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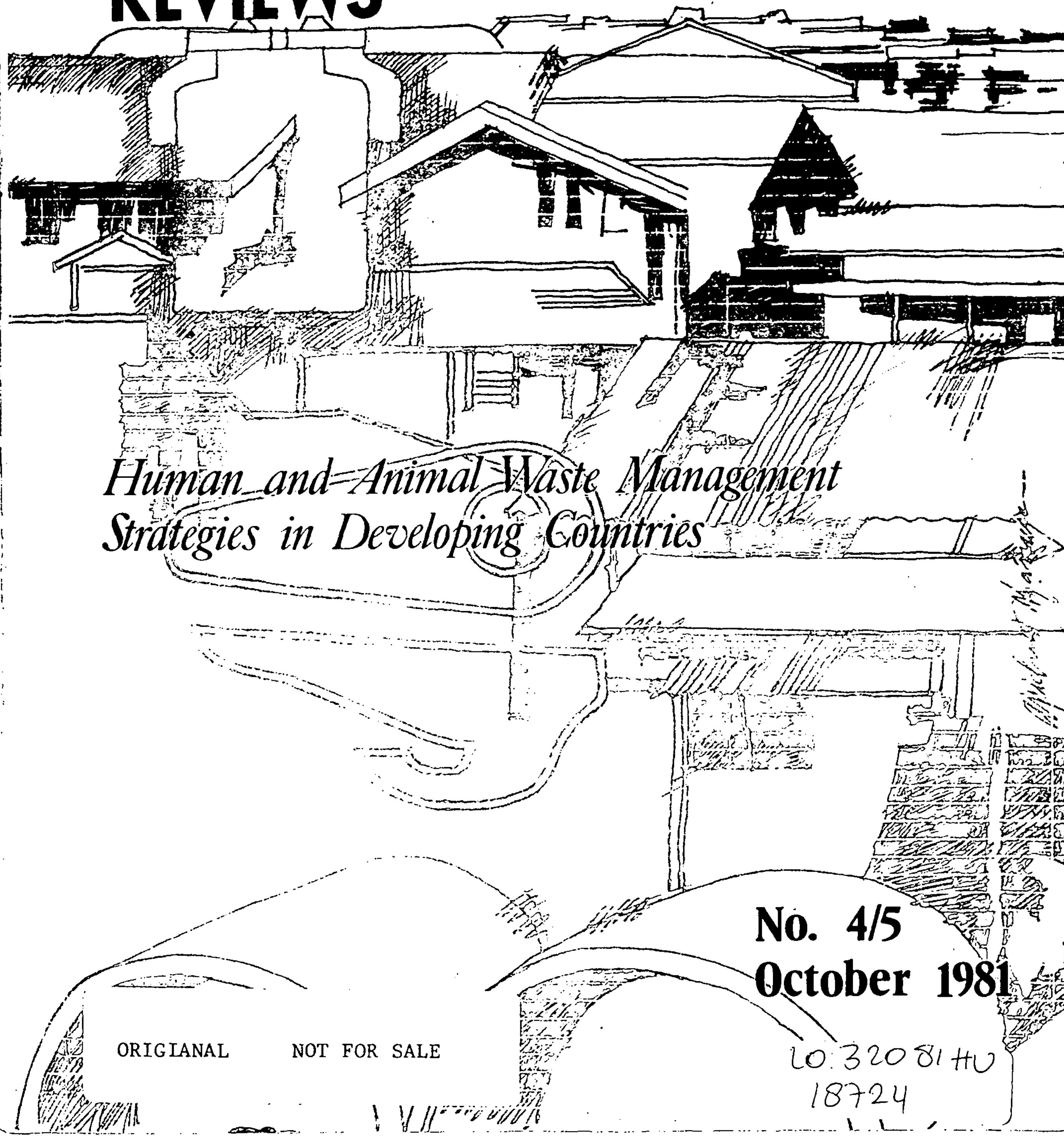

Human and Animal Waste Management Strategies in Developing Countries

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HUMAN AND ANIMAL WASTE MANAGEMENT STRATEGIES IN DEVELOPING COUNTRIES

by

ENSIC Review Committee on Waste Management

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CONTENTS

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1. INTRODUCTION

In many developing countries there is a direct conflict between economic development on the one hand, and environmental pollution control on the other. While the former provides greater employment leading to a generally higher standard of living, the latter commands a low priority in terms of national investment. This is because it has not been realized in these countries that the quality of the environment in which we live, work and play affects the quality of life itself and that there is an obvious interaction between the two. Rapid population growth, increasing urbanization and industrial development in developing countries have resulted in a deterioration in the quality of the environment. Pollution abatement strategies in these countries should be consistent with the nature of the environment and appropriate for the local conditions. The problem is all the more complex in these countries due to the high rate of illiteracy, which indirectly affects public attitude towards pollution abatement measures, and also due to funding limitations on the part of local agencies (1,2). Beneficial meteorological and socioeconomic conditions i.e. utilizing the tropical climate and cheap labor prevalent in these countries, should be taken advantage of in planning waste treatment systems. For economic reasons, employing low cost treatment alternatives in lieu of sophisticated technologies utilizing imported equipment, will be preferable (3).

2. SCOPE AND OBJECTIVE OF THE REPORT

The objective of this document is to review briefly in general the various treatment alternatives for waste management, both human and animal, and to identify those alternatives that have particular relevance or importance to developing countries. Some selection criteria have also been outlined to aid in the choice of the most appropriate technology, taking into consideration technical, economic, health and sociocultural factors. The scope of this review is restricted to human and animal wastes and merely provides an overview of the various options available for waste treatment and disposal in developing countries. No attempt has been made to provide detailed design considerations for the various options. ENSIC is undertaking detailed studies of these different alternatives separately, and two such studies have been published in the past (4,5).

