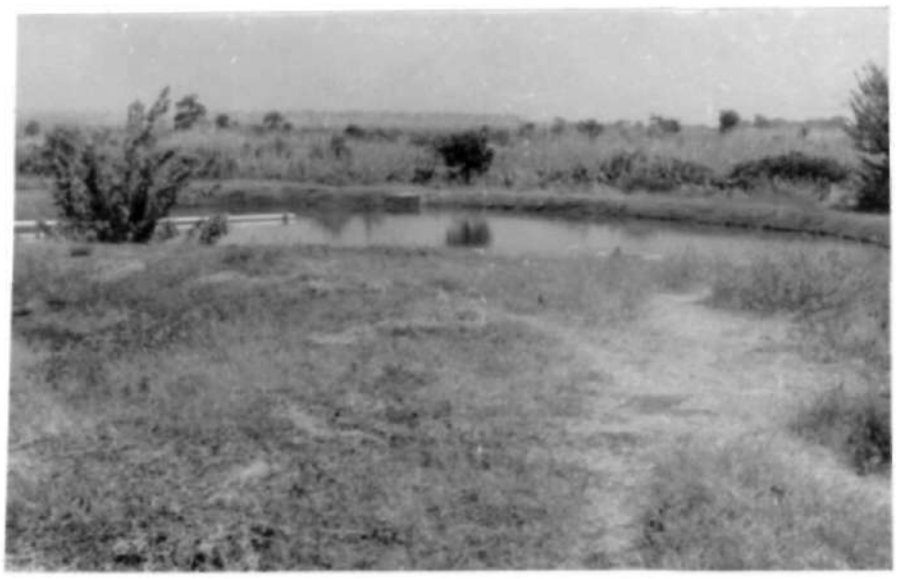


PLATE 4-1: MATURATION POND MB-2, AT A.B.U., ZARIA



PLATE 4.2: EXPERIMENTAL PILOT PONDS (INFLOW CHANNEL AT L.H.S.)



PLATE 4.3: EXPERIMENTAL PILOT PONDS (OUTFLOW CHANNEL AT L.H.S.)

was operated in two parallel streams:

FA - MA-1 - MA-2 - OUT

FB - MB-1 - MB-2 - OUT

After the construction of the two experimental pilot ponds, in August 1985, the ponds were run continously until a resonable degree of sealing and steady state was obtained. During this period, a measuring cylinder and stop-watch were used to calibrate the flow rates into and out of the ponds. In order to obtain a 5-day detention time, at flow rates of 1.05×10^3 litres/day were maintained for the two experimental pilot ponds. Though the two experimental pilot ponds were constructed side by side (see plate 4-2 and 4-3) influent flow rates of 1.60×10^3 litres/day and 1.73×10^3 litres/day for pond A and pond B respectively had to be used. This could be attributed to the difference in percolation rates in the two experimental pilot ponds, pond A being essentially of a clay base, and pond B a sandy-clay base and thus higher percolation.

Studies in the experimental pilot ponds were conducted in November and December 1985, in two runs (I and II). During these runs Orechromis niloticus fingerlings were stocked in the ponds as follows:-

Run I: Pond A - 40 fingerlings or 5.0 fish/m^2

Pond B - 20 fingerlings or 2.5 fish/m^2

Run II: Pond A - 10 fingerlings or 1.25 fish/m^2

Pond B - 0 (No fish stocked)

Fingerling sizes ranged from about 5.4 cm to 10 cm, in total length with a mean value of about 7.7 cm. Their ages being about 6 weeks to 11 weeks, at the commencement of each run. They were amongst the offsprings of the 404 fishes initially stocked in the maturation pond MB-2 May.

4-3 Experimental Runs

4-3.1 Pilot Ponds Study

The experimental pilot ponds were run for a period of about 8 weeks after construction before they were stocked with fish. This enabled sufficient time for self-sealing of the ponds as well as allowed a near steady state conditions to be achieved. The pilot pond tests were conducted in two runs, each lasting a period of about three weeks. This length of time enabled sufficient data to be collected at each run. Before the second run was conducted the ponds were emptied and the old fish used in the first run were removed and replaced with new stock from the maturation pond, MB-2.

4-3.2 Fish Growth Study

The study on the fish growth was conducted over a period of six months, being sufficient time for this specie of fish, Orechromis niloticus to grow to maturity. About October, after period of five months some of the fish had attained maturity and had started reproducing.

At the commencement of the fish growth studies in May, 1985, as many as 100 of the 404 fish fingerlings bought, at Maska fish farm, died within 24 hours of being placed in the maturation pond, MB-2, though there were no observed deaths during transportation. At the commencement of the experimental pilot pond studies in November, 2 fingerlings in pond A and one fingerling in pond B, were observed to have died within 24 hours of being placed in the ponds. No fish deaths were reported during run II. The likely causes of death could be:-

- overcrowding of about 400 fingerlings in two large, 1m^3, containers. Insufficient surface area of contact for recreation resulted in the

fingerlings having to breath directly into the air, which their respiratory systems were not yet adjusted to.

- though ice blocks were being added in order to maintain a relatively constant temperature the 1 hour trip from Maska to Zaria, Kaduna State, could probably have exhausted the fingerlings.
- change in environmental conditions in pond, MB-2, as different from their Maska fish farm habitat, such as algae concentration and species, presence of other aquatic organisms as well as temperature could have contributed significantly.

There was also the problem of no inflow into maturation pond, MB-2, as the faculative pond FB, (see Fig. 4-1) in which MB-2 was in series with, was "blocked". Pond FB had to be emptied in order to gain access to the submerged influent pipes and thus remove the blockage. As a result of no inflow a few days after the emptying of pond FB, which did not start refilling until November 1985 as well as the increase in population due to the new offsprings, the growth of the initial fish population stocked could have been significantly reduced during this period and after.

4-4 Sampling Procedure and Method of Analysis

Throughout the two experimental pilot pond runs, the influent feeds and the effluents from both pilot ponds were analysed, on alternate days, for Dissolved Oxygen, pH, alkalinity, total solids, suspended solids, chlorophyll-a, BODs and COD. Sampling of the influent and the effluent was done at about the same time, (10:000 hrs.) on every day of analysis, throughout the investigation. 24-hr. monitoring of the wastewater influent and effluent were conducted at 4-hour intervals, and parameters measured were: dissolved oxygen, pH and alkalinity.

The weight, of about 20 to 50, of the initial fish population stocked in maturation pond, MB-2, were taken monthly (except during the months of July and August) during the study period (from May to November, 1985). After each weighing the fishes were returned to the pond. After a growing period of 6 months, some bacteriological tests were carried out on some of the fish to ascertain the suitability of the fish for human consumption. Attempts were also made to identify the various algal species present in the maturation pond, MB-2, during the entire period of this study.

4-4.1 Dissolved Oxygen (DO)

Dissolved oxygen measurements were taken using a DO (Y.S.I 5700 series probe) electrode and a Y.S.I. model 57 oxygen meter. The meter was always calibrated using air saturated water in a closed bottle. A magnetic stirrer, incorporated with the probe, was used for gentle stirring of the sample each time DO measurements were taken.

4-4.2 pH

pH measurements were taken, making use of a glass electrode and a Pye Unicam (Model 292, MK2) pH meter. The electrode was washed with distilled water, initially before use and between samples. pH 7.0 buffer solution on the 6-14 pH scale, and were used for all initial calibrations of the pH meter.

4-4.3 Alkalinity

The analysis of the influent and effluent samples for total alkalinity was carried out by titrating 50ml. of sample against 0.02N sulphuric acid. 3 drops of methyl orange indicator, corresponding to an end point of pH 4.50, was used for each titration. The total alkalinity was computed using: Alkalinity as = $\frac{\text{ml (of 0.02N) acid to end point} \times 1000}{\text{ml of sample used.}}$ 4-1

mg/l Ca CO3

4-4.4 Total Solids

50ml. of sample was poured in a preweighed crucible completely evaporated on a water bath, and dried at 105°c for 1 hour. After which it was cooled in a dessicator and weighed again. The Total Solids in 50ml. of sample was obtained from the difference in weight of the crucible with dried sample matter and the crucible only, and the results were converted to mg/l. of sample.

4-4.5 Suspended Solids

Whatman No. 1 filter papers were used to filter out the suspended solids from 50ml of sample which was then poured into a preweighed crucible completely evaporated on a water bath, and dried at 105°c for 1 hour. The crucible is then cooled in a dessicator and weighed again. The soluble solids in 50ml of sample was obtained from the difference between the final and initial weights of the crucible. The results were then converted to mg/l of sample.

The suspended solids in the sample, expressed in mg/l was obtained as the difference between the total solids (obtained as described above 4-4.4) and the soluble solids, expressed in mg/l of sample.

4-4.6 Chlorophyll-a

According to Standard Methods (APHA (1965) the following reagents were prepared:

(i) 1gm. of finely divided magnesium carbonate powder was suspended in 100ml of distilled water.

(ii) 90% aqueous acetone solution was made from 90 parts acetone with 10 parts distilled water, by volume.

The procedure for pigment extraction was as follows:-

1. 30ml of sample was concentrated bycentrifuging, in a Gallenkamp Junior centrifuge, at 2500 r.p.m. for 10 minutes with 0.2ml of magnesium carbonate suspension being added to the samples before centrifuging.
2. The clear supernatant was then poured off and the centrifugate transferred to a tissue grinder using 3ml aqueous acetone solution. The sample was then macerated.
3. After the sample had been well macerated, it was transferred to a calibrated screw-cap tube and the volume was brought up to 5ml with aqueous acetone solution, and stored in a refrigerator in the dark for 18 hours at 4°c.
4. After 18 hours, the extract was clarified by centrifuging in the closed tube for 20 minutes at 1500 r.p.m. and after centrifugation the classified extract (the supernatant) was decanted into another clean calibrated screw-cap tube and the total volume of extract measured.
5. The clear extract was then transferred to a standard Bauch and Lomb test tube and the optical density determined at 663nm, 645nm, and 630nm using a Bauch and Lomb spectronic 20 spectrophotometer. As wavelength determinations were above 595nm (the red portion of the wavelength scale) an accessory red filter and red sensitive photo tube were used.

The concentration of chlorophyll-a in the extract was calculated from the equation:

$$Ca = 11.64(D\ 663)-2.16(D645)+0.10(D630) \qquad - 4\text{-}2$$

where D663, D645 and D630 are the absorbance at 663nm, 645nm, and 630nm respectively.

$$\text{Chlorophyll a } (\text{mg/m}^3) = \frac{\text{CaX Volume of Extract (0.004) litres}}{\text{Volume of Sample, } (30\times10^{-6})\text{m}^3} \quad - \quad 4\text{-}3$$

4-4.7 Chemical Oxygen Demand (COD)

COD tests were carried out for influent wastewater and both filtered and unfiltered effluent samples. Filtered influent COD could not be measured, because of the limited number of condensers available at each time for refluxing the samples.

Sample preparations for COD refluxing and test consisted of: 10ml of sample, 5ml of 0.025N potassium dichromate, 0.2gm. of mercury sulphate and 15ml. conc. sulphuric acid (containing 22gm silver sulphate per 2.5 litere bottle of conc. sulphuric acid).

A refluxing time of 120 minutes was maintained throughout the study. 3 drops of ferroin indicator was used for each titration, and ferrous ammonium sulphate titrant was standerdized each day of analysis, throughout the study. The standardization of ferrous ammonium sulphate provided a good check on the results obtained for blank titrants.

4-4.8 Biochemical Oxygen Demand (BOD)

BOD tests were carried out for influent and effluent samples, over a 5 day incubation period at a temperature of 20°c, all DO determinations were carried out with the DO electrode and DO meter.

A 1:5 sample dilution in 300ml BOD bottles using dilution water prepared in accordance with Standard Methods (APHA (1965)) was carried out for all the tests. The aeration of the dilution water was achieved by stirring on a magnetic stirrer for about 2 hours.

