Intermediate treatment involves the use of chemical coagulants to improve solids removal in the sedimentation process. This method is more widely used in industrial nations where it provides certain advantages. However, the disadvantages of this process for developing countries include the following: the transportation time and costs of chemicals, the degree of sophistication required to properly handle the chemicals. the increased volumes of settled solids produced, and the increased difficulty in dewatering the solids produced such that they may be applied to the soil as fertilizer.

Secondary treatment, or biological treatment, is facilitated by microorganisms either aerobically or anaerobically. The microorganisms decompose or stabilize waste materials, initially by a transfer of organic compounds to the biomass. This biomass may be free floating, affixed to stones, or present in the interstices of soils and sands. The rapid transfer of organics to the microorganisms is followed by oxidation and subsequent utilization of the organic matter for the growth of new organisms.

Methods used for secondary treatment include intermittent sand filters, trickling filters, activated sludge, stabilization ponds, and oxidation ditches. Some of these methods are applicable to developing countries and will be discussed later in this section.

Tertiary treatment, or "advanced" waste treatment, provides greater removal of suspended solids and reduction of BOD than does secondary treatment. In general, the methods used require considerable sophistication in design, construction, and operation and are rarely performed even in developed countries. The treatment processes are primarily utilized for the removal of specific constituents under special conditions, such as intensive industrialization, high population density, and limited resources, at a high cost.

Conventional sewage treatment plants have not been detailed here; the emphasis is on feasible alternatives for rural areas and less developed urban areas. Although conventional treatment plants do exist in some developing countries, they are not viewed as the best alternatives for numerous reasons (Gloyna, 1971; Mara, 1977). These disadvantages include the following:

- The methods involve many stages.
- They require highly technical training of personnel.
- They require equipment that must be imported.
- They are not well suited to tropical climates (i.e. low-rate trickling infiltration).
- They are wasteful of water (a critical concern for many arid and semi-arid developing countries); and produce large quantities of sludge that must be treated before disposal.
- They are overall expensive to install and maintain, and therefore may only serve the wealthy.

<u>Waste Stabilization Ponds</u>

Waste stabilization ponds are generally the most highly recommended wastewater treatment methods for developing countries (Mara, 1977; Okun & Ponghis, 1975). The ponds are simple shallow earthwork basins requiring virtually no equipment and a minimum of material. Construction may be economically accomplished by hand where labor is plentiful, or with earth moving equipment where this is readily available. Additionally, waste stabilization ponds are the least expensive alternative for community wastewater treatment in developing countries with no compromise in effectiveness. In fact, these are the most effective alternative in terms of destruction of pathogenic bacteria and ova of intestinal parasites. Disadvantages associated with this process are that relative large areas of land are required and that, in cold climates, odors are produced after freezing and thawing of pond surfaces. These drawbacks are insignificant in most developing countries.

The design of a waste stabilization pond is dependent upon the treatment objectives. Although the pond system is generally designed to receive untreated domestic or industrial wastes, it may also be designed to treat primary or secondary plant effluents, excess activated sludge, or diluted nightsoil. Additionally, ponds may be used to pretreat wastes, reducing BOD and populations of pathogens.

Many different names are commonly used for waste stabilization ponds, including sewage lagoons, oxidation ponds, redox ponds, maturation ponds, facultative lagoons, anaerobic lagoons, aerobic stabilization ponds, and mechanically assisted oxidation ponds. For the purposes of this manual, the following definitions provided by Gloyna (1971) will be used:

"The term waste stabilization pond is used to describe any pond or pond system designed for biological waste treatment. A pretreatment anaerobic waste stabilization pond is essentially a digester that requires no dissolved oxygen, since anaerobic bacteria break down the complex organic wastes. An aerobic waste stabilization pond is one in which aerobic bacteria break down the wastes and algae, through photosynthetic processes, provide sufficient oxygen to maintain an aerobic environment. A facultative waste stabilization pond is one in which there is an upper aerobic zone (maintained by algae) and a lower anaerobic zone. Aerobic, facultative, and anaerobic organisms might be found in a facultative waste stabilization pone. A mechanically aerated waste stabilization pond is one in which mechanical aerators either supplement or replace algae as a means of providing the required dissolved oxygen. This type of pond may function as an aerobic or facultative system. In some mechanically aerated ponds the turbulence may not be sufficient to keep all solids in suspension; therefor, sludge may settle and undergo anaerobic decomposition while most of the pond remains aerobic.