3. THE WASTE PROBLEM

With increasing urbanization and industrial development it is natural to expect an increase in the production of pollutants. Similarly, with increases in farm size and productivity per farm worker livestock production also takes on the characteristics of industrial complexes. It is now quite obvious that some livestock production techniques potentially can have detrimental effects on environmental quality.

In developed countries like the U.S., Japan, etc., these problems are quite evident. For example, in Japan, the quality of nightsoil produced amounts to 119,945 kl/d (FY 1975) (6). The total quantity of domestic wastewater influent in the 8 treatment plants that serve the inner city of Tokyo was estimated in 1978 to be 5240000 cubic meters/day. The volume of sludge produced after secondary treatment by the eight wastewater treatment plants in Tokyo inner city was 3400 metric tons (25% of solids content) (7). It has been predicted that in New York State in the U.S. the quantity of sludge generated annually may almost double during the years 1975-1985 from 356,000 dry tons to 689,000 dry tons (322,956 tonnes to 625,047 tonnes) (5). The total number of animals in the United States in 1972-73, those in feedlots or confined housing, and the total daily waste production and 5-day BOD for different animals are shown in Table 1 (9).

Although the awareness for environmental degradation is not so prevalent in developing countries, the potential problem very much exists and is envisaged to escalate with increased urbanization, increasing population densities, construction and improvement of sewage treatment facilities and increases in farm size and productivity per farm worker. The total human population in the world as of 1977 is about 4.1 billion of which developed countries contribute about 1.1 billion and developing countries about 3 billion (10). The total population in developing countries is almost 3 times as much as all developed countries. Hence we can expect a greater domestic waste generation rate in these developing countries. The problem is all the more critical since these countries have very few treatment facilities and a major portion of the domestic sewage and sludge go unnoticed or uncared for, into the environment. This could be highly detrimental in the long run. Some examples of the magnitude of domestic waste generated in some developing regions is shown in Table 2, from which the potential problem is readily evident.

Similarly, livestock pollution in developing countries has received very little attention, possibly because this contribution is viewed as natural and too insignificant to be considered along with the more complex problems caused by the urban centers. However, it may be envisaged that livestock production too will take on the characteristics of industrial complexes as farm sizes increase. Besides, the population of livestock is much more in the developing countries as compared with that in the developed countries. This is depicted in Table 3. Hence the problem may be greater in developing countries since an increased quantity of waste will be produced. Tables 4 and 5 illustrate the tremendous

Table 1. Waste Production by Various Animals (9).

Animal	Population as of 1972-73, in millions	Numbers in feedlots or confined housing, in millions	Average weight of animal, in pounds (kilograms)	Total waste[a] in pounds/ head/day[b] (kilograms/ head/day)	BOD_5 in pounds/head/ day[b] (kilograms/head/ day)	Population equivalent
Beef Cattle	101	14	800 (363)	40-60 (18-27)	1.0-1.5 (0.45-0.68)	8-10
Dairy Cattle (milk cows, replacement heifers, breeding stock)	16	11.5	1,300 (590)	96 (44)	2.0 (0.19)	–
Swine	62	Almost 100%	100 (45)	–	–	2
Chickens						
Broilers[c]	468	100%	–	0.05 lbs/ lb/da	0.0044 lbs/ lb/da	–
Laying Hens	478	100%	–	0.059 lbs/ lb/da	0.0044 lbs/ lb/da	–
Sheep and lambs	17.7	4.2	–	15.5 (7.0)	0.35 (0.16)	2
Turkeys	90[d]	Almost 100%	15 (6.8)	0.90 (0.41)	0.05 (0.023)	1/3
Ducks	1.86	100%	3.5 (1.59)	–	0.011-0.065 (0.005-0.029)	–
Horses[c] *(pleasure, farm racing)*	7.5	0.275	–	82 (37)	0.8 (0.36)	–

[a] Total excreta including faeces and urine.

[b] All units for waste and BOD_5 production are in pounds (kilograms)/head/day except for those for chickens (broilers and laying hens) in pounds/pound of bird/day as indicated.

[c] Manure for broilers and horses is mixed with bedding material or litter.

[d] Given peak population of turkeys during summer due to seasonal operations.

Table 2. Human Waste Production in Some Developing Regions.

Region	Year of Report	Nature of Waste	Quantity generated	Ref.
Rangoon	1978	Nightsoil	12,000–15,000 gal./day	11
India	1978	Sewage	800 MGD	12
India	1978	Sludge	300,000 tons/year	13
Bangkok, Thailand	1980	Sludge *	600 m^3/day	127

* from cesspools serving 4.2 million people

Table 3. Livestock Population in 1977 – 1000 head (10).

Region	Horses	Cattle	Buffaloes	Pigs	Sheep	Goats	Chickens	Ducks
World	61561	1212861	130863	666274	1027859	410343	6335085	155167
Dev'ped All	22264	439025	828	296724	504407	23999	2903431	49439
Dev'ping All	39296	773836	130035	369550	523451	386344	3431654	105728

Table 4. Livestock Waste Production in Some Developing Countries.