4-4.9 Bacteriological Tests

Bacteriological tests for enterobacteria as well as Salmonella/Shigella were carried out on samples of the fish gut and flesh. Selenite broth was used as an initial enrichment medium in the tests conducted. In the subsequent step Maconkey agar was used and the samples were incubated at 35°± 0.5°c for 48 hrs. in order to determine the types of indicator organisms, if present, in the samples. A second test involved the use of Salmonella/Shigella agar (SSA) after Selenite broth enrichment medium was used on the samples. The samples were incubated at 37°c and 41°c for a 24 hour period.

CHAPTER 5

RESULTS AND DISCUSSIONS

In this chapter a presentation of the results obtained and observations made during the investigations is made.

5-1 Influent and Effluent Characteristics for the Pilot Pond

The summary of influent and effluent wastewater parameters for the experimental pilot pond study are shown in Table 5-1 (also see tables AI to A6 in the appendix). Figures 5-1 to 5-8 show the complete influent and effluent wastewater data collected in the two ponds, during the two runs. As the two ponds were fed from the same influent source, the effluent characteristics from both ponds were related to the same set of influent characteristics during each run.

5-1.1 DO, pH and Alkalinity

The average DO values for run I were: 5.23, 5.33 and 5.22mg/l for influent, pond A effluent and pond B effluent, respectively. Average DO values for run II were: 7.67, 7.31 and 7.65mg/l for influent, pond A effluent and pond B effluent respectively. The results show that D.O. concentration values for run I were lower than those for run II. The DO of the influent wastewater tend to have some influence on the DO concentrations of the effluents from the pilot ponds. One may add that the oxygen demand as a result of fish respiration and other activities did not seem to have much effect on the DO concentrations, as the influent and effluent DO values were rather close.

24-hour monitoring were conducted to study the diurnal variations in DO concentrations in the influent and pond contents, during runs I and II.

The results are furnished in tables -11 and A-12 in the appendix, and Fig. 5-9 and 5-10. The DO concentrations for the two runs were found to increase in the influent and effluent with increase in intensity of sunlight and reaeration - a maximum being attained at about 16:00 hrs. After 16:00 hrs., the DO concentrations decreased to a minimum at about 04:00 hrs. Sunlight intensities were not very pronounced before noon as a result of the dusty harmattan haze, which tended to clear after noon. The after noon (16:00 hrs.) sampling showed supersaturation of DO during run II: 10.80, 10.60 and 10.7mg/l for influent, pond A effluent and pond B effluent respectively. A minimum value of 2.10mg/l DO in pond A during run I was observed, this pond had a fish population of 40 fingerlings (or 5.0 fish/$1m^2$). Since the fish did not die, one may conclude that 2.10mg/l DO concentration was sufficient for fish and algae respiration; at night.

Average pH values observed for influent; pond A effluent, and pond B effluent, during run I were: 8.13; 8.12 and 8.12 respectively. During run II pH values were 8.10, 8.13 and 8.18 for influent; pond A effluent; and pond B effluent, respectively. The pH ranges during run I were: 7.20-9.00 for influent; 7.20-9.05 for pond A effluent; and 7.20-8.95 for pond B effluent while during run II the pH ranged from 7.55 to 8.40 for influent; 7.30 to 9.15 for pond A effluent; and from 7.45 to 8.50 for pond B effluent.

Since the pH values of the effluent wastes followed a similar pattern as the influent pH, it would appear that the pH values of the influent wastewaters, among other things had some influence on the pH of the effluents from the ponds.

The average values of the alkalinity were: 81.70; 79.85 and 80.07mg/l for influent; pond A effluent; and pond B effluent respectively, during run I. During run II average alkalinity were: 95.85; 96.30 and 97.58mg/l for

influent; pond A effluent; and pond B effluent, respectively. Like the DO concentrations and pH values, influent alkalinity values had some influence on the alkalinity of the effluent from the experimental pilot ponds.

5-1.2 Total Solids; Suspended Solids and Chlorophyll-a

Values for Total Solids ranged from 260-900mg/l for influent; 180-460mg/l for pond A effluent; and 220-500mg/l for pond B, during run I. While during run II Total Solids ranged from 360 - 740mg/l for influent; 280-640mg/l for pond A effluent; and 280-620mg/l for pond B effluent. Average total solids values were: 461.8, 318.2 and 347.3mg/l for influent; pond A effluent and pond B effluent, respectively, during run I. For run II average total solids were 496.7; 386.7 and 440.0mg/l for influent; pond A effluent and pond B effluent; respectively. Average suspended solids were 214.5; 65.0; and 110.9mg/l for influent; pond A effluent; and pond B effluent respectively, during run I. During run II average suspended solids concentrations were: 275.0; 156.7 and 215.0mg/l for influent; pond A effluent; and pond B effluent respectively.

Chlorophyll-a was used as an index of algal biomass, though it does not account for the presence of non-photosynthetic components of pond ecosystems. The average chlorophyll-a concentrations were 79.0; 31.6; and 33.3mg/m^3 for influent; pond A effluent; and pond B effluent respectively, during run I. During run II average chlorophyll-a values were 78.4; 55.4 and 54.8mg/m^3 for influent; pond A effluent; and pond B effluent respectively. The lowest chlorophyll a concentration observed was 14.6mg/m^3. The highest chlorophyll-a concentration value observed was 112.4mg/m^3 chlorophyll-a concentration observed in the influent (and thus the effluent from maturation ponds MA-2 and MB-2), show that the ABU waste stabilization pond system, during the period of study on the experimental pilot ponds was

able to achieve an effluent quality of about 11.24mg/l suspended solids. Increased detention time as well as the presence of fish population could have reduced this value considerably, as evident in the average chlorophylla values for experimental pilot ponds A and B.

As was to be expected, total solids and suspended solid concentrations in the ponds should generally correspond to the extent of algal growth. Fig. 5-11 and 5-12 show the relationship between chlorophyll-a concentrations and suspended solids concentrations, during run I and run II. From regression analysis the suspended solid concentrations for a known chlorophyll-a concentration can be obtained and vice-versa, from:

Run I

Influent: SS = 103.4+2.13 (Chlorophyll-a) - 5-1

Pond A: SS = 61.79+0.487 (Chlorophyll-a) - 5-2

Pond B: SS = 112.65-0.019 (Chlorophyll-a) - 5-3

Run II

Influent: SS = 1.6+3.34 (Chlorophyll-a) - 5-4

Pond A: SS = 54.5+1.79 (Chlorophyll-a) - 5-5

Pond B: SS = 72.0+2.61 [Chlorophyll-a) - 5-6

where, SS is given in mg/l, and

chlorophyll-a values are in mg/m^3

Positive intercepts on the suspended solids concentration axis indicates that some suspended solids concentration not due to chlorophyll-a, such as non-photosynthetic components of the pond ecosystem, were present in the samples.

5-1.3 Total COD, Soluble COD and Total BOD5

Observed values of Total COD ranged from 20.0-33.3mg/l for influent; 16.0-23.7mg/l for pond A effluent; and 13.3-23.7mg/l for pond B effluent,

during run I. While during run II, total COD values ranged from 18.4-35.7mg/l for influent; 17.5-24.mg/l for pond A; and 16.0-30.3mg/l for pond B effluent. Average T-COD values for run I were: 25.6; 19.9; and 18.9mg/l for influent; pond A effluent; and pond B effluent, respectively. While during run II average T-COD values were: 25.2; 20.1; and 20.9mg/l for influent; pond A effluent; and pond B effluent, respectively. During run II, Soluble-COD concentrations were: 14.8 and 15.3mg/l for effluent of pond A and pond B, respectively. As total COD values were always higher than corresponding soluble COD values, non-soluble COD (TCOD-SCOD) were thus positive in all samples taken. Filtered algae and other suspended matter in the wastewater must have thus contributed significantly to the Total COD concentrations.

Total BOD5 values for run I were: 15.25, 13.13 and 11.38mg/l for influent; pond A effluent; and pond B effluent, respectively. While for run II, total BOD5 values were: 15.44, 13.25 and 13.47mg/l for influent; pond A effluent and pond B effluent, respectively. The Total BOD5 values ranged from 14.0-16.5mg/l for influent, 11.75-14.50mg/l for pond A effluent and 9.0-13.75mg/l for pond B effluent, during run I. While during run II, Total BOD5 values ranged from: 13.0-18.25mg/l for influent; 9.5-18.25mg/l for pond A effluent and 9.0-19.25mg/l for pond B effluent. The highest Total BOD5 value obtained was 19.25mg/l and the lowest Total BOD5 was 9.0mg/l. As all Total BOD5 concentrations were less than 20mg/l, one may conclude that the BOD5 of effluents from the experimental pilot ponds as well as the ABU waste stabilization pond system are suitable for discharge into receiving streams, based on the "20/30 Royal Commission Standard", (Mara, (1976); Feachem, et. al., (1977)).

Fig. 5-13 shows the relationship between the organic strength, in terms of TCOD and TBOD5, during run II for influent, pond A effluent and

pond B effluent. Based on regression analysis, of the data collected, the following regression equations describing the relationship between TCOD and TBODs of influent and the effluents from the ponds, A and B, during run II were obtained:

Run II

Influent: TCOD = -0.424 + 1.62(BODs) - 5-7

Pond A: TCOD = 20.075 - 0.035(BODs) - 5-8

Pond B: TCOD = 14.584 + 0.433(BODs) - 5-9

Positive intercepts on the COD axis (as obtained for pond A and pond B effluents) indicate that the wastewater contained some nonbiodegradable matter, which could however be chemically oxidized.

5-2 Treatment Efficiency

In order to estimate the treatment efficiency, during the study, the percentage reductions in the treatment parameters monitored during the two runs are tabulated in table A-7 to A-10 in the appendix, and summarized in table 5-2.

5-2.1 Total Solids, Suspended Solids and Chlorophyll-a

The average values of the percentage removal of total solids were: 30.13% for pond A; and 19.94% for pond B during run I. During run II average percentage removal of total solids were: 30.29% for pond A and 20.62% for pond B. The maximum percentage of Total Solids removal was obtained in pond A, during run I, in which there was a fish population of 40, or 5 fish/m^2.

The suspended solids removal ranged from: 33.3-85.7% for pond A and 0.0-77.8% for pond B, during run I. During run II suspended solids removal ranged from 15.0-66.7% for pond A and 14.3-67.9% for pond B. The average suspended solids removal were: 63.2% for pond A and 44.6% for pond B,

TABLE 5-1 SUMMARY OF INFLUENT AND EFFLUENT PARAMETERS FOR PILOT PONDS

PARAMETERS	RUN	OPERATING POND	INFLUENT		EFFLUENT	
			RANGE	AVERAGE	RANGE	AVERAGE
DO (mg/l)	Run I	A	3.95-6.45	5.23	4.00-6.40	5.33
		B			4.00-5.90	5.22
	Run II	A	6.80-8.55	7.67	6.85-8.00	7.31
		B			5.70-8.40	7.65
pH	Run I	A	7.20-9.00	8.13	7.20-9.05	8.12
		B			7.20-8.95	8.12
	Run II	A	7.55-8.40	8.10	7.30-9.15	8.13
		B			7.45-8.50	8.18
ALKALINITY (mg/l)	Run I	A	68.0-103.5	81.7	61.3-95.7	79.85
		B			61.0-96.3	80.07
	Run II	A	77.0-107.0	95.85	78.0-110.5	96.3
		B			77.3-111.0	97.58
TOTAL SOLIDS (mg/l)	Run I	A	260-900	461.8	180-460	318.2
		B			220-500	347.3
	Run II	A	360-740	496.7	280-640	386.7
		B			280-620	440.0
SUSPENDED SOLIDS (mg/l)	Run I	A	120-480	214.5	20-140	65.0
		B			40-200	110.9
	Run II	A	180-400	275.0	80-340	156.7
		B			120-300	215.0
CHLOROPHYLL-a (mg/m^3)	Run I	A	29.5-110.6	79.0	18.0-86.0	31.6
		B			19.6-81.5	33.3
	Run II	A	35.0-112.4	78.4	14.6-105.0	55.4
		B			23.0-97.2	54.8
TCOD (mg/l)	Run I	A	20.0-33.3	25.6	16.0-23.7	19.9
		B			13.3-23.7	18.9
	Run II	A	18.4-35.7	25.2	17.5-24.3	20.1
		B			16.0-30.3	20.9
SCOD (mg/l)	Run I	A			6.7-21.67	13.60
		B			6.7-21.67	12.30
	Run II	A			80-203	14.8
		B			9.0-19.2	15.3
BOD5 (mg/l)	Run I	A	14.0-16.5	15.25	11.75-14.5	13.13
		B			9.00-13.75	11.38
	Run II	A	13.00-18.25	15.44	9.0-19.25	13.47