"Ponds receiving untreated wastewaters are referred to as raw or primary waste stabilization ponds. Ponds receiving effluents from primary settling tanks or secondary biological treatment units are called secondary waste stabilization ponds. Similarly, a second or third pond in a series of ponds functions as a secondary facultative or aerobic treatment unit. A pond whose primary function is to reduce the number of disease causing microorganisms through extended detention time is called a maturation pond. A maturation pond may also be used to rear fish such as carp and it may then be termed a fish pond. The physical layout and mode of operation can also be used to categorize a pond system. Ponds may be designed to operate singly, in series, or in parallel.

"Most waste stabilization ponds, as at present used, are facultative treatment units. In this respect, they resemble rivers and lakes. Aerobic conditions are maintained near the surface and sometimes throughout most of the depth of the pond. However, an anaerobic environment persists near the bottom, where there will always be some settled organic debris."

Mara (1977) recommends a number of these methods in particular combinations as being most suitable and effective for developing countries. These include facultative ponds, maturation ponds, anaerobic pretreatment ponds, high-rate ponds, and mechanically aerated ponds (aerated lagoons). Additionally, he recommends oxidation ditches. All of these types of installations will be discussed here.

Facultative waste stabilization ponds are, as previously mentioned, the most widely used type of installation. Facultative pond depths are typically 1-1.5 meters. Shallower depths are not recommended since aquatic plant growth, and therefore mosquito breeding sites, cannot be prevented. Furthermore, depths greater than 1.5 meters promote excessive anaerobic conditions.

Facultative ponds may, depending upon the sequence in which they are used, require periodic desludging. This may occur every 10 to 20 years. Regular maintenance requirements are simple yet critical to proper pond operation. These include cutting of grass on the embankments and removing of scum from the surface of the pond. Although these operations are clearly simple to perform, training of operating personnel in the principles of operation and to recognize malfunctions is critical.

Maturation ponds typically follow facultative ponds in series. They are completely aerobic and their primary function is the reduction of fecal bacteria and the general control of final effluent quality. This control is governed by the size and number of maturation ponds. Optimal detention times vary with environmental conditions, however, minimal requirements are five to seven days (Bradley & Alvares Da Silva, 1976). Each pond is capable of a 90 percent to 95 percent reduction in fecal coliform numbers (Mara, 1977). The depth of a maturation pond may be as much as three meters, however, 1-1.5 meters is recommended for maximal removal of enteroviruses (Mara, 1977).

Anaerobic ponds are typically loaded with strong organic wastes and large populations of anaerobic organisms which quickly deplete all oxygen available in the influent. They are most useful for the treatment of strong organic industrial or agricultural wastes and as primary units followed by facultative and maturation ponds.

Anaerobic ponds are highly efficient in BOD removal and therefore reduce the total land required for a treatment facility. However, they require increased maintenance, i.e., they must be desludged more frequently than facultative ponds (3-5 years as opposed to 10-20 years). A potential problem associated with anaerobic ponds is odor production. This may be avoided, however, by proper design and maintenance of a proper volumetric loading (Mara, 1977).

High rate ponds are considered to be potentially beneficial for developing countries, however, at present, they are still used only experimentally. They are designed to receive high loadings of previously settled sewage and ultimately to convert the organic matter to protein, in the form of algal cells. These algae must then be harvested and used as feed for animals. The principles behind this method appear to satisfy numerous problems simultaneously. However, as yet, the process has not been adapted for practical use, primarily due to difficulties in harvesting the algae at reasonable cost (Mara, 1977).

High rate ponds are shallow in depth (20-40 cm) and therefore the photic zone extends to the bottom. Stabilization occurs rapidly, requiring only one to three days detention time.

Gloyna (1971) indicates that mechanical aeration provides a low-cost treatment alternative when waste loads increase, space is limited, and high quality effluents are required. In these ponds, aerobic and facultative organisms are supplied with oxygen by mechanical aerators (typically surface-type units). During this treatment process waste materials are rapidly converted to bacterial cells. These must be removed from the effluent, either by a series of maturation ponds or by conventional sedimentation tanks followed by aerobic sludge digestion.