Country	Year Reported	Nature of Waste	Quantity Produced	Ref.
Burma	1978	Cattle Manure	27.1 million tons	11
India	1978	Cattle Dung	880 million tons	12
Malaysia	1974	Dry Faeces	674,279 tons/year	14

Table 5. Potentiality of Animal Population and the Amount of Dung Produced in India as of 1978 (15).

Animal	Population in million	Amount of dung million tons/year (Wet Weight)
Horses	9.9	930*
Cattle	181.0	1,200
Buffaloes	61.0	1,800
Pig	8.8	182*
Sheep	40.4	165*
Goat	70.7	150*

* Approximately computed.

livestock waste generation potential of some Asian countries.

The developed countries have often realized the hazards of pollution when it is too late and when they become too conspicuous, leading to a lot of suffering to mankind. The developing countries, on the other hand, should learn from the follies of the more industrialized countries and be prepared to abate the potential problems even before they can be manifested. The waste management strategies in the developing countries will be unique to the region and should take into consideration the characteristics of the wastes, economics of treatment, manpower development, social factors or social acceptance, etc.

4. CHARACTERISTICS OF WASTES

A good waste management strategy warrants a thorough understanding of the composition of the wastes, before deciding the most suitable treatment alternative or alternatives. This will also ensure proper design of the system for maximum efficiency.

In developed countries industrial discharges are the major cause of water pollution but in urban areas of most developing countries domestic wastes contain the major proportion of pollutants entering receiving waters. This is not only due to the limited extent of industrialization, but also to the fact that municipal discharges are largely untreated. Feedlot runoff and uncontrolled runoff of livestock waste can also contain significant concentrations of pollutants. In any country there are many types of wastes and different ways of classifying them. Similarly, the quality characteristics of wastes may be measured in a variety of ways.

One way of classifying wastes based on how they pollute water is as follows: (a) Toxic Wastes, and (b) Oxygen Depleting Wastes.

(a) Toxic Wastes

These are chiefly derived from industrial or agricultural activities. Thousands of toxic organic chemicals are used and produced by industries. Many are discharged to the municipal treatment plant and may ultimately end up in sewage sludge. The presence of toxic and hazardous chemicals in wastewater has caused problems with both wastewater treatment and sludge disposal. As a result there has been increased emphasis on reducing the amount of all toxic contaminants discharged to municipal wastewater treatment plants. Industries are not the sole contributor of contaminants to wastewater. Commercial establishments such as retail stores, restaurants, laundromats, garages, hospitals, schools, laboratories and photo processors contribute to the load of wastewater contaminants. Stormwater runoff from areas served by combined sewers contains zinc and cadmium from tire wear, lead from gasoline, metals from gutters, and corrosion from other metal objects. The household itself is a source of contaminants. Home plumbing (copper and galvanized water pipes), household commodities (detergents, bath soaps), and solids from garbage grinders contribute to wastewater. Livestock wastes or runoff also contain some amount of toxic substances due to the use of disinfectants in livestock house cleaning, metals from waste handling systems, etc.

The discharge of significant quantities of toxic materials into a receiving water makes it unfit for water supply and recreational purposes and has a marked effect on the flora and fauna present.

(b) Oxygen Depleting Wastes

Oxygen depleting wastes are released by industries processing natural products and by animals, including man. Whilst this effect is a form of indirect toxicity, it is sufficiently important to warrant separate consideration. Substances contributing to oxygen depletion of a stream would normally fall into 3 groups: chemical reducing agents which exert an immediate oxygen demand; biologically labile substances (such as organic matter in sewage) which exert an oxygen demand during their stabilization; and surface-active agents, such as synthetic detergents and oil, which interfere with the transfer of oxygen into solution at the air-water interface. The combined effect would be to deplete the free dissolved oxygen resources which would, in the absence of pollution, be maintained at the saturation level for the particular conditions of the receiving water.

Another useful method of wastes classification is based on their behaviour in receiving waters distinguishing between non-degradable (or conservative) and degradable (or non-conservative) substances. Nondegradable wastes are diluted and may be changed in form after discharge but are not appreciably reduced in weight. Degradable wastes are reduced in weight by the biological, physical and chemical processes which occur in natural waters. An example of non-degradable materials is the synthetic organic chemicals in runoff from agricultural land and from livestock production. These synthetic organic chemicals come from fertilizers, pesticides and herbicides used in agricultural producton, and pesticides and disinfectants used in animal production. One problem with complex chemical compounds, which are increasingly found in surface waters, is that of identification and measurement of the often minute concentrations present. Degradable wastes include organic discharges such as domestic sewage. Unstable organic materials are converted into stable inorganic materials by the bacteria in natural waters. This process, termed self-purification, will be aerobic in the presence of dissolved oxygen in the water or anaerobic when the system is overloaded and all dissolved oxygen is depleted. Under anaerobic conditions, offensive odours containing methane and hydrogen sulphide, among others, are produced.

This paper focuses principally on methods effective in the treatment, disposal and utilization of biologically degradable human/animal wastes. However, some of these alternatives also offer effective treatment of non-degradable wastes, if properly managed.

4.1 Human Waste

(a) Night Soil

When human faeces and urine are collected without dilution in large volumes of water, it is called night soil. Nightsoil varies in composition from country to country, place to place and with different dietary habits. This variation in composition is depicted in Table 6. This variation should be taken into account in developing an efficient nightsoil disposal strategy. The importance and uniqueness of nightsoil treatment and disposal in developing countries have been brought out by a recent global survey by WHO (21) which indicated that 25% of the urban population in these countries has no access to a sanitary facility, while more than 50% of the urban population is not served by sewerage connections. The main problem facing these countries is the lack of sufficient funds to provide facilities for this purpose. As long as this handicap exists, these countries have to think of other low cost alternatives appropriate for disposal of nightsoil.