FIG. 5-4 INFLUENT AND EFFLUENT TOTAL SOLID FOR PILOT PONDS

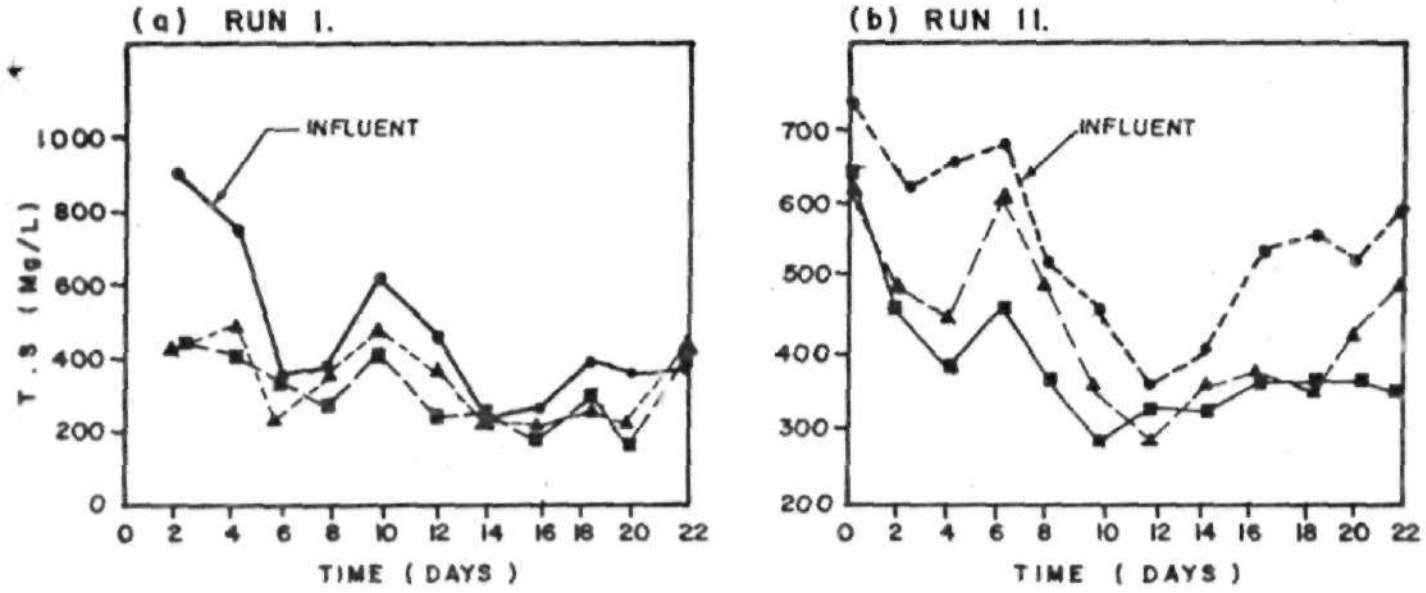


FIG. 5-5 INFLUENT AND EFFLUENT SUSPEND SOLIDS FOR PILOT PONDS

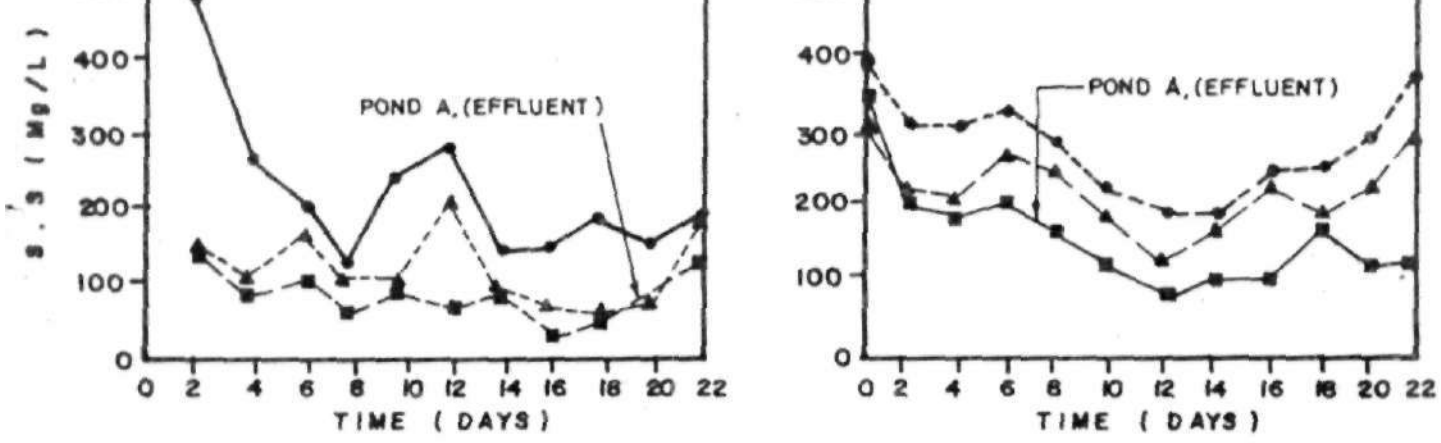


FIG. 5-6 INFLUENT AND EFFLUENT CHLOROPHYLL FOR PILOT PONDS

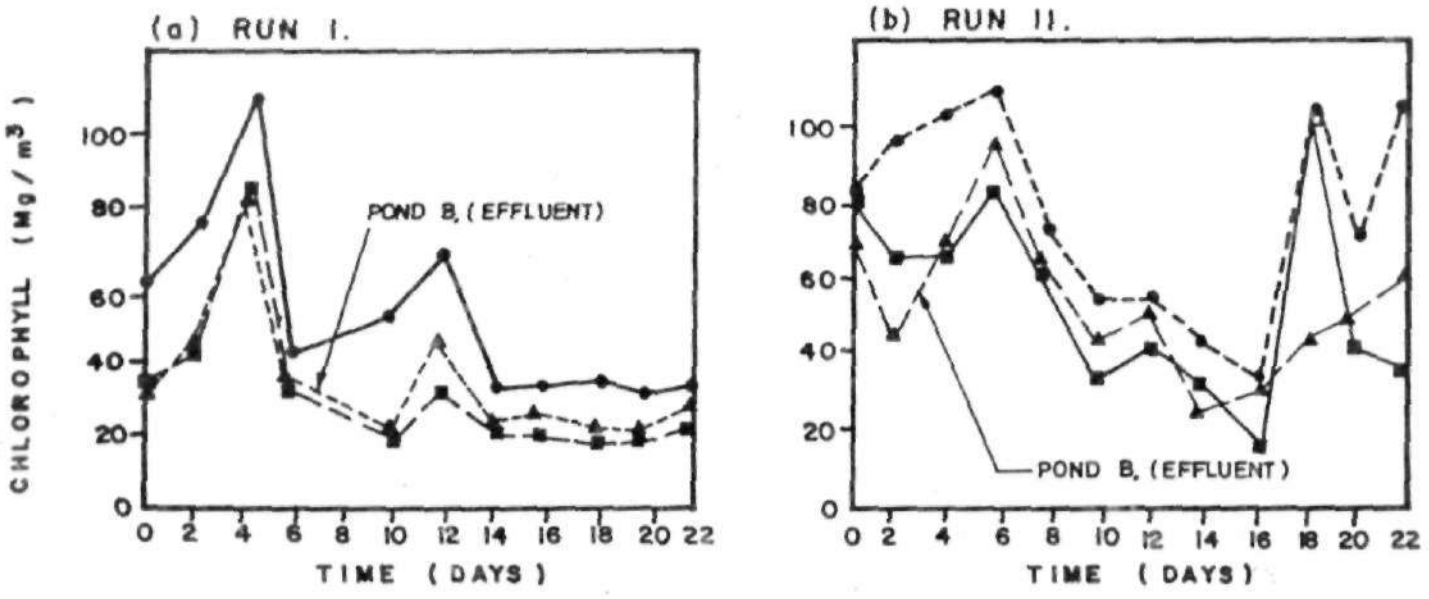


FIG. 5-7. INFLUENT AND EFFLUENT TCOD FOR PILOT PONDS

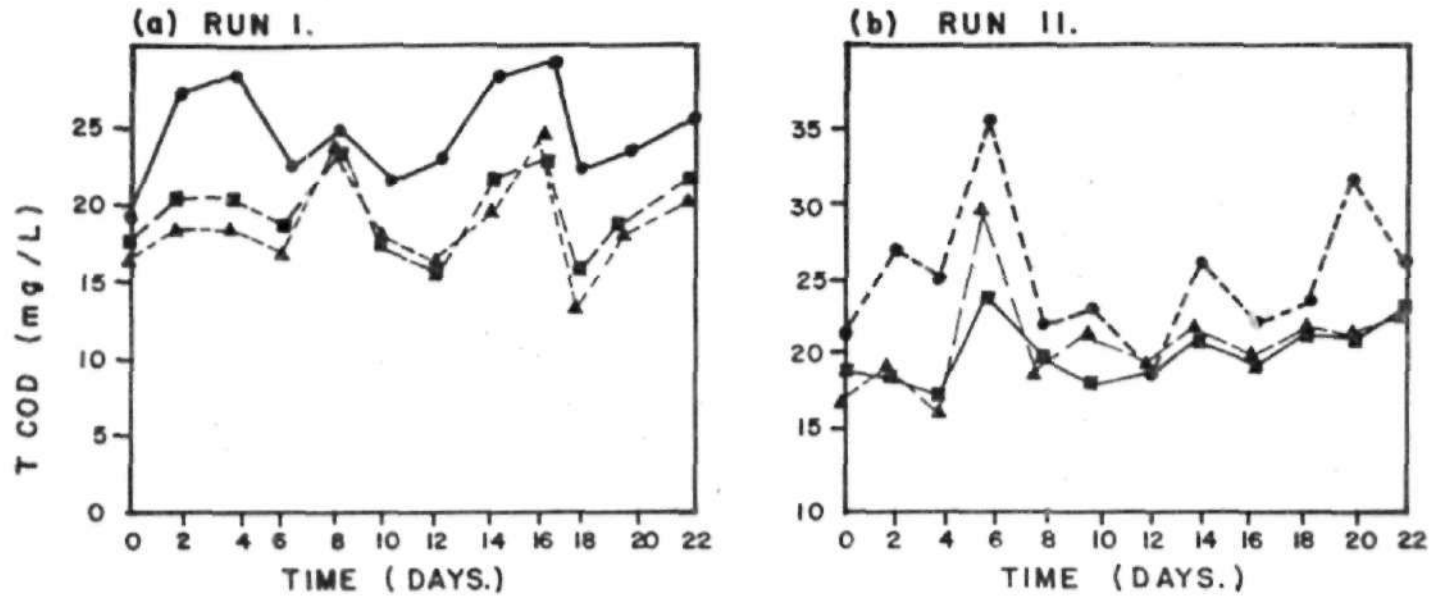