Mara (1977) recommends preliminary treatment before entrance into the aerated ponds. Additionally, he suggests the system is most efficient when maturation ponds follow, in series, the aerated pond. If the sedimentation tank and sludge digester are chosen, however, he recommends using the oxidation ditch, rather than the mechanically aerated pond, since smaller quantities of highly mineralized sludge are produced by the former.

Clearly the aerated lagoon requires greater construction and maintenance inputs than do the previously described types of stabilization ponds. Depths are typically three to four meters and the bottom must be lined such that the aerator does not destroy or erode it. Mara recommends the use of either butyl rubber; masonry, or mass concrete as lining materials. Additionally, a reliable source of electricity with backup must be available to power the aerators. Training of personnel must, of course, be more extensive than with simpler types of ponds.

The oxidation ditch functions similarly to the aerated lagoon in that the oxygen is supplied by mechanical aeration and the resultant biological activities are similar. However, the oxidation ditch system is more complex, more costly, and requires a much higher degree of skill in its operation. The principal advantage of this system is that the sludge is recycled through the system. This provides three major benefits: the waste is oxidized more quickly, the sludge is more thoroughly stabilized and ready for drying, and less sludge is ultimately produced.

Oxidation ditches are long continuous channels 1.5-2 meters deep. Rotors maintain constant mixing within the ditches. Preliminary treatment is recommended (Mara, 1977). Operators must not only maintain the mechanical and electrical equipment in perfect operation, but must also control the suspended solids concentration by diverting the return sludge flow to the sludge drying beds on a daily basis. Additionally, the frequency at which this must be performed is determined only through monitoring of levels of suspended solids in each individual ditch (Mara, 1977).

The waste stabilization pond system may be comprised of one pond only (typically facultative) or, most frequently, of a number of ponds in sequence. As indicated in Exhibit 2, anaerobic and facultative ponds may be aligned either singly or in parallel. Where a higher degree of treatment is required, maturation ponds are added following facultative ponds. Also indicated are systems whereby wastes from aqua privies, mechanically aerated aerobic ponds, or primary or secondary biological treatment are further treated in facultative ponds.

Gloyna (1971) has provided a listing of suitable treatment alternatives for different waste characteristics. These are summarized in Exhibit 3.

Assessment and Planning Factors

Suggested methods of minimizing mosquito breeding through the design and control of construction features include: (a) designing the pond so as to permit complete water-level control and drainage, (b) clearing vegetation from the bottom before filling, (c) levelling the bottom, (d) designing the pond to hold water by artificially sealing the bottom with chemicals, clay, or other materials, and (e) proper maintenance of the embankment slopes.

It is desirable to erect some type of fence around the waste stabilization ponds. Signs describing the facility should also be displayed.

A certain number of hand tools are required, and the operator to whom they are supplied should be responsible for their proper use and maintenance. Hand tools that might be most useful include lawn mowers, barrows, saws, claw hammers, measuring tape, pliers, screwdrivers, wirecutting pliers, metal

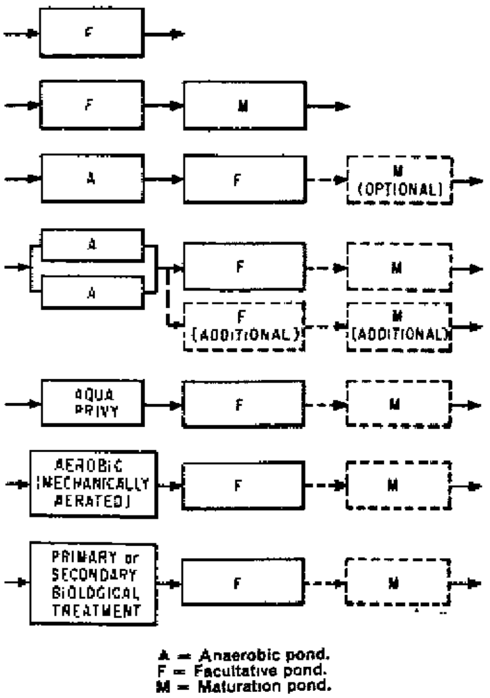

Exhibit 2 A number of typical waste stabilization pond systems (Gloyna, 1971) p. 58