Table 6. Composition of Nightsoil in Some Developed and Developing Countries.

Constitutent \ Region (Ref.)	Japan (20)	Thailand (17)	Vietnam (18)	India (12)	China (19)
Moisture, %	95	–	–	–	–
Organic matter, %	3.44	–	5.7	–	–
Inorganic matter, %	–	–	1.3	–	–
Ash, %	1.6	–	–	–	–
NaCl, %	1.02	–	–	–	–
Carbon, %	–	54.1 (C)	–	–	–
Nitrogen, %	0.57 (N)	3.6 (N)	1.07 (N)	5.8 (N)	0.6 (N)
Phosphorus, %	0.06 (P)	0.9 (P)	0.26 (P_2O_6)	2.0 (P)	0.2 (P_2O_6) 0.09 (P)
Potassium, %	0.22 (K)	–	0.22 (K_2O)	1.8 (K)	0.3 (K_2O) 0.25 (K)
C/N Ratio	–	15.2	–	–	–

(b) Sewage

Domestic sewage will be discharged from any community which is sewered but has no treatment plant. Treatment plant effluent will be less polluted than raw sewage, the extent depending on the efficiency or degree of treatment, but for large communities may still be a significant burden on a receiving water. As mentioned in the previous section, more than 50% of the urban population has no access to sewerage and there are very few sewage treatment facilities in developing countries. However, more and more sewage production may be expected with improvement in sewerage and as sewage treatment facilities are built or improved in developing countries. The composition of a waste discharge is a function of both water use and materials wastage, and in the case of domestic sewage, is dependent on climate and habits of people. The characteristics of sewage in some developed and developing countries are set out in Tables 7 and 8.

(c) Sewage Sludge

Sewage sludge is the accumulated solids concentrated during the treatment of a community's wastewater. A wastewater treatment plant removes pollutants in two major ways: by settling out suspended solids and by converting dissolved solids into suspended solids (secondary treatment) that are subsequently removed. During primary treatment, wastewater flows to a clarifier where suspended solids settle out by gravity and are referred to as primary sludge. Secondary treatment is generally a biological treatment process, in which microorganisms metabolize dissolved solids such as carbohydrates, fats and proteins, and produce new microorganisms, which become suspended solids. The processed wastewater flows to a secondary clarifier where the suspended microorganisms are removed by settling. These solids are referred to as secondary sludge.

For a community to develop a sound management plan, it is necessary to have a better understanding of what sludge contains. Although no two sludges are identical, some generalizations can be made about their physical, chemical and

Table 7. Chemical Composition of Raw Municipal Sewage in Developed Countries.

Constituent	Concentration, ppm	References
pH	6.5-8.0	22
Nitrogen		
Total nitrogen	15-60	22
" "	30	23
Organic nitrogen	5-19	22
Ammonia nitrogen	10-40	22
Nitrate nitrogen	0.0-1.0	22
Phosphorus		
Total phosphorus	6-20	22
" "	10	23
Organic phosphorus	2-5	24
Inorganic phosphorus	4-15	24
BOD_5 (20 C degrees)	100-300	24
" " "	200	23
COD	250-1000	24
"	450	23
TOC	100-300	24
Sulfates	20	23
Chlorides	30-100	24
"	100	23
Calcium	10	23
Magnesium	5	23
Potassium	10	23
Sodium	50	23
Toxic elements		
Cadmium	0.007-0.019	25
Chromium	0.008-0.09	25
Copper	0.012-0.21	25
Lead	0.075-0.12	25
Nickel	0.014-0.09	25
Zinc	0.200-0.25	25
Boron	0.2	23

Table 8. Characteristics of Raw Municipal Sewage in Some Developing Countries and Regions.

Constituent \ Region (Ref.)	AIT, Bangkok (26)	India (27)	Technion, Israel (28)	Yogur, Israel (29)
BOD, mg/l	120 – 130	–	330	279
COD, mg/l	100 – 436	–	750	844
Suspended solids, mg/l	22 – 121	–	260	342
Volatile suspended solids, mg/l	12 – 86	–	–	–
Total dissolved solids, mg/l	64 – 210	–	–	–
Total N, mg/l	29	74 – 30 (sic)	80	79
Organic N, mg/l	9	–	–	–
Ammonia N, mg/l	16	–	–	–
pH	6.2 – 7.2	–	–	–
Temperature, °C	22 – 31	–	–	–
Total P, mg/l	–	12 – 14	15	15
Chlorides, mg/l	–	50 – 116	–	–
Calcium, mg/l	–	0 – 148	–	–
Magnesium, mg/l	–	0 – 105	–	–
Potassium, mg/l	–	23 – 40	–	–
Sodium, mg/l	–	30 – 78	–	–
Total coliforms per 100 ml	–	–	10^8	10^8

microbiological characteristics. The typical physical and chemical characteristics as well as the metal content of sewage sludges in a developed country like the United States are shown in Tables 9, 10 and 11 respectively as compared with some sludge characteristics in Asian countries as featured in Table 12. Although the sludge problem in developing countries is not being viewed seriously due to the very small amounts being produced in the few treatment facilities existing presently, the potential sludge problem may be envisaged to escalate with increased urbanization, increasing population densities, and the resulting increase in the construction, expansion and improvement of sewage treatment facilities.