FIG. 5-8. INFLUENT AND EFFLUENT BODS FOR PILOT PONDS

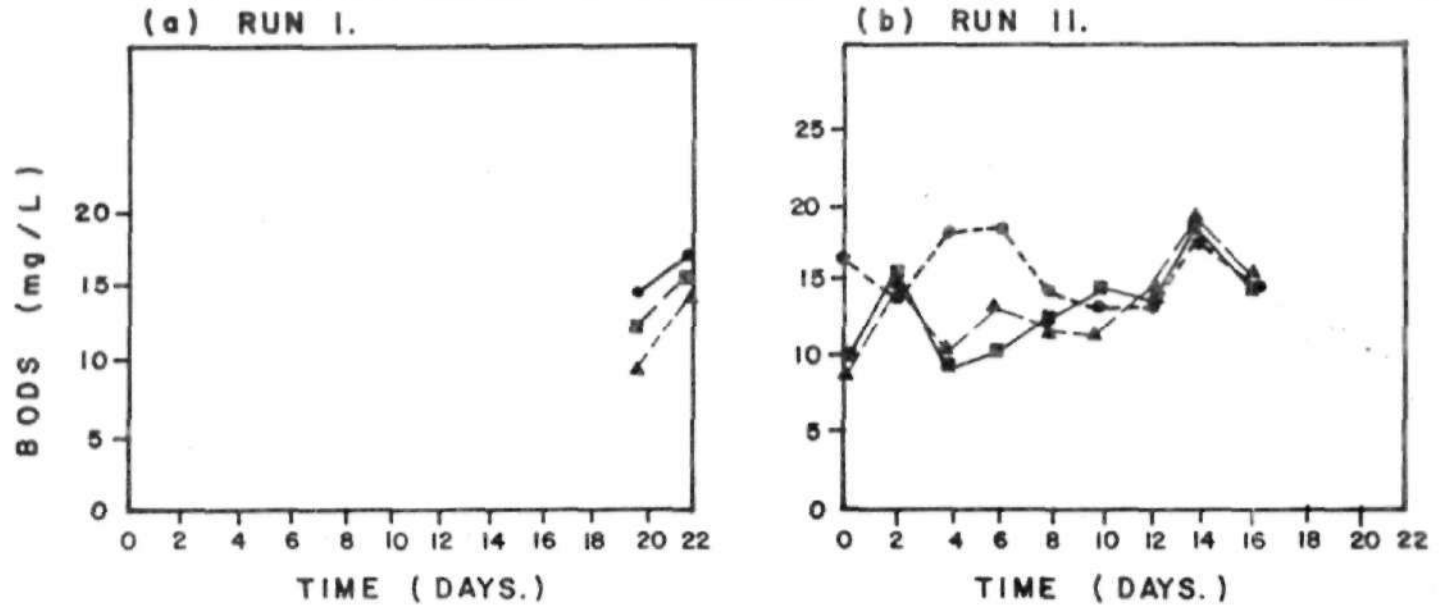


FIG. 5 - 9 DIURNAL VARIATION IN D.O FOR RUN 1.

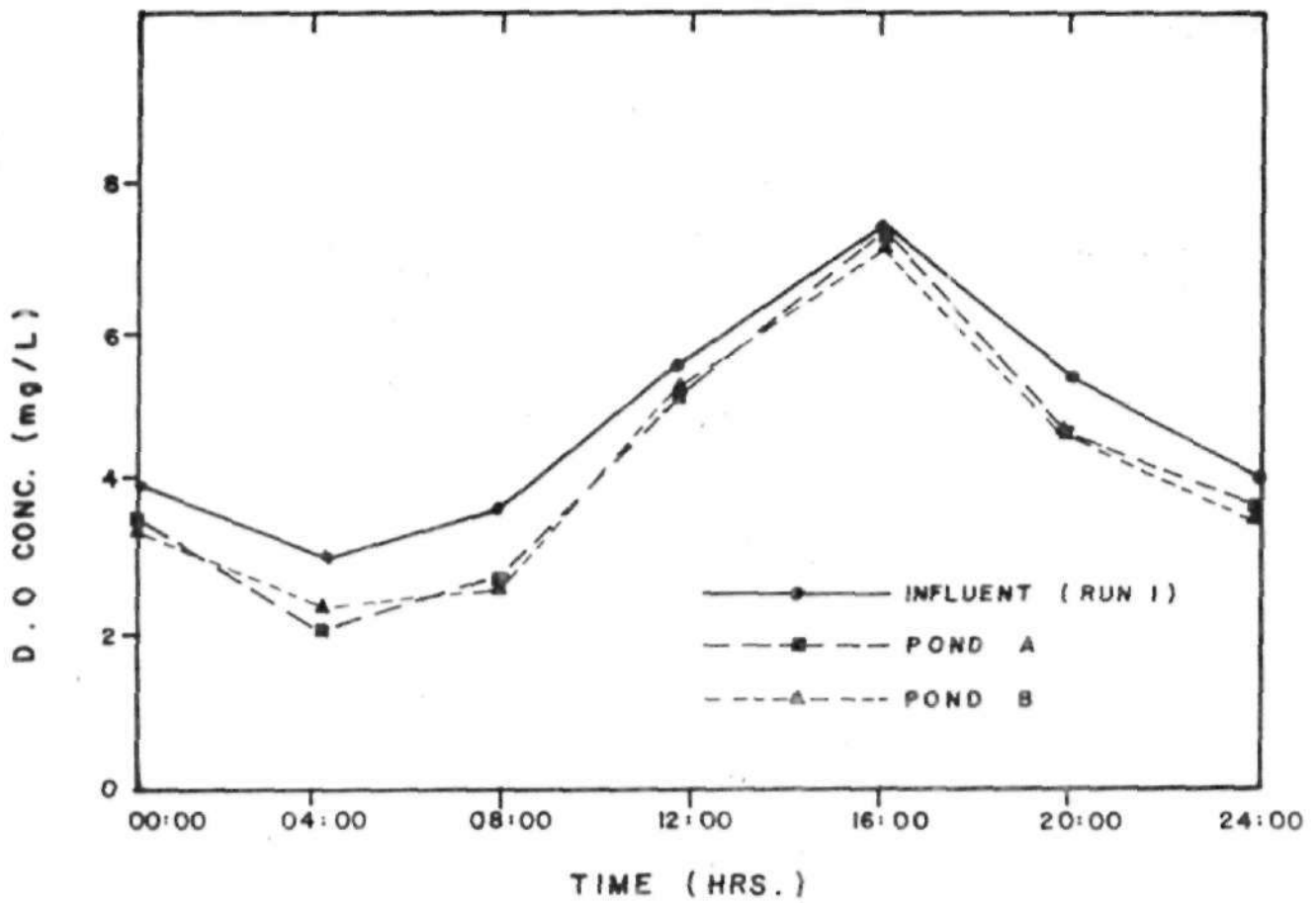


FIG. 5 - 10 DIURNAL VARIATION IN D.O FOR RUN 2

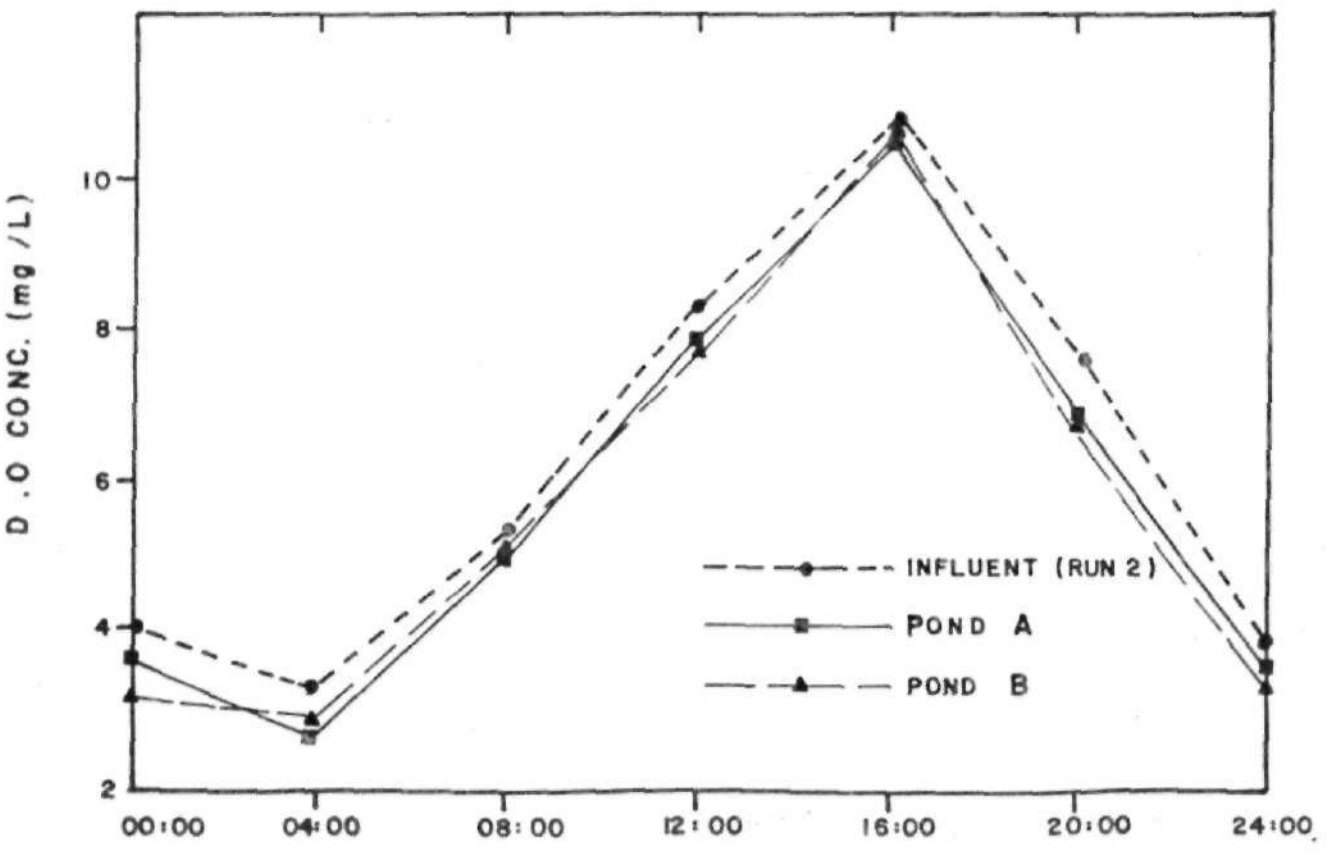


FIG. 5-11. CHLOROPHYLL - a - S.S CORRELATIONS, FOR RUN I.

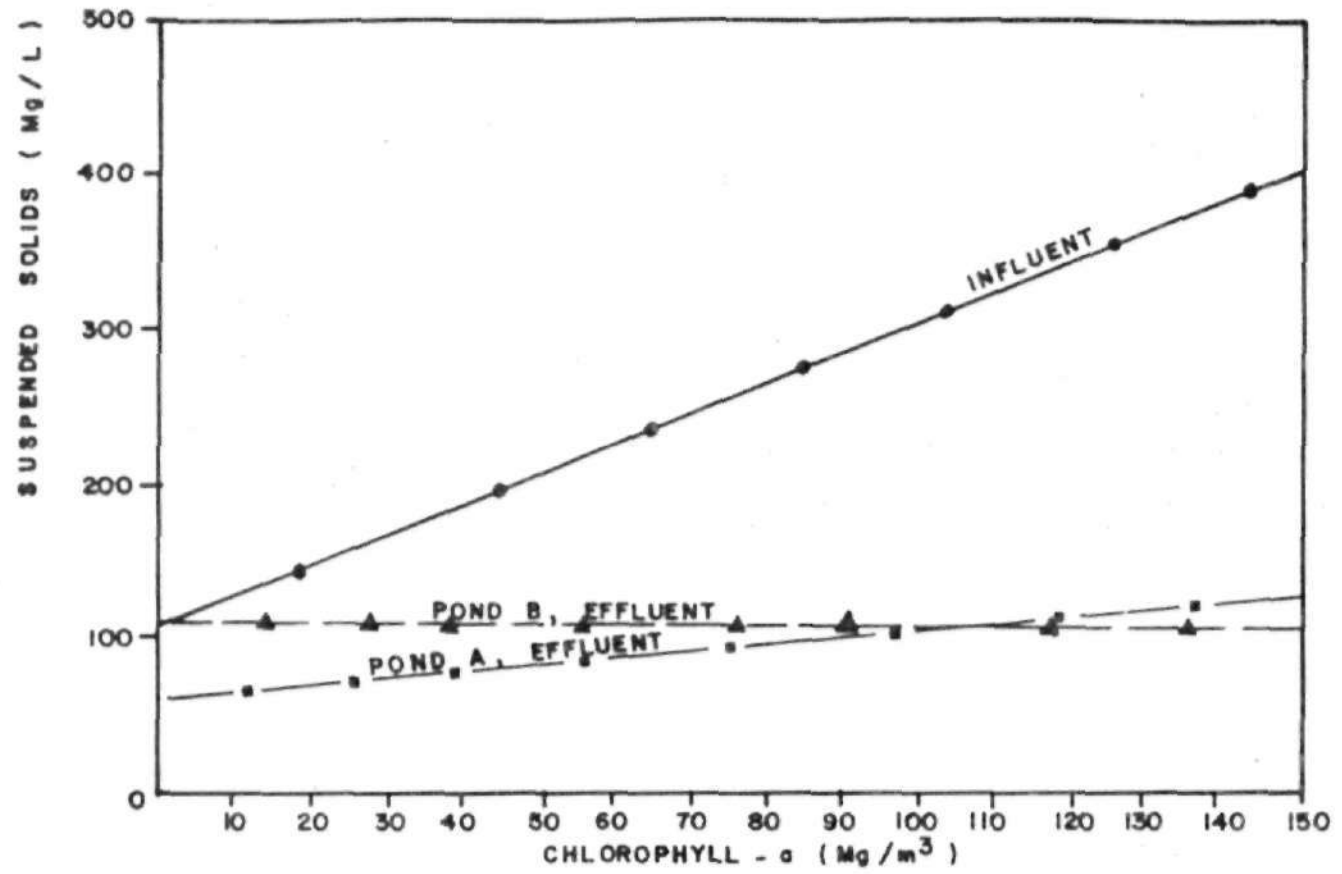


FIG. 5-12. CHLOROPHY - a - S.S CORRELATIONS, FOR RUN II.