Exhibit 3

Treatment Alternatives

Waste Characteristics	Suitable Treatment Processes
High solids content (i.e., nightsoil with minimum water added)	a. A + F b. A + F + M
Water-carried waste (domestic only)	a. A + F + M b. F c. F + M
Water-carried waste (domestic and industrial	a. A + F + M b. F c. F + M d. MA + F + M

A = anaerobic pond
F = facultative pond
M = maturation pond
MA = mechanically aerated pond

shears, pipe cutters, pipe seamers, pipe wrenches, pipe vices, grinding wheels, and scrubbing brushes.

For some facilities it may be desirable to provide a portable petrol-driven pump, light and heavy duty hoses, a portable insect spray applicator, a small rowing boat, grease guns, suitable grease and oils, a supply of paints, and a stock of certain spare parts that are not readily obtainable.

Provision should be made for determining the volume and BOD concentration of the waste water in a waste stabilization pond. For large facilities, routine flow and analytical measurements should be made. Flow measurements are needed to determine the most efficient mode of operation and to provide data for future additions to the treatment plant. Periodic measurements indicating the influent and effluent concentrations of BOD and coliform organisms are desirable. These tests can be carried out by inspectors sent from a central laboratory.

Additional measurements that might make for better control and more efficient operation include: (a) diurnal pH and oxygen fluctuations in the ponds, (b) pH of the influent and effluent, (c) total solids, suspended solids, and volatile solids in both influent and effluent, (d) total organic nitrogen, ammonia, nitrates, and phosphates in the influent and effluent, (e) oxidation reduction potential in the various ponds, particularly in the anaerobic pretreatment unit, (f) detailed chemical analyses of either the influent or the domestic water supply, (g) chemical oxygen demand, particularly if industrial wastes are involved, (h) ultimate BOD, (i) sulfate ion content of influent waters, and (j) the biochemical degradation rate K_T for various temperatures. Obviously, not all of these measurements are necessary for the operation of small or medium-sized facilities, but the list illustrates what might be desirable for the best management of larger and complex facilities, including research establishments.

Control of insects is important. The degree of mosquito infestation in ponds is in direct proportion to the extent of emergent vegetation. Both Culex and Anopheles larvae have been found in poorly operated ponds. If water is available, the ponds should be filled immediately to operational levels to discourage the growth of vegetation. Undesirable vegetation in the ponds or on the dikes must be eliminated periodically by cutting or by using a suitable herbicide. The cut plants must not be permitted to float on the pond, for this will provide shelter for mosquitos. Similarly, water-loving trees such as willows and poplars should not be planted around the ponds.

Larvicidal measures should be undertaken if significant mosquito breeding takes place. The following larvicides have been used effectively in some ponds: a thin layer of kerosene or diesel oil, two percent DDT and oil, lindane dust (3% gamma isomer), and 2 percent malathion. Caution should be exercised when using these substances, for excessive use may produce harmful effects on receiving watercourses.

The introduction of top-feeding minnows (Gambusia) to secondary or tertiary ponds is another effective way of controlling certain larvae. Other fish, such as Tilapia mossambica and T. melanopleura, and the guppy (Poecilia reticulata) have also been used successfully for the control of mosquitos in maturation ponds and some underloaded facultative ponds.

The heavy scum layers that may form on anaerobic ponds can be conducive to fly breeding. Both the common housefly, Musca domestica, and the filter fly, Psychoda, common in trickling filters, can breed in or around anaerobic pretreatment ponds and at the scum-laden edges of poorly operated facultative and aerobic ponds. One method of fly control is to break up the scum by frequent wetting. Fly-traps with poisoned bait can also be used around anaerobic pretreatment units.

Around anaerobic ponds, particularly those in which animal wastes are treated, flies can become a serious problem. The larvae of the common housefly, Musca domestica, and the biting stablefly, Stomoxys calcitrans, develop in most forms of organic sludge. Fortunately, the ponds themselves are not as attractive to the adults of these species, nor are there likely to be live maggots in well-managed anaerobic ponds, although Musca larvae and pupae may be contained in poultry manure and some adults may emerge if the manure accidentally floats to the surface (Hart & Turner, 1965).