(d) Grey Water

The effort to develop improved methods of onsite wastewater management has led to the development of a powerful strategy in the developed countries, i.e. waste segregation and separate treatment. This has led to the concept of separating grey water from black water or toilet water. (32,111). Grey water in other words is domestic wastewater not containing excreta. The strategy involves using an alternative toilet system, such as a composting or closed-loop recycle unit for the toilet wastes which would reduce the wastewater flow volume and pollutant load of residential households to that from the basins, sinks and appliances (often collectively referred to as grey water) (32).

The characterization of grey water depends on the various kinds of living habits and personal hygiene. The different cleaning agents, dishwashing, bathing, and other household liquids used by a family will somewhat alter the physical, chemical, biochemical and microbiological characters of grey water

Table 9. General Physical Characteristics of Various Types of Sludge (30).

Sludge	Color	Other Physical Properties	Odor	Digestibility (Amenability to Further Biological Stabilization)
Primary sedimentation	Gray	Slimy	Extremely offensive	Readily digested
Chemical precipitation (primary)	Black, red surface if high in iron	Slimy, gelatinous, gives off considerable gas	Offensive	Slower rate than primary sedimentation
Activated sludge	Brown, dark if nearly septic	Flocculent	Inoffensive, earthy when fresh; putrifies rapidly	Readily digested
Trickling filter humus	Brownish	Flocculent	Relatively inoffensive, decomposes slowly	Readily digested
Digested sludge	Dark brown to black	Contains very large quantity of gas	Inoffensive if thoroughly digested; like tar or loamy soil.	Well stabilized
Septic tank sludge	Black		Offensive (H_2S) unless very long storage time	Mostly stabilized

Table 10. Typical Chemical Composition of Raw and Digested Sludge (30).

Item	Raw Primary Sludge		Digested Sludge	
	Range	Typical	Range	Typical
Total dry solids (TS), %	2.0-7.0	4.0	6.0-12.0	10.0
Volatile solids (% of TS)	60-80	65	30-60	40.0
Grease and fats (ether soluble, % of TS)	6.0-30.0	–	5.0-20.0	–
Protein (% of TS)	20-30	25	15-20	18
Nitrogen (N, % of TS)	1.5-4.0	2.5	1.6-6.0	3.0
Phosphorus (P_2O_5, % of TS)	0.8-2.8	1.6	1.5-4.0	2.5
Potash (K_2O, % of TS)	0-1.0	0.4	0.0-3.0	1.0
Cellulose (% of TS)	8.0-15.0	10.0	8.0-15.0	10.0
Silica (SiO_2, % of TS)	15.0-20.0	–	10.0-20.0	–
pH	5.0-8.0	6.0	6.5-7.5	7.0
Alkalinity (mg/l as $CaCO_3$)	500-1,500	600	2,500-3,500	3,000

Table 11. Typical Values for Metals in Sludges (31).

Metal	Value, ppm		
	Range	Mean	Median
Silver	nd*-960	225	90
Arsenic	10-50	9	8
Boron	200-1,430	430	350
Barium	nd-3,000	1,460	1,300
Beryllium	nd	nd	nd
Cadmium	nd-1,100	87	20
Cobalt	nd-800	350	100
Chromium	22-30,000	1,800	600
Copper	45-16,030	1,250	700
Mercury	0.1-89	7	4
Manganese	100-8,800	1,190	400
Nickel	nd-2,800	410	100
Lead	80-26,000	1,940	600
Strontium	nd-2,230	440	150
Selenium	10-180	26	20
Vanadium	nd-2,100	510	400
Zinc	51-28,360	3,483	1,800

*nd = not detected.

Table 12. Characteristics of Some Wastewater Sludges from Asia (3).

Type of Sludge	Source	Date Collected	Solids Content (%)	Volatile Solids (%)	pH	Volatile Acids (mg/l)
Raw primary sludge	Ulu Pandan Sewage Treatment Plant, Singapore	March 1965 – Mean	4.5	80	5.8	860
	Odai Sewage Treatment Plant, Tokyo, Japan	July 1964 – Mean	5.1	43	6.2	–
Night soil	Unspecified, Japan	1962	1.9-4.2	45-67	7.8	–
	Taipei, Taiwan	1956-7 Summer Mean	2.73	63	9.4	–
		Winter Mean	2.87	60	8.9	–
Night soil sludge	Unspecified, Japan	1962	3.7	40	8.6	–
	Bangkok, Thailand	1965-67 Minimum	1.25	60	6.9	360
		Mean	3.65	67	7.7	750
		Maximum	6.40	71	8.5	1,700
Septic tank sludge	Bangkok, Thailand	1965-67 Minimum	1.1	44	7.0	120
		Mean	3.1	71	7.8	320
		Maximum	5.6	90	8.5	950
Digested sluuge	Odai Sewage Treatment Plant, Tokyo, Japan	July 1964 – Mean	5.6	32	7.3	500
	Ulu Pandan Sewage Treatment Plant, Singapore	March 1965 – Mean	9.0	58.5	7.1	83

between families. Table 13 shows the range of flows and characteristics of grey water which were compiled from various reports in developed countries. Developing countries have done very little research in this field and hence data on grey water characteristics in these countries are forthcoming.

Table 13. Range of Flows and Characteristics of Grey Water in Some Developed Countries (33).

Grey Water Flow - 40% - 70% of Total Flow		
Item	Combined Sewage	Grey Water Range
BOD_5	150-350 mg/l	100-300 mg/l
S.S.	100-400 mg/l	85-300 mg/l
T.N.	20-80 mg/l	3-25 mg/l
PO_4	10-100 mg/l	8-95 mg/l
Grease	50-150 mg/l	60-150 mg/l
Temp.	30-40° C	40-60° C
Flow	0.15-0.21[a]	0.13-0.17[a]

[a] Flow in m^3/capita/d.