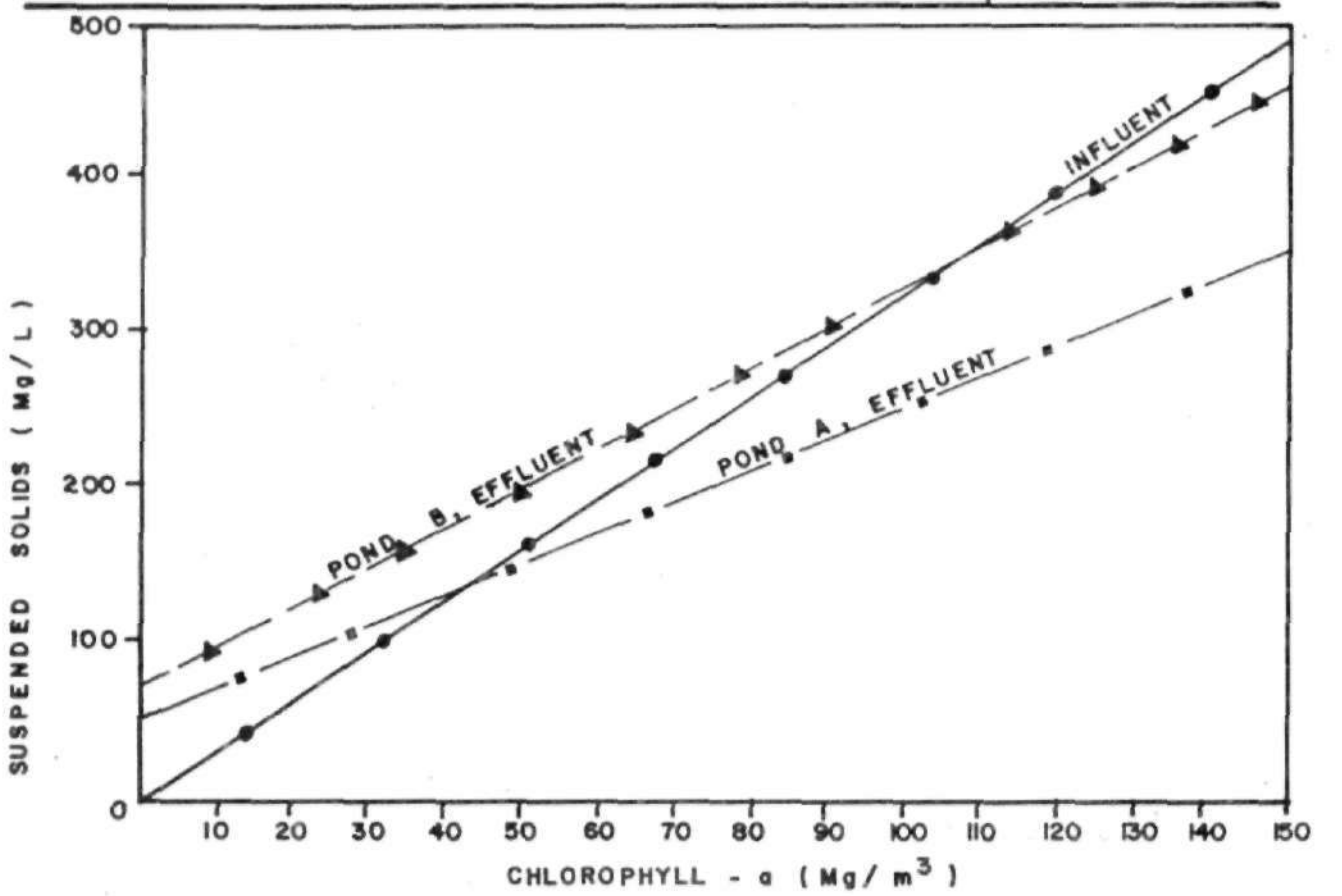
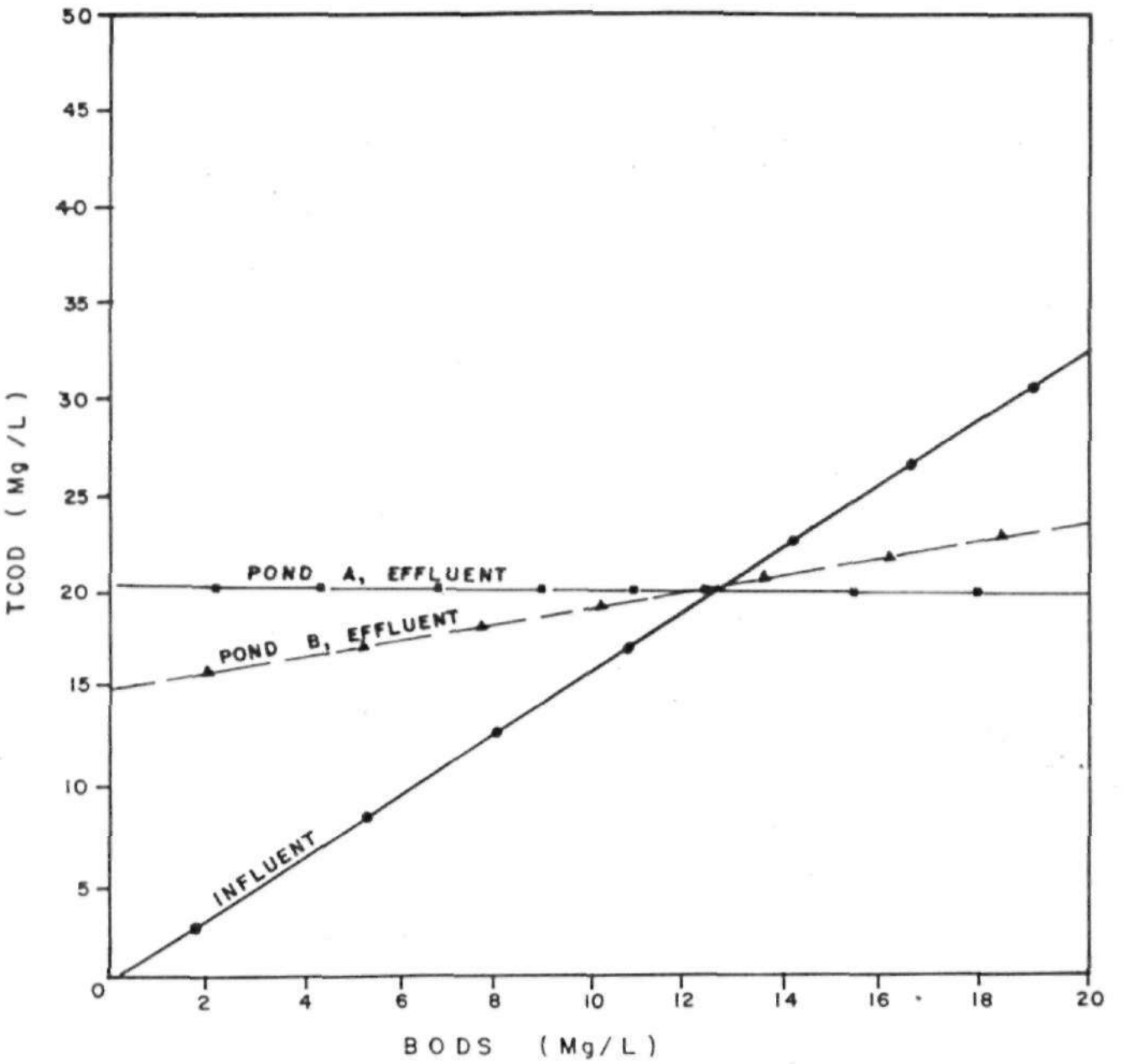


FIG. 5 - 13. TCOD — BODS CORRELATION FOR RUN II.



INFLUENT

POND A, EFFLUENT

POND B, EFFLUENT

during run I and during run II 44.1% for pond A and 45.3% for pond B. Suspended solids removal were significantly influenced by the number of fish present in the pilot ponds. The highest suspended solids removal during the study was 85.7% and was obtained in pond A during run I (which had the highest fish population of 40).

Average chlorophyll-a removal rates during run I were: 39.4% for pond A and 35.2% for pond B, while during run II were 30.4% for pond A and 27.3% for pond B. Increases in chlorophyll-a concentrations of 2.2% for pond A and 1.7% for pond B, both during run II were observed.

5-2.2 Total COD, Soluble COD and Total BODs

Average Total COD removal values were: 21.7% for pond A and 26.7% for pond B, during run I. During run II average total COD removal values were: 19.4% and 16.6% for pond A and pond B, respectively. Pond A and B showed increases in TCOD during run II.

Average soluble COD removal values were 46.1% for pond A and 51.6% for pond B, during run I, and 39.4% for pond A and 37.9% for pond B, during run II. The Soluble COD removal ranged from 15.7-77.1% for pond A and 15.7-77.1% for pond B, during run I. While during run II, soluble COD removed ranged from 18.2-70.4% for pond A and 19.7-64.4% for pond B. Average total BODs removed during run I were 14.1% for pond A and 26.2% for pond B, while during run II were 14.7% for pond A and 11.3% for pond B. Pond A showed an increase in BOD5 of 11.5% and pond B increases in BOD5 of 10.7%, both during run II, when the fish population in the ponds were 10 fish and no fish for ponds A and B, respectively.

TABLE 5-2 SUMMARY OF % REMOVAL FOR INFLUENT AND EFFLUENT PARAMETERS FOR PILOT PONDS

PARAMETERS	RUN	OPERATING POND	MINIMUM	MAXIMUM	AVERAGE
TOTAL SOLIDS	Run I	A	- 7.7	48.9	30.13
		B	- 16.0	35.3	19.94
	Run II	A	13.5	43.3	30.29
		B	3.8	39.3	20.62
SUSPENDED SOLIDS	Run I	A	33.3	85.7	63.21
		B	0.0	77.8	44.62
	Run II	A	15.0	66.7	44.13
		B	14.3	67.9	45.33
CHLOROPHYLL-a	Run I	A	21.5	62.0	39.4
		B	13.2	57.0	35.19
	Run II	A	- 2.2	67.7	30.41
		B	- 1.7	57.1	27.33
TCOD	Run I	A	7.8	31.3	21.69
		B	7.8	40.4	26.74
	Run II	A	- 1.6	35.9	19.43
		B	- 1.6	36.8	16.55
SCOD	Run I	A	15.7	77.1	46.08
		B	15.7	77.1	51.59
	Run II	A	18.2	70.4	39.42
		B	19.7	64.4	37.97
BOD5	Run I	A	12.1	16.1	14.10
		B	16.7	35.7	26.20
	Run II	A	- 11.5	47.2	14.73
		B	- 10.7	45.5	11.32

5-3 The Influence of Varied Fish Stocking on the Performance of the Ponds

Results of total and suspended solids as well as chlorophyll-a concentrations showed that the presence of fishes in the experimental pilot ponds, as well as the additional detention time provided for the waste-water effluent in the pilot ponds was able to significantly reduce the total solids by as much as 48.9%; suspended solids by as much as 85.7% and chlorophyll-a by as much as 67.7%. For these three parameters, the highest removals were obtained in pond A during run I, when the pilot pond had a fish population of 40 fingerlings (or 5.0 fish/m^2).