Midges have occasionally created a nuisance. In New Zealand, the indigenous midge Chironomus zealandicus has caused considerable trouble when ponds were not loaded to the capacities for which they were designed. However, the midge population can be controlled by increasing the organic load on the ponds. Chemical control around the perimeters of the pond has also proved initially effective, although it has often been followed by the development of insecticide resistance.

Embankments should be inspected regularly for erosion due to wind, wave action, surface run-off, or burrowing animals. Any necessary repairs to the embankment must be made immediately after the damage occurs. The dikes should be seeded with grasses, fertilized and mown. Long rooted plants such as alfalfa should not be used because they may impair the water-retaining capacity of the dike.

Odors may arise from a number of situations. Frequently they are associated with the decay of mats of algae that have been blown to a bank or corner. Chlamydomonas, for example, can grow rapidly, spread over pond surfaces, reduce the penetration of light to the remainder of the pond, and with the assistance of the wind accumulate in the corners where it decomposes and produces vile odors. In other instances, particularly during periods of high water temperatures in shallow ponds, sludge mats rise from the bottom. These masses of organic debris usually accumulate in corners, and if it is not disturbed, the entire mass may become covered with blue-green algae. Usually the bacterial activity is intense and the odors are overpowering.

The solution to the mat problem is immediate dispersal. Agitation of the surface will usually cause the floating mass to break up and settle to the bottom. A jet of water from a garden or fire hose will normally create enough turbulence to achieve this. Another remedy employed by some is to use an outboard motor or an engine-powered paddle wheel to agitate the surface. Such devices have the advantage of flexibility in that they can be mounted on rafts and moved from place to place.

In all probability, an odor or a change in color is a warning of a major change in the performance of a pond system and operators should be alert to recognize such signs. Frequently, odors accompany illicit waste releases that cause a rapid change in the pond biology. Normally a maturation pond has a characteristic green color; the facultative pond most frequently appears green or brownish green, but may occasionally look quite pink or exhibit some other variation in color; the anaerobic pond looks greyish black.

When the characteristic green color of a pond begins to change or disappear, the operator should look for things that may be causing this. Changes in the volume, organic load, temperature, light, turbidity, etc. may cause changes in the existing algal pattern. A color change from green to black, accompanied by floating mats of material from the bottom of the pond, usually indicates rapid fermentation of the bottom sediments, frequently as a result of changes in pond temperature or in the character of the waste-water.

Occasionally ponds receiving either domestic or industrial wastes develop a pink color. This is sometimes occasioned by the development of colored microorganisms, particularly in facultative ponds during the summer and autumn if the sulfide or sulfate concentration is high. Chief among the types that have been noted are Chromatium, Thiospirillum, and Thiopedia, but other small rod-shaped and spiral forms have also been detected. The larger microorganisms such as Chromatium and Thiospirillum are mostly restricted to ponds receiving typical municipal wastes, while Thiopedia rosea and smaller forms are likely to be present in ponds receiving industrial wastes. Generally these microorganisms are associated with waters that contain excess hydrogen sulfide.

The presence of such colored microorganisms seems to indicate some prior overloading, stratification, or operational deficiency. Invariably, a pond receiving industrial wastes that contain relatively large amounts of BOD and hydrogen sulfide or sulfates will support periodic blooms of these microorganisms.

Sulfides in a pond can be oxidized by colorless sulfur bacteria and by colored photosynthetic bacteria. The top layer of the pond, where both dissolved oxygen and hydrogen sulfide can occur, offer the best environmental conditions for the growth of colorless sulfur bacteria, but such bacteria are not often found in stabilization ponds, or occur only in rather small numbers. The oxidation of sulfides by colorless sulfur bacteria is therefore negligible compared with that by photosynthetic bacteria and by dissolved molecular oxygen. Photosynthetic sulfur bacteria are very often found in large numbers in stabilization ponds, particularly during the summer and autumn, and impart to the pond a characteristic brown or red color.

In all of these cases, the appearance of photosynthetic sulfur bacteria was accompanied by a reduction in hydrogen sulfide odors: for this reason these bacteria are sometimes referred to in the literature as "biological deodorizers."