Developing countries, in general, face a serious problem of shortage of drinking water. Besides, in regions where flushing toilets are used, the average toilet consumes 40-50% of domestic water supply, which is not rational. With the recent development of several types of toilets, namely: waterless toilets, the vacuum sewage system, composting toilets, etc., it is now possible to eliminate the use of drinking water for toilet flushing and to direct our attention to the grey water treatment and disposal. On-site systems may be facing certain problems, namely high groundwater table, relatively impervious soils, and small lot sizes. In such cases, the grey water treatment systems along with the improved blackwater disposal systems are recommended.

4.2 Animal Wastes

Like human wastes, animal wastes also show a lot of variation in their characteristics. Animal wastes have been well characterized in the developed countries. For example, in the United States the Task Committee on Agricultural Waste Management (9) has investigated the strategies for animal waste management in the U.S. According to the Committee, the mass of wet manure produced per gram of animal per day and the variation in the solids concentration of wet manures are as shown in Table 14. A comparison of the average weight of wet manure produced per unit weight of animal per day for all the animals shows that the values range between 0.062 g/g for poultry to 0.084 g/g for cattle. Considering that these data were collected at different farms and by different investigators, the difference between the average values reported is small and narrow, and it suggests that the production of manure per unit weight of animal is highly correlated to animal weight (9).

According to Taiganides (33), waste production may be assumed to be directly proportional to the total live weight (TLW) of the animals, as is shown in Table 15. Daily waste excretions (faeces and urine) (total wet weight) may

Table 14. Physical Characteristics of Animal Wastes (9).

Animal (1)	Gram per Day per Gram of Animal		
	Wet manure (2)	Total solids (3)	Volatile solids (4)
Poultry	0.0234	0.011	–
	0.027-0.087	0.011-0.022	0.0084-0.017
	0.074	0.021	–
	–	0.014	0.0098
	–	0.013	0.0101
	–	0.013-0.019	–
	0.072	0.0086	0.0054
	0.83	–	–
Average	0.062	0.014	0.0096
Swine	0.084	0.011	–
	0.028-0.095	0.008-0.016	0.0068-0.0136
	0.087	0.016	–
	–	0.0080	0.0063
	–	0.0097	0.0080
	–	0.0050	0.0035
	–	0.0071	–
	–	0.0048	0.0033
	0.074	0.0059	0.0047
	–	0.0099	0.0070
Weighted Average	0.074	0.0089	0.0054
Cattle (Dairy)	0.071	0.0114	–
(Dairy)	0.058	0.0087	–
(Dairy)	–	0.0104	0.0083
(Dairy)	–	0.0068	0.0057
(Dairy)	–	0.0075	–
(Dairy)	0.124	0.0025	0.0018
Average (Dairy)	0.084	0.0079	0.0053
(Beef)	0.082	0.0197	–
(Beef)	0.039-0.074	0.0095-0.0114	–
(Beef)	0.063	0.0095	–
(Beef)	0.067	0.0090	0.0069
(Beef)	–	0.0036	0.0032
(Beef)	0.063	0.0050	0.0040
(Beef)	–	0.0091	–
Average (Beef)	0.066	0.0095	0.0047
Sheep	0.072	0.016	–
Ducks	–	0.016	–

Table 15. Bio-Engineering Parameters of Animal Wastes (33).

Parameter	Symbol	Units	Pork Pigs	Laying Hens	Feedlot Beef	Feedlot Sheep	Dairy Cattle
Wet excreta waste	TWW	% TLW/day	5.1	6.6	4.6	3.6	9.4
Total solids	TTS	% TWW	13.5	25.3	17.2	29.7	9.3
		% TLW/day	0.69	1.68	0.70	1.07	0.89
Volatile solids	TVS	% TTS	82.4	72.8	82.8	84.7	80.3
		% TLW/day	0.57	1.22	0.65	0.91	0.72
Biochemical oxygen demand	BOD	% TTS	31.8	21.4	16.2	8.8	20.4
		% TVS	38.6	29.4	19.6	10.4	25.4
		% TLW/day	0.22	0.36	0.13	0.09	0.18
COD/BOD	–	Ratio	3.3	4.3	5.7	12.8	7.2
Total Nitrogen	N	% TTS	5.6	5.9	7.8	4.0	4.0
		% TLW/day	0.039	0.099	0.055	0.043	0.036
Phosphorus	P	% TTS	1.1	2.0	0.5	0.6	0.5
		% TLW/day	0.007	0.034	0.035	0.007	0.004
Potassium	K	% TTS	1.2	1.7	1.5	2.4	1.4
		% TLW/day	0.008	0.029	0.011	0.026	0.012

range from 3.6 percent of TLW for sheep to 9.4 percent of TLW for dairy cows. In other words, the amount of wastes generated per day from animals whose total weight adds up to 1000 kg can be estimated as 36 kg for sheep, 46 kg for beef cattle, 51 kg for pork pigs, 66 kg for laying hens and 94 kg for dairy cattle. The amount of waste excreted is affected also by the type of ration and the age of animal. Young animals excrete more waste than mature animals. Pigs, for example, in 16 to 30 kg TLW range may excrete waste equal to 8.5 percent of their own TLW, while older pigs in the 66-100 kg TLW may excrete daily wastes equal to only 4.9 percent of their TLW. The quantities of wastewaters or wastes to be handled would, in general, be larger than those given in Table 15 due to the addition of diluted water, washwater, moisture absorbing materials, litter, etc.