High turbidity, of brown clay colouration, was observed to be rather pronounced in the pilot ponds, during run I. During run II, pond A showed some signs of turbidity due to brown clay colouration while pond B, with no fish population, had a predominantly green algae colour. The brown clay colouration could be atributed to the action of the fish population on the earthen embankments of the pilot ponds.

Though wire mesh was provided at the inlet to the diversion pipe, leading into the experimental ponds, some duckweed (lemna paucosta) seedlings, from maturation pond MA-2 (see Fig. 4-1) were able to enter into the ponds, during the period of study. These duckweed seedlings however failed to grow during run I as they were probably consumed by the fishes presnt in the ponds. During run II, however, some of the duckweed were able to grow in pond A while the growth in pond B was so pronounced that the duckweed had to be skimmed off periodically, during the study.

The organic strength parameters were influenced by the presence of fish in the experimental ponds. Slightly higher removal efficiencies were obtained for pond A and B, during run I and pond A, during run II when compared to pond B, during run II. Influent and effluent sampling a times showed increases in TCOD during run II. Maximum SCOD removal tended to

decrease with decrease in fish population in the pilot ponds. BOD5 values did not show direct correlation with fish population in the ponds, however, pond A and B during run II showed increases in BOD5. The fact that pond A and pond B during run I were at all times able to provide some BOD5 removal probably indicates that fish population contributed significantly to BOD5 in the ponds.

5-4 Productivity of Fish in Maturation Pond, MB-2

The weight of some of the Orcchromis niloticus placed in maturation pond, MB-2 were measured monthly, during the period of study, from May to November, 1985. Weight sampling were however not conducted in July and August.

Average monthly weights and ranges of the largest fish caught during sampling are shown in Table 5-3. Also figure 5-14 shows the rate of growth of the fishes. A range of 99.53 to 190.74gm, with an average of 150.2gm was obtained at the end of the six months study period. This indicates a growth rate of 0.83g/day or $0.14g/m^2$ day, based on a fish population of 300 and mid-depth area of maturation pond, MB-2, of $1,800m^2$ (see Table 4-1).

Though the yield appears rather low, probably due to under stocking, one must remember that only samples were taken and the weights of those fishes caught for sampling could be on the low side. Towards the latter period of the study there was increased problem of catching the fish, as they had become more mature and "aware" - more often than not it was their offsprings that were being caught. The low yield could also be be attributed to the problem of no inflow into facultative pond FB, (see Fig. 4-1) which pond MB-2 in series with. Pond FB got blocked in August and the content had to be emptied. For maintenance work to be undertaken, and di not resume operation until December. As no influent was going into MB-2

the stocked fish as well as their offsprings had to make do with the nutrients available in the maturation pond, before pond FB got blocked. A better estimate of the yield would have been to include the weight of the offsprings produced. The large number of offsprings, as well as the fact that only sample weights of between 20 to 50 fishes were being taken monthly, did not make it possible to include the offsprings as part of the overall productivity.

Reproduction had commenced in September, which indicates that the Orechromis niloticus attained maturity in less than five months. The Orechromis niloticus (formerly referred to as Tilapia niloticus) are typical mouth-brooders, the female take up the eggs and later take sole charge of guarding and rearing the fry. According to Huet, (1972), in keeping with the size of the fish, there may be upto 2,000 eggs in a clutch. Such large numbers of fry increases the population density and decrease the mean growth rate. This may raise total productivity, but individual growth could be slowed down to an uneconomical rate. Although free sprawning is desirable, the large reproductive capacity of the tilapias is their main disadvantage.

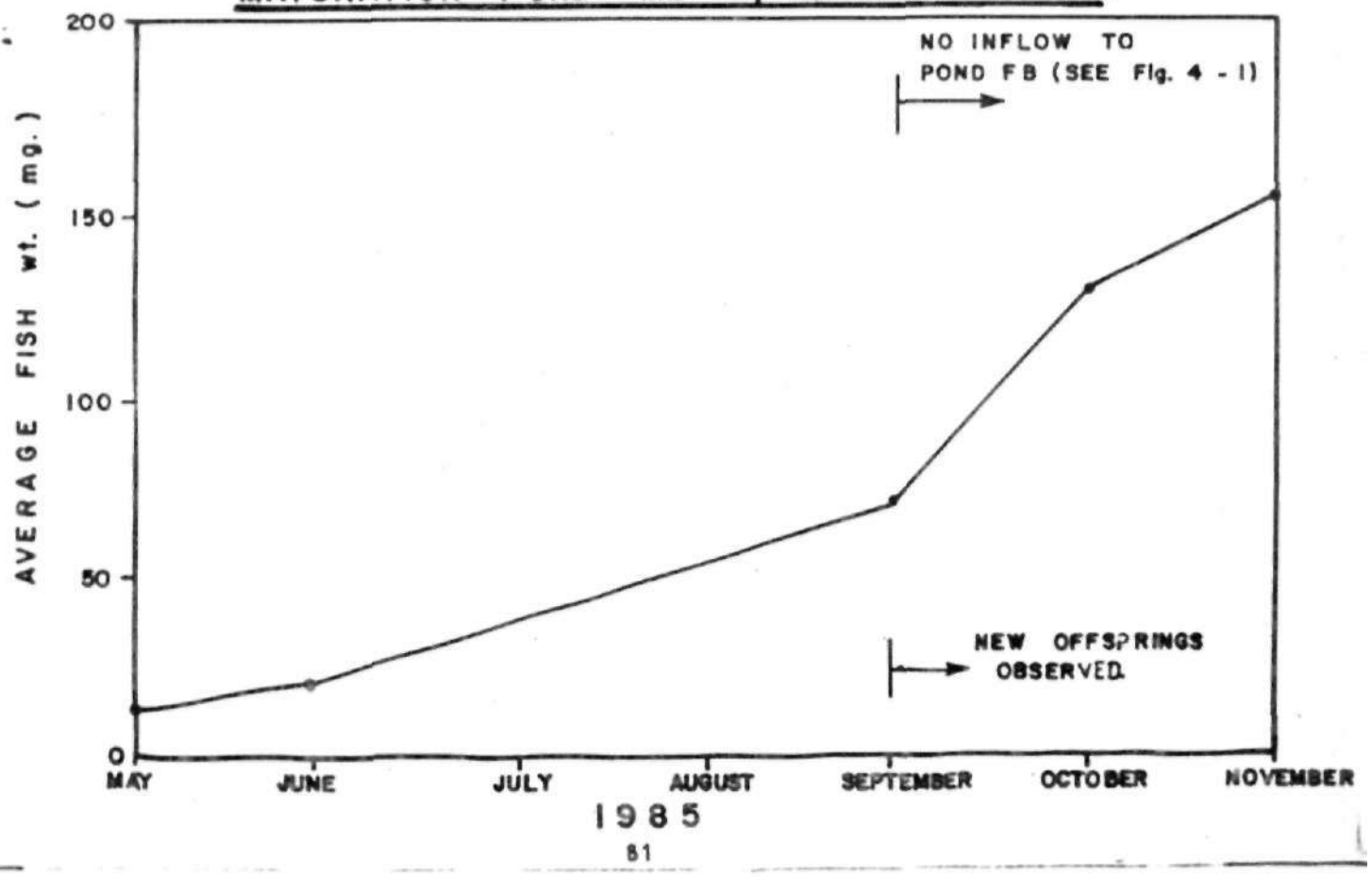
To effect some control some 20 Hemichromis fasciatus were included in the fish stocked, being about 5% of the total fish population. The Hemichromis fasciatus is a small voracious cichlid, appearing very much like the tilapias, which can be used to reduce the sprawning of tilapias. Huet (1972), estimates that an addition of 2% of Hemichromis is enough to obtain a balanced cultivation.

Hemichromis fasciatus caught during sampling (though not weighed) appeared better fed than the Orechromis niloticus. The presence of Hemichromis fasciatus in the aquatic system did not seem to be very effective in controlling the sprawning of the tilapias, as evident in the

TABLE 5-3 FISH GROWTH IN MATURATION POND MR-2

MONTH	NO SAMPLED	AVERAGE WEIGHT (gm)	WEIGHT RANGE (in gm)
MAY	50	12.74	5-10-19.39
JUNE	50	18.86	11.62-26.74
JULY	--	--	--
AUGUST	--	--	--
SEPTEMBER	50	67.03	56.81-96.47
OCTOBER	30	126.54	111.12-152.26
NOVEMBER	23	150.19	99.53-190.74

FIG. 5-14. RATE OF GROWTH OF OREOCHROMIS NILOTICUS KEPT IN MATURATION POND MB-2, AT ABU ZARIA.



large number of tilapia offsprings caught during sampling.

Payne, (1975) mentioned four methods commonly used to limiit population size:

(i) Manual control of fry numbers;

(ii) Control using a predator, such a Hemichromis fasciatus feeding on tilapias;

(iii) Monosex culture; and

(iv) Introduction of a species with a long immature phase.

Since the purpose of stocking fish is essentially for effluent polishing, oversprawning may result in poorer effluent quality. Monosex culture would be suitable where fish yield is being considered. Fish species with long immature phase would be suitable as indicators of undesirable pollutants. Control using a predator is highly species specific and the degree of control provided cannot be readily regulated. Manual control of fry number will result in increased contact with the wastewater, as well as being a rather tideous and time consuming method.

5-5 Biological Observations

5-5.1 Bacteriological Results

Bacteriological tests were conducted on the gut and flesh of some mature Orechromis niloticus, at the end of the study period, in December, 1985. Results obtained indicate the presence of rod-shaped, gram negative lactose fermenting (to pink) microorganism - the coliform group of bacteria, as defined in APHA (1965). Salmonella/Shigella tests conducted indicated no presence of sulphite reducing organisms in the fish gut and flesh.

The indicator concept has been long established in sanitary microbiology, although it is generally accepted that a universally perfect

indicator of pathogens does not exist. All bacteria, exclusive of faecal origin are useful to some degree as indicators of pathogens from intestinal sources, but as indicators of viruses, such bacteria have special limitations.

Test for viruses, as well as faecal streptococci, standard coliform and faecal coliforms were not conducted due to unavailability of necessary media and suitable equipment. These tests are highly desirable, as highly eutrophic fish pond systems are highly favourable environments for bacteria. The pollution contribution by fish in terms of comparing faecal counts of coliform and streptococci bacteria, would have provided more information on the problems fish feaces may cause in the aquatic treatment system.

5-5.2 Aquatic Plants in the Pond System

The predominant algae species observed, in the pilot ponds and field scale maturation pond, MB-2, during the period of study were: Chlorella, Euglena, Coelastrum, Scenedesmus, (quadricauda), Trachelomonas (Espeda) and Crucigenia.

The predominance of green algae in the ponds indicates the achievement of ideal symbiotic relationship, when nutrients released via bacterial decomposition are assimilated by the algae. In turn the algae releases oxygen via photosynthesis and support aerobic decomposition. The absence of blue-gren algae in a superficial highly favourable environment may be due to the perculiar biotic nutritional or physical characterisitic of the waste stabilization pond, (Lewis, (1978)).