In a comprehensive study of the activities of photosynthetic sulfur bacteria in waste stabilization ponds, Green (1966) found that the brown color sometimes imparted to the pond occurs when the concentration of sulfide in the pond is high and the photosynthetic bacteria store it as sulfur granules in the cell; when the sulfide concentration decreases and the sulfur granules are oxidized by the cell, the color imparted by photosynthetic sulfur bacteria is a vivid red. Because of their photosynthetic activity, these bacteria do not help to reduce the BOD of the wastes and may even tend to increase it (Green, 1966). It should be remembered that this photosynthetic activity does not produce any molecular oxygen.

Trees will interfere with the performance of the pond. Large trees will impede the natural wind action and may reduce the light intensity at the surface of the pond. Moreover, leaves falling into the pond will interfere with photosynthetic processes, add to the BOD load, and possibly create insect control problems. Wherever possible, large trees within 40 to 60 meters of the pond embankment should be removed.

The hydrodynamic and physical shape of a pond has a distinct effect on its performance. For example, surface aeration and photosynthetic oxygenation can be enhanced by both thermal mixing and wind action. Both forms of mixing are beneficial.

When the temperature is falling, mixing can occur without wind action. During periods of rising temperatures, however, wind action is required, and then stratification usually occurs. Dye tests have verified these observations. Wave action is determined largely by the fetch, i.e., the continuous extent of exposed water. A fetch of about 300 meters will usually ensure circulation and mixing to a depth of 1 meter.

Wastewater Disposal

Some streams may best be used for receiving wastewaters. While the stream water quality may be low, in no instance must it become a public nuisance, as would result, for example, from a complete disappearance of oxygen. Even to achieve this low standard will often require a high degree of treatment— in areas where water resources are limited, stream flows are low and wastewater loads are high.

The quality of the wastewater that can be discharged into a stream will be a function not only of this standard quality and the flow in the stream, but also of the ability of that stream to assimilate wastes and to purify itself. Streams, lakes, and oceans, when polluted with biodegradable organic wastes, may purify themselves naturally and return to virtually their original state if the amount of pollution is within their assimilative capacity.

When an organic waste is discharged into a watercourse, the turbidity of the water tends to increase. At the same time, the oxygen requirements of the wastes tend to reduce the oxygen content of the stream. This is maintained both by surface reaeration and by photosynthesis, the process whereby green plants and algae remove carbon dioxide from the water and supply oxygen to it. The increased turbidity interferes with the passage of the sunlight necessary for photosynthesis, so that the reaeration capacity of the stream is somewhat reduced. The wastewaters themselves may also interfere with oxygen transfer at the surface of the stream, thus further reducing reoxygenation.

The stream begins to recover when the rate of oxygen demand created by the wastes begins to be exceeded by the rate of reoxygenation; the latter is proportional to the DO deficit. High stream flows, turbulent flows, low temperatures, and a well balanced ecological system all tend to contribute to high assimilative capacity. If a stream is to be maintained for its designated use the year round, the critical period is during low flow periods in the summer when the assimilative capacity is lowest and the requirements are generally the highest.

Where waters are to be used for drinking, the coliform count is of interest. Conditions that make for high assimilative capacity with regard to BOD may be the very conditions that tend to preserve the coliforms, and with them any pathogens that may be present. Low temperatures and high velocities in a stream which provide a high assimilative capacity, may mean that viable organisms are carried to a downstream water intake in greater numbers than is the case where the water is relatively slow-moving and the temperatures are high, thus favoring bacterial die-away. Consequently, a stream pollution investigation aimed at determining the degree of treatment required cannot always be based on the same set of parameters, but must also take into account the purposes to be served by the waters in question.

While a large number of quantitative approaches have been developed for assessing the assimilative capacity of streams, from the point of view both of organic matter and microorganisms, these are seldom directly applicable to streams that have not previously been studied. Those responsible for studies of the assimilation capacity of streams must therefore initiate programs of data collection and comprehensive studies of water quality, and relate them to the pollution of the stream, so that the assimilative capacity can be determined by means of the formulae that have been developed. It is beyond the scope of this publication to describe the methods used for determining the assimilative capacity of receiving waters. A useful introduction to this subject is given by Fair et. al. (1968) and by Klein (1959-1966).