The variation in the 5-day BOD, soluble COD and nutrients contents of manures on a weight basis for various animals as reported by the Task Committee on Agricultural Waste Management in the U.S.A. (9) is shown in Table 16. As can be seen in the table, these values reported by various investigators vary widely. However, considering that none of the operating characteristics of the animal raising and waste management operations were available, the numbers probably are as good as can be expected. Defecated waste values just approximate total constituent amounts that must be handled pursuant to final disposition. Analyses should be made of actual wastes to be managed for more accurate design data and evaluation of unit process or total system performance.

The Task Committee on Agricultural Waste Management (9) in the U.S.A. also reported that feedlot runoff quantity and quality are highly variable, and depend on many factors, i.e. animal density, operation techniques, soil moisture, soil characteristics, topography, and rainfall intensity. (A feedlot or concentrated animal operation is defined as any facility where animals are confined and fed or maintained for a total of 45 days or more in any 12-month period; and crops, vegetation, and post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility). It is very difficult to predict runoff characteristics because of the many intrinsic

Table 16. Organic and Nutrient Characteristics of Animal Wastes (9).

	Grams per Day per 1,000 grams Animal					
Animal	BOD	COD	Ammonia nitrogen	Total nitrogen	Phosphorus (P_2O_5)	Potassium (K_2O)
Poultry	-	-	-	1.12	0.72	0.36
	-	-	-	0.27-1.27	0.22-1.00	0.11-0.42
	-	-	-	1.10	-	-
	3.33	11.1	0.13	0.67	0.58	-
	2.91	11.2	0.52	0.70	0.60	0.27
	3.33-7.11	-	-	-	-	-
	1.33-2.22	-	-	-	-	-
	-	-	-	0.23	0.37	-
	3.74	7.1	-	0.58	0.72	-
	4.27	-	0.12	-	-	-
Average	3.46	9.8	0.26	0.74	0.60	0.30
Ducks	2.0-4.0	-	-	8.00	0.6-1.6	-
Swine	-	-	-	0.51	0.32	0.62
	-	-	-	0.42-0.60	0.29-0.32	0.34-0.62
	-	-	-	0.53	-	-
	2.0	7.6	0.24	0.32	0.25	0.11
	4.3	5.4	-	0.64	-	-
	-	4.7	-	-	-	-
	2.5	-	-	-	-	-
	2.2	-	-	0.70	-	-
	5.6	-	-	-	-	-
	-	-	-	0.41	0.55	-
	3.1	6.4	-	-	-	-
	2.0	5.2	-	-	-	-
	3.2	9.3	-	0.44	0.67	-
Average	3.1	6.4	0.24	0.51	0.42	0.40
Beef	-	-	-	0.36	0.115	0.274
Cattle	-	-	-	0.35-0.44	0.11-0.12	0.27-0.34
	-	-	-	0.29	-	-
	1.11-2.22	10.0	-	0.26	-	-
	1.02	3.26	0.11	0.26	-	-
	-	-	-	0.41	0.25	-
	1.87	15.0	-	0.16	0.31	-
	1.84	-	-	-	-	-
Average	1.61	9.42	0.11	0.32	0.18	0.29
Sheep	-	-	-	0.86	-	-
	-	-	-	0.34	0.25	-
Average	-	-	-	0.60	0.25	-
Dairy	-	-	-	-	0.30	-
Cattle	-	1.53	19.1	-	-	-
	0.31	1.53	8.4	-	0.38	0.12
	-	1.32	5.8	0.23	0.37	-
	-	0.44	-	-	0.49	-
	-	0.95	5.7	-	0.16	0.11
Average	0.31	1.15	9.8	0.23	0.34	0.12

variables.

Feedlot runoff concentrations depend upon time of the year and management techniques (9). The concentration of the various pollutants in feedlot runoff is the highest during the initial phase of rainfall and decreases as runoff continues. After the feedlot surface becomes covered with manure, the quality of runoff is no longer affected by manure depth but by manure composition, rainfall intensity, water content of the manure pack, and the type of feedlot surface.

The results of several studies describing the magnitude and variability of constituents in feedlot runoff in a developed countries like the U.S.A. from both paved and unpaved lots with different animal densities are summarized in Table 17. The variable nature of the runoff indicates the significant slug effect that these discharges could have on a stream.

Although data on the pollutional and nutritional characteristics of animal wastes are available for developing countries as presented in Tables 18 through 24, data for feedlot runoff constituents is forthcoming, probably due to fewer large scale, intensive livestock production in these countries. Pollutional trends similar to the developed countries (as discussed above) may be expected in these countries also as livestock production becomes more intensive, warranting appropriate pollution abatement measures.

5. OPTIONS FOR WASTE MANAGEMENT

Pollution is ubiquitous in the developing countries. With high population and little past investment in control measures, serious manifestations are apparent. Hence rational treatment systems or methods should be adopted for pollution abatement in these countries based on manpower and other resources that are readily available.

5.1 Human Waste

(a) Alternatives in Water Pollution Abatement

A rational technological approach to the control of water pollution in developing countries must take advantage of all management possibilities which can be economically justified. The combination of technological measures resulting in the least cost solution will, theoretically, provide the best pollution control system. However, in practice there may be other factors e.g. operational factors which militate against their adoption.