CHAPTER 6

CONCLUSION AND RECOMMENDATION FOR FURTHER INVESTIGATION

6-1 Conclusion

The following conclusions can be made from the results of this study:

- The stocking of fish in polishing ponds offer a valuable method for upgrading the effluent from waste stabilization pond systems, as they provide some degree of improved effluent quality and nutrient removal. Fish presence in the polishing ponds can play a significant role in the reduction of total solids, suspended solids, and algae concentration, which may exert a deleterious effect on downstream aquatic systems or create problems for reuse.
- The polishing pond aquatic system is able to sustain fish life and reasonable fish productivity. More detailed bacteriological tests are, however, needed to determine the suitability of the fish for human consumption or other uses.
- Orechromis nilotucus, fish, of 5.0 fish/m^2 were able to survive in a DO concentration of 2.10mg/l.
- The A.B.U. waste stabilization pond system, due to the inclusion of Fish in the maturation pond MB-2, was able to provide effluent quality of 11.24mg/l suspended solids and BODs of 19.25mg/l as compared to values of 165mg/l and 31.0mg/l respectively, previously reported by Onuoha (1980), when no fish was stocked.

The comparatively low level of interest in using fish and other biological systems for wastewater treatment, in developing countries is suprising. Though these systems provide additional resource utilization and a times revenue, it is apparent that wastewater treatment and disposal is still given low priority in these countries.

It is clear that fish or other microorganisms raised in wastewater have a high probability of becoming contaminated with bacteria, viruses and toxix chemicals. However, the public health risks may not be greater than in natural water, in most tropical developing countries, where no Effluent Standards exist. Use of biological systems, such as the use of fish population, have good potential for achieving successful and efficient wastewater treatment. Fish yield from this biological treatment system can provide a source of much needed protein diet, in developing countries. The stocking of fish may also increase awareness and help generate interest in treatment plant operators, who despite the minimum maintenance requirements for stabilization pond systems, tend to neglect its maintenance completely.

6-2 Plans for Further Investigations

This study can hardly be said to provide complete information on the use and performance of fish for upgrading waste stabilization pond effluents. The study has also not provided sufficient insight into the potential of stabilization pond systems as suitable aquaculture systems, for fish growth. Additional investigation and development is necessary to further define the conditions under which fish population can be effective in nutrient removal and effluent upgrading.

The objectives of such a proposed study should include:-

- investigation of fish species, varied age stocking, number for optimum polishingand polyculture for improved effluent quality, fish productivity and suitability as early warning systems.
- the effect of fish on benthic deposits, surface growths and vegetation, as well as the much talked about mosquito control
- suitable methods and means of controlling fish sprawning and establishing an optimum harvesting strategy for the animals.

- the effect of fish activity on the aquatic system, in terms of turbidity, oxygen demand, and faecal pollution.
- investigate the presence and concentrations of bacteria, virus, and toxic chemicals, and evaluate the disease risk associated with occupational exposure to wastewater (particularly during fish harvesting, and long term effect on consumers of such fish).

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APPENDIX A

TABLE A-1 INFLUENT AND EFFLUENT PARAMETERS FOR RUN I

DATE	INFLUENT			EFFLUENT					
				POND A			POND B		
	DO (mg/1)	pH	ALKALINITY (mg/1)	DO (mg/1)	pH	ALKALINITY (mg/1	DO (mg/1)	pH	ALKALINITY (mg/1)
08.11.85	5.70	7.65	67.0	5.50	7.10	61.3	5.90	7.20	61.0
10.11.85	6.40	7.65	78.0	5.60	7.60	74.0	5.40	7.50	73.3
12.11.85	6.45	8.65	70.5	6.40	8.55	64.5	5.60	8.20	89.0
14.11.85	5.30	8.30	68.0	5.75	8.75	78.0	5.60	8.55	74.0
16.11.85	5.35	7.70	-	5.60	8.05	-	5.45	8.20	-
18.11.85	5.25	9.00	103.5	5.30	8.20	90.5	5.25	8.10	86.0
20.11.85	5.40	8.40	74.6	5.70	8.50	78.7	5.60	8.45	75.0
22.11.85	5.50	8.70	82.0	5.65	9.05	84.0	5.65	8.95	82.5
24.11.85	5.00	8.00	82.7	5.45	8.35	81.7	5.30	8.35	72.7
26.11.85	4.40	8.30	82.3	4.55	8.10	81.3	4.50	8.15	79.3
28.11.85	3.95	7.95	92.3	4.00	8.00	95.7	4.00	8.05	96.3
30.11.85	4.10	7.20	97.7	4.45	7.20	88.7	4.40	7.70	91.7

TABLE A-2 INFLUENT AND EFFLUENT PARAMETERS FOR RUN 1

DATE	INFLUENT			EFFLUENT					
				POND A			POND B		
	TS (mg/1)	SS (mg/1)	CHLORO.a (mg/m3)	TS (mg/1)	SS (mg/1)	CHLORO.a (mg/m3)	TS (mg/1)	SS (mg/1)	CHLORO.a (mg/m3)
08.11.85	-	-	58.3	-	-	34.01	-	-	34.01
10.11.85	900	480	74.9	460	140	42.4	440	140	44.4
12.11.85	760	260	110.6	420	80	86.0	500	100	81.50
14.11.85	360	200	39.5	360	100	31.0	260	160	34.3
16.11.85	380	120	40.6	280	60	24.7	380	100	19.6
18.11.85	600	240	-	360	80	-	480	100	-
20.11.85	460	280	47.4	260	60	18.0	360	200	20.4
22.11.85	260	140	67.7	280	80	30.4	260	80	43.7
24.11.85	280	140	30.3	200	20	20.5	240	60	25.0
26.11.85	380	180	39.4	300	40	20.7	260	40	20.1
28.11.85	340	140	29.5	180	-	18.0	220	60	19.7
30.11.85	360	180	30.5	400	120	21.6	420	180	24.0

TABLE A-3 INFLUENT AND EFFLUENT PARAMETERS FOR RUN I

DATE	INFLUENT (mg/l)			EFFLUENT (mg/l)					
				POND A			POND B		
	TCOD	SCOD	BOD5	TCOD	SCOD	BOD5	TCOD	SCOD	BOD5
08.11.85	20.0	-	-	18.0	11.3	-	17.3	7.3	-
10.11.85	28.3	-	-	21.0	9.3	-	19.0	7.7	-
12.11.85	29.3	-	-	20.7	6.7	-	18.7	6.7	-
14.11.85	23.7	-	-	19.3	11.7	-	17.0	11.0	-
16.11.85	25.7	-	-	23.7	21.67	-	23.7	21.67	-
18.11.85	22.0	-	-	17.7	13.7	-	18.7	16.0	-
20.11.85	23.3	-	-	16.0	10.0	-	16.0	9.3	-
22.11.85	29.0	-	-	22.0	21.67	-	20.33	18.00	-
24.11.85	33.3	-	-	23.0	14.7	-	25.3	13.0	-
26.11.85	22.3	-	-	16.3	13.3	-	13.3	6.7	-
28.11.85	24.0	-	14.0	19.0	13.3	11.75	17.7	16.0	9.00
30.11.85	26.3	-	16.50	22.3	16.3	14.50	20.3	14.0	13.75

TABLE A-4 INFLUENT AND EFFLUENT PARAMETERS FOR RUN II

DATE	INFLUENT			EFFLUENT					
				POND A			POND B		
	DO (mg/l)	pH	ALKALINITY (mg/l)	DO (mg/l)	pH	ALKALINITY (mg/l	DO (mg/l)	pH	ALKALINITY (mg/l)
02.12.85	7.90	7.55	77.0	7.95	7.30	78.0	7.95	7.45	77.3
04.12.85	7.90	7.60	80.50	7.75	7.50	78.5	7.50	7.75	82.0
06.12.85	7.35	8.20	88.7	7.60	8.20	90.7	7.60	8.45	92.0
08.11.85	6.80	8.00	87.3	5.60	8.20	88.0	5.70	8.50	90.0
10.12.85	7.60	8.20	93.0	7.00	9.15	95.5	7.20	8.70	111.0
12.12.85	7.50	8.20	106.0	6.90	8.40	110.5	7.60	8.35	108.0
14.12.85	7.50	7.95	102.0	8.00	8.10	104.0	7.80	8.20	105.3
16.12.85	8.55	8.00	99.0	7.50	8.25	106.3	8.00	8.20	106.0
18.12.85	7.45	8.40	106.0	6.85	8.05	102.0	7.90	7.90	96.0
20.12.85	7.35	8.30	107.0	6.90	8.30	104.0	7.95	7.80	97.0
22.12.85	8.10	8.35	102.0	7.90	8.00	98.5	8.40	8.45	104.0
24.12.85	8.05	8.40	101.7	7.80	8.05	100.0	8.15	8.45	102.3

TABLE A-5 INFLUENT AND EFFLUENT PARAMETERS FOR RUN 11

DATE	INFLUENT			EFFLUENT					
				POND A			POND B		
	TS (mg/1)	SS (mg/1)	CHLORO.a (mg/m3)	TS (mg/1)	SS (mg/1)	CHLORO.a (mg/m3)	TS (mg/1)	SS (mg/1)	CHLORO.a (mg/m3)
02.12.85	740	400	83.0	640	340	84.8	620	300	68.6
04.12.85	620	300	97.0	460	200	67.0	480	220	45.81
06.12.85	660	300	106.3	380	180	67.1	460	200	70.00
08.12.85	680	320	112.4	460	200	84.4	620	260	97.2
10.12.85	520	280	72.4	360	160	59.5	500	240	66.4
12.12.85	460	220	55.0	280	120	35.1	360	180	43.5
14.12.85	360	180	54.5	320	80	40.8	280	120	49.7
16.12.85	400	180	42.0	320	100	31.3	360	160	23.0
18.12.85	540	240	35.0	360	100	14.6	360	220	35.6
20.12.85	560	240	105.0	360	160	105.0	340	180	45.0
22.12.85	520	280	72.0	360	120	40.5	420	220	50.1
24.12.85	600	360	105.7	340	120	34.1	480	280	62.2

TABLE A-6 PERCENTAGE REMOVAL FOR PONDS, DURING RUN I

DATE	POND A			POND B		
	TCOD	COD	BOD_5	TCOD	COD	BOD_5
08.11.85	10.0	43.5	-	13.5	63.5	-
10.11.85	25.8	67.1	-	32.9	72.8	-
12.11.85	29.4	77.1	-	36.2	77.1	-
14.11.85	18.6	50.6	-	28.3	53.6	-
16.11.85	7.8	15.7	-	7.8	15.7	
18.11.85	19.5	37.7	-	18.2	27.3	-
20.11.85	31.3	57.1	-	31.3	60.1	
22.11.85	24.1	25.3	-	29.9	37.9	
24.11.85	30.9	55.9	-	24.0	61.0	-
26.11.85	26.9	40.4	-	40.4	70.0	
28.11.85	20.8	44.6	16.1	35.6	33.3	35.7
30.11.85	15.0	38.0	12.1	22.8	46.8	16.7

$$*SCOD = \frac{SCOD\ eff}{TCOD\ inf}$$

TABLE A-7 INFLUENT AND EFFLUENT PARAMETERS FOR RUN II

DATE	INFLUENT (mg/1)			EFFLUENT (mg/1)					
				POND A			POND B		
	TCOD	SCOD	BOD5	TCOD	SCOD	BOD5	TCOD	SCOD	BOD5
02.12.85	21.7	-	16.50	19.3	14.00	10.00	17.3	14.0	9.0
04.12.85	27.0	-	14.00	19.0	8.0	15.75	19.0	10.0	15.5
06.12.85	25.3	-	18.00	17.5	10.30	9.50	16.0	9.0	10.5
08.12.85	35.7	-	18.25	24.3	14.70	10.50	30.3	17.0	13.75
10.12.85	22.0	-	14.25	20.0	18.0	12.50	19.0	17.0	12.25
12.12.85	23.0	-	13.00	17.7	15.3	14.50	21.7	13.0	11.50
14.12.85	18.4	-	13.00	18.7	14.0	13.50	18.7	14.3	14.25
16.12.85	26.0	-	17.50	21.0	16.0	18.25	22.0	16.0	19.25
18.12.85	22.3	-	14.50	19.0	15.7	14.75	19.7	17.0	15.25
20.12.85	23.3	-	-	27.3	14.7	-	22.0	18.7	-
22.12.85	31.50	-	-	20.2	16.83	-	21.50	19.20	-
24.12.85	26.0	-	-	22.7	20.3	-	23.0	18.0	-