For the disposal of wastewaters into lakes and oceans, a somewhat different approach must be used because the dispersion of the effluents may be poor or highly variable and uncertain. Effluents tend to be less dense than lake waters or seawater because lakes are generally colder than wastewaters and seawater contains high salt concentrations. Wastewaters, therefore, tend to rise to and remain at the surface, where they cause the greatest nuisance.

Wastewaters should therefore be discharged at as great a depth as pssible, so as to promote mixing and dilution. Physical, chemical, and biological studies are often required in order to determine the assimilative requirements for the protection of the ecosystems. In addition to the conventional methods, radioactive tracers may also be used in large projects for studying dilution and dispersion. Graham and Valdes-Pinilla (1971) have described such investigations on the marine disposal of wastewaters from Manila.

Marine outfalls often constitute an economical means of wastewater disposal because the high dilution available and the lack of evidence of harm to health from bathing in polluted seawater reduce treatment requirements. Rawn et. al. (1961) have developed guidelines for the depth of discharge of an outfall in order to achieve desired dilution ratios. Even with adequate dilution, however, preliminary treatment, i.e., screening or flotation, is necessary to prevent floating solids from being blown on shore or fouling the water. Many successful designs of outfalls have been described (Pearson, 1960).

Experience with prolonged marine disposal of treated and untreated wastewaters has demonstrated serious adverse effects on the ecological balance of the marine environment. These long term consequences and current research in this area should be examined before using this method of disposal.

Wastewater Reuse

Wastewater reclamation has different meanings for different countries, depending on the particular needs or interests of the region concerned. For example, it may mean the use of wastewaters for irrigation, for culturing fish, for the creation of recreational facilities, for industrial use, or for groundwater recharge. These issues are of particular concern in areas where water and/or food are scarce.

Additionally, there may be economic advantages to be gained from the reuse of wastewaters. Clearly, the most efficient system for dealing with human wastes is one that incorporates reuse into it. However, as with all environmental issues, tradeoffs must be made, giving due considration to costs, technological feasibilities, cultural priorities, etc. This is clearly illustrated by the fact that although thorough treatment of wastewaters for unrestricted use would be acceptable in terms of health and environment, the costs of achieving that level of purification are prohibitive.

The reuse methods to be considered in the following sections include agricultural use, fish ponds, biogas plants, industrial use, and recreational use. Additionally, a final section will discuss handling and disposal of sludge.

The principal uses of excretary materials in agriculture are as fertilizer or as irrigant. Both have been practiced in many parts of the world for many years. Ideally, these methods provide optimal solutions for developing countries, returning nutrients to the soil, recycling wastewaters, and contributing to the production of much-needed food. However, these benefits must be weighed against the potential risks to the population of contracting any of the numerous communicable diseases known to be present in wastewaters. Direct application of human excrement to the soil presents definite public health hazards. Most conventional treatment processes cannot completely remove pathogens from wastewaters, with the exception of highly complex and expensive processes. Shuval (1977), in a review of these issues, proposes a compromise whereby feasible technologies are used, however, effluents are only applied to certain types of crops, thereby reducing the potential public health risk.

Okun and Ponghis (1975) describe the differential standards recommended by the World Health Organization for agricultural uses of treated wastewaters. The following categories are differentiated in order of increasing quality requirements.

- Orchards and vineyards.
- Fodder, fiber crops, and seed crops.
- Crops for human consumption that will be process to kill pathogens.
- Crops for human consumption in the raw state.

Fish ponding with waste materials is widely practiced in Asia. Wastes including sewage, nightsoil, animal manure, and plant wastes are deposited in ponds as either pond fertilizer or fish feed. This method provides an effective means of utilizing valuable organics and other nutrients as well as an effective means of disposal and treatment. Numerous approaches are in practice in different parts of Asia. For example, in India, raw sewage is fed into fish farms; in China, Indonesia, and Malaysia, latrines are built directly over the fish pond; in Thailand, Taiwan, and Sri Lanka, nightsoil is collected by cart and transferred to fishponds (McGarry, 1977). Additionally, in many European countries, biologically treated sewage effluent is fed into fish ponds where fish culture becomes a form of tertiary treatment.