TABLE A-8 PERCENTAGE REMOVAL FOR PONDS, DURING RUN I

DATE	POND A			POND B		
	T.S	S.S	CHLORO-a	T.S	S.S	CHLORO-a
08.11.85	-	-	41.7	-	-	41.7
10.11.85	48.9	70.8	43.4	51.1	70.8	40.7
12.11.85	44.7	69.2	22.2	34.2	61.5	26.3
14.11.85	0.0	50.0	21.5	27.8	20.0	13.2
16.11.85	26.3	50.0	39.2	0.0	16.7	51.7
18.11.85	40.0	66.7	-	20.0	58.3	-
20.11.85	43.5	42.9	62.0	21.7	28.6	57.0
22.11.85	-7.7	85.7	55.1	0.0	42.9	35.5
24.11.85	28.6	85.7	32.3	14.3	57.1	17.5
26.11.85	26.7	77.8	47.5	31.6	77.8	49.0
28.11.85	47.1	-	-	35.3	57.1	33.2
30.11.85	33.3	33.3	29.2	-16.7	0	21.3

TABLE A-9 PERCENTAGE REMOVAL FOR PONDS, DURING RUN II

DATE	POND A			POND B		
	T.S	S.S	CHLORO-a	T.S	S.S	CHLORO-a
02.12.85	13.5	15.0	-2.2	16.2	25.0	17.3
04.12.85	25.8	33.3	30.9	22.6	26.7	52.8
06.12.85	42.2	40.0	36.9	30.3	33.3	34.1
08.12.85	32.3	37.5	24.9	8.8	18.8	13.5
10.12.85	30.8	42.9	17.8	3.8	14.3	8.3
12.12.85	39.1	45.5	36.2	21.7	60.9	20.9
14.12.85	16.7	55.6	25.1	22.2	66.7	8.8
16.12.85	20.0	44.4	25.5	10.0	60.0	45.2
18.12.85	33.3	58.3	58.3	33.3	59.3	-1.7
20.12.85	35.7	33.3	0.0	39.3	67.9	57.1
22.12.85	30.8	57.1	43.8	19.2	57.7	30.4
24.12.85	43.3	66.7	67.7	20.0	53.3	41.2

TABLE A-10 PERCENTAGE REMOVAL FOR PONDS, DURING RUN 11

	POND A			POND B		
DATE	TCOD	SCOD*	BOD_5	TCOD	SCOD*	BOD_5
02.12.85	11.1	35.5	39.4	20.3	35.5	45.5
04.12.85	29.6	70.4	12.5	29.6	63.0	-10.7
06.12.85	30.8	59.3	47.2	36.8	64.4	41.7
08.12.85	31.9	58.8	42.5	15.1	52.4	24.7
10.12.85	9.1	18.2	12.3	13.6	22.7	14.0
12.12.85	23.0	33.5	-11.5	5.7	43.5	11.5
14.12.85	-1.6	23.9	-3.8	-1.6	22.3	-9.6
16.12.85	19.2	38.5	-4.3	15.4	38.5	-10.0
18.12.85	14.3	29.6	-1.7	11.7	23.8	-5.2
20.12.85	17.2	36.9	-	5.6	19.7	-
22.12.85	35.9	46.6	-	31.7	39.0	-
24.12.85	12.7	21.9	-	11.5	30.8	-

*SCOD = SCOD eff/TCOD inf

TABLE A-11 INFLUENT AND EFFLUENT PARAMETERS FOR RUN I

TIME	INFLUENT			EFFLUENT					
				POND A			POND B		
	DO (mg/l)	pH	ALKALINITY (mg/l)	DO (mg/l)	pH	ALKALINITY (mg/l	DO (mg/l)	pH	ALKALINITY (mg/l)
00:00	4.10	8.60	78	3.7	8.3	85	3.5	8.25	89
04:00	3.00	7.50	81	2.1	7.35	90	2.35	7.40	87
08:00	3.7	7.8	77	2.7	7.3	86	2.6	7.60	82
12:00	5.50	7.85	98	5.20	7.80	101	5.3	7.60	89
16:00	7.40	8.60	83	7.30	8.15	88	7.10	8.00	89
20:00	5.30	8.20	74	4.60	8.50	78	4.60	8.50	83

TABLE A-12 INFLUENT AND EFFLUENT PARAMETERS FOR RUN 11

TIME	INFLUENT			EFFLUENT					
				POND A			POND B		
	DO (mg/1)	pH	ALKALINITY (mg/1)	DO (mg/1)	pH	ALKALINITY (mg/1	DO (mg/1)	pH	ALKALINITY (mg/1)
00:00	4.05	8.40	78	3.8	8.35	77	3.25	8.20	76
04:00	3.30	7.90	81	2.7	7.45	79	2.95	7.65	81
08:00	5.45	7.70	95	5.15	7.75	96	5.20	8.10	95
12:00	8.30	8.20	107	8.00	8.00	104	7.90	8.15	108
16:00	10.80	8.75	98	10.60	8.35	97	10.70	8.40	94
20:00	7.70	9.30	88	7.10	9.05	86	6.95	9.10	85

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APPENDIX B

ECONOMIC ASSESSMENT

In any technological investigation it is useful to carry out an economic analysis of the various processes and configuration that are being studied. This will not only provide a rough estimate of overall economic viability, but also helps to highlight the steps and variables that will be the most costly and therefore deserves mores study and investigation.

Considering a hypothetical community of 50,000 persons and suitable design values for tropical developing countries. The community will produce:

FLOWRATE - 50,000p. x 140l/p.d. = 7×10^3 $m^3/d.$

BOD5 - 50,000p. x 50g/p.d. = 2.5×10^3 kg.BODs/d.

COD - 50,000p. x 70g/p.d. = 3.5×10^3 kg.COD/d.

Based on an areal loading rate of 300 kg.BODs/ha.d.

- Facultative Pond Area = $(2.5 \times 10^3)/300$ = 8.4ha.
- Volume of Pond (1m deep) = 8.4ha. x 1.0m = 8.4×10^4 m^3
- Detention time = $[8.40 \times 10^4]/(7 \times 10^3)$ = 12 days.

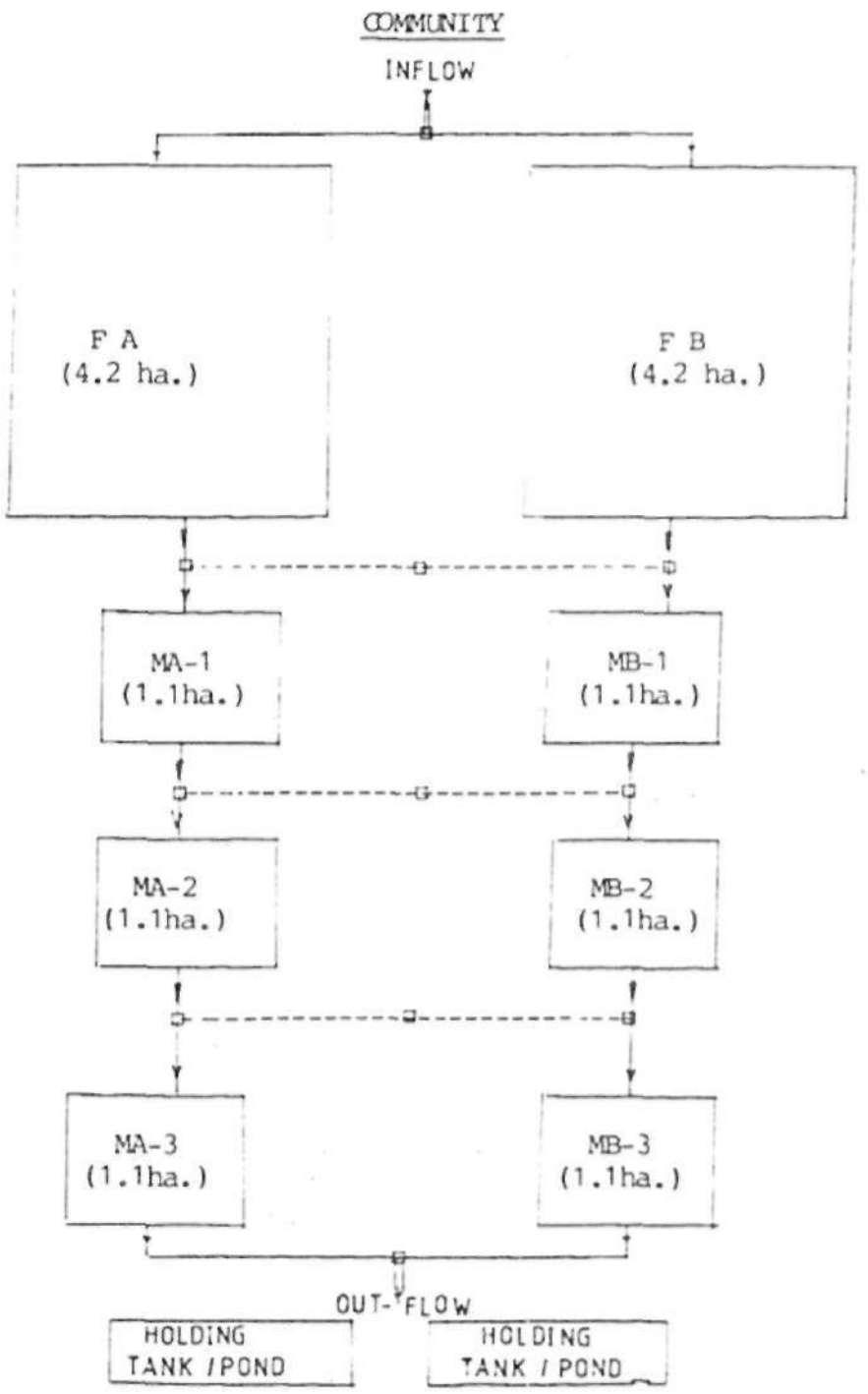
Based on a 5-day detention time in each maturation pond.

- Capacity of maturation pond = $7 \times 10^3 \times 5 = 3.5 \times 10^4$ m^3
- Required capacity of maturation pond, assuming a 40% loss in flow due to percolation and evaporation the facultative pond = $0.60 \times 3.5 \times 10^4$ m^3 = 2.1×10^4 m^3
- Required surface area of maturation pond (1.0m deep) = 2.1ha.

Two facultative ponds, (FA and FB) in parallel can be provided, and each connected to a series arrangement of three naturation ponds. Provision for series operation could also be made.

Parallel Operation: FA - MA1 - MA2 - MA3
FB - MB1 - MB2 - MB3

FIG. B-1 PROPOSED STABILIZATION APOND SYSTEM LAYOUT FOR HYPOTHETICAL



NOTE: NOT TO SCALE

Fish can be stocked in any of the two ultimate (MA3 and MB3) or penultimate (MA2 and MB2) maturation ponds. Using a fish stocking of 2.5 $fish/m^2$, a total of 2.5 $fish/m^2$ (1.1 $x10^4$ m^2 x 2) = $5.5x10^4$ fish fingerlings

If a growth rate of 0.83g/d. is attained, then a one year stocking of fish gives a yield of $5.5x10^4$ x 0.83g/d x 360 = 16,400kg. fish/year.

Capital cost involved in the stocking and harvesting of fish in the maturation ponds:

- Cost of fish rack and net	-	N 2,500.00
- Cost of cold storage equipment	-	N 7,500.00
- Cost of holding tank (off-flavour treatment	-	N 5,000.00
		N15,000.00

Additional recurrent expenditure involved in stocking and harvesting of fish in the maturation ponds:

- Cost of fingerlings of $5.5x10^4$ @ N0.15/fingerling	-	N 8,250.00
- Additional labour costs in harvesting and transportation	-	N 6,750.00
		N15,000.00

Based on Mara's (1976) suggestions on labour requirements, a supervisor and six labourers are required. Cost of labour:-

- 1 Supervisor @ N5,000/annum	-	N 5,000.00
- 6 Labourers @ N2,000/annum	-	N15,000.00
		N20,000.00

Revenue from fish yield (assuming a 20% loss due to handling and other losses) at N4.00/kg. of fish:

(16,400kg. x 0.8) x N4.00/kg.	-	N52,480.00