In spite of this widespread practice, the health consequences of eating the fish from ponds are not well understood. Where fish are eaten raw, certain parasites capable of existing in fish and other aquatic organisms as intermediary hosts are definitely a disease problem (McGarry, 1977). Further research is recommended before this method be applied in areas not already using it.

Biogas Plants

The biogas plant provides a relatively simple means of generating methane gas by fermentation of human and farm wastes. The process involves anaerobic digestion of the wastes and collection of the gases produced. Additionally, the solids, or effluent slurry may be used as soil conditioner or fertilizer.

Various types of materials may be fed into the biogas plant including nightsoil, animal waste, and vegetable waste. McGarry (1977) discusses the health and economic implications of the biogas plant. He indicates that the financial viability of the method has not yet been determined nor has its cultural acceptability. Nevertheless, it is fairly effective in destroying most pathogens. McGarry recommends this method as worthy of consideration for developing countries.

Imhoff tanks accomplish both sedimentation and sludge digestion in a single, two-story structure. They are widely used throughout the world, particularly in small communities. One reason for this is that operation and maintenance for Imhoff tanks is less complex and therefore less costly than many other methods. Imhoff tanks are well suited for use in warm climate countries where local temperatures facilitate the decomposition of waste matter. These systems cannot be heated and therefore may not function well in cold climate.

Among the few, yet important, maintenance requirements are cleaning of gas vents and removal of a certain percentage of the sludge periodically to reduce odors. Neither of these duties requires a high level of technical skill.

Wastewater treatment plant effluents may be used as industrial water supplies. Initially, such effluents were used in areas where other water supplies were not available; their use was later extended to situations where effluents were cheaper than piped water supplies because of the close proximity of the wastewater treatment plant and the high cost of potable water.

Possible reuse of treatment plant effluents in industrial processes is limited by the following requirements. Adequate volumes of effluent must be continuously available. The effluent must be suitable in quality or the cost of the necessary processing must be less than that of treating alternative supplies. The use of wastewater in the process must not endanger public health.

Quality requirements in the reuse of wastewater in industry depend on the industry and on the specific use within the industry. For once through cooling, the requirements are the least stringent. Where wastewater is to be used in cooling towers, however, salts and nutrients may cause serious difficulties. Nutrients, in particular, encourage the growth of slimes, and large quantities of chlorine may be required to prevent clogging of the towers.

An additional requirement to be satisfied by wastewater for industrial use is that the quality should not be highly variable. An equalizer or storage basin for the treated wastewater can be used where the industrial demand varies; it will also smooth out variations in quality in the discharge from the treatment plant. Industrial requirements are generally so variable that special efforts to provide wastewater for industry should not be made until the specific industrial operation to be served has been identified.

Specialized treatment (activated carbon, electrodialysis, distillation or reverse osmosis) to remove refractory and inorganic materials should normally be provided by the industry concerned.

The quality required of a treated wastewater effluent will vary with the types of recreational activities to be performed and the size of the body of water into which it is discharged. Typically lakes are used for a variety of activities such as water-contact sports and boating and fishing. The wastewater used for these purposes should undergo primary and secondary treatment. Additionally, for water-contact sports, disinfection may be required.

Sludge Handling and Disposal

Sludge, composed of solids removed from wastewater through treatment plus any water entrained with those solids, accumulates to varying degrees with different treatment processes. If a method of treatment is chosen, or already is in existence, which produces large quantities of sludge, these must be handled (i.e., dewatered, destabilized), and disposed in some manner.

Accepted methods of sludge handling include concentration, digestion, dewatering, drying, and incineration. Initial handling may involve either concentration or digestion, followed by dewatering, drying, and/or incineration. Digestion followed by air drying on sludge drying beds has been recommended for use in developing countries (Okun & Ponghis, 1975). Additionally, lagoons are recommended for drying (drying lagoons) or for ultimate disposal of predigested sludge (Okun & Ponghis, 1975).

There are numerous technologies available for sludge handling and disposal. Examples of these include vacuum filtration, solid drying beds, filters, filter presses, and centrifugation. Those methods and others are extensively described in Treatment of Sludges by Vesiland (see Recommended Resources). The ultimate disposal of sludge should minimize both environmental and health hazards. Alternatives include disposal in permanent lagoons, sanitary landfills, or as soil builder.

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