Fig. 1 shows the cycle of water used by society wherein water and other materials are inputs to a city and wastewater is the one of the outputs with which we are concerned (36). There are obviously many points in this cycle at which an attempt could be made not only to minimize the quantity of polluting materials being discharged, but also to reduce the effects of the discharged pollutants. It may be mentioned at this stage that a surface water body has a certain capacity to accept waste discharges (called its assimilative capacity) without seriously affecting future uses of the water. The assimilative capacity of any receiving water will depend on: the nature of waste discharges; the degree of waste dilution, dispersion and degradation; and the quality demands of subsequent water uses.

Technological alternatives available for improving the quality of receiving waters are summarized in Table 25. Although many of the alternatives suggested apply more to industrial discharges, they have been mentioned here as some are

Table 17. Cattle Feedlot Runoff Characteristics (Range of Constituent Values)(9).

Milligrams per liter							
Suspended solids	Ortho phosphate (PO_4)	Total nitrogen	Organic nitrogen	Ammonia nitrogen	Nitrate nitrogen	BOD	COD
1400-13400	-	-	-	-	-	500-3300	-
-	-	-	6-800	2-700	0-1270	1000-12000	2400-38000
1000-7000[a]	-	-	-	-	-	300-6000	-
-	-	-	-	-	-	1500-9000	4000-15000
1400-12000	15-80	-	-	1-139	0.1-11	-	2500-15000
-	20-30	-	600-630	270-410	-	5000-11000	16000-40000
1500-12000	-	-	-	16-140	-	-	3000-11000
1400-12000	62-1460[b]	-	265-3400	-	-	800-7500	-
1400-198000	-	1429-5765	-	-	0-17	-	1300-77804
-	59-1200[b]	1500-10000	-	-	0-31	-	10900-286000

[a] Volatile solids.

[b] Total phosphorus as PO_4.

Table 18. Composition of Pig Manure in China (19).

Source	Composition %					
	Organic matter	N	P_2O_5	P	K_2O	K
Pig manure (fresh)	15.0	0.60	0.40	0.18	0.44	0.37
Pig urine	2.0	0.30	0.12	0.05	1.00	0.83
Pig manure (air-dried)	34.32	2.12	0.98	0.43	2.45	2.03
Pig manure (litter)	34.00	0.48	0.24	0.11	0.63	0.52

Reported by Yueh Chi Peoples' Commune, Jiangsu Province

Table 19. Nutrient Contents of Some Animal Manures in China (19).

	N %	P_2O_5 %	P %	K_2O %	K %
Buffalo	0.30	0.25	0.11	0.10	0.08
Sheep	0.70	0.60	0.26	0.30	0.25
Poultry	1.63	1.54	0.68	0.85	0.71

Table 20. Composition of Raw Cow Manure as Reported from Israel (29).

Component	Raw Cow Manure (wet basis) g/kg
Total solids	166
Total volatile solids	135
COD total	155
Total Kjeldahl nitrogen	5.3
Ammonia nitrogen	1.6
Total phosphate as PO_4	4.1
Volatile acids	10.2
pH	7.2

Table 21. 12 Months Weekly Average Characteristics of Raw Pig Wastewater in Singapore (34).

Wastewater Parameter	Symbol	Raw Wastewater mg/l (± S.E.)
Total Solids	TTS	6456 (253)
Total Suspended Solids	TSS	4475 (227)
Biochemical Oxygen Demand	BOD	2892 (152)
Chemical Oxygen Demand	COD	7334 (353)

Table 22. Analysis of Several Types of Animal Dung in Burma (11). (Oven Dry Basis)

Sl. No.	Kind of dung	Total N %	P %	K %	Ca %	Mg %	S %	Total C %	C:N ratio
1.	Cow dung	1.40	0.92	1.08	2.60	0.18	1.62	35.40	24:1
2.	Effluent (cow dung)	2.79	1.04	1.83	2.71	0.30	3.83	30.94	11:1
3.	Buffalo dung	1.36	1.06	0.22	2.40	4.90	1.30	31.40	23:1
4.	Swine dung	3.98	1.63	0.42	0.08	1.80	0.39	37.10	9:1
5.	Horse dung	5.49	1.72	1.20	1.24	2.70	0.71	18.54	3.4:1
6.	Chicken dung	2.70	0.66	0.69	0.60	0.97	1.23	27.50	10:1
7.	Duck dung	1.59	0.57	0.86	1.15	2.30	0.92	12.30	8:1
8.	Goat dung	2.71	1.98	1.93	1.60	1.63	0.36	32.47	12:1

Table 23. Chemical Analysis of Some of the Animal Wastes Used in Fiji (35).

Sr. No.	Material	Nitrogen %	Phosphorus %	Potassium %	Sodium %	Calcium %	Magnesium %	Loss on ignition %
1.	Poultry manure							
	- caged bird	4.22	3.51	0.30	0.12	5.80	0.67	64.6
	- deep litter	4.77	2.16	1.88	0.24	2.32	0.69	81.1
2.	Cattle manure	1.79	0.31	0.52	0.06	0.84	0.40	64.9
3.	Pig manure	1.92	1.22	0.88	0.11	0.60	0.49	52.1
4.	Goat manure	2.04	0.73	0.47	0.06	1.58	0.55	69.3

Notes: 1. Materials 1 - 4 were air dried and analysed.

2. The above values would differ greatly from farm to farm depending on the quality of feed given to the animals and the soil fertility level for cattle.

Table 24. Chemical Analysis of Some Animal Faeces in Malaysia (14).

Livestock	%N	%P	%K	%Ca	%Mg	Remark
Poultry	4.00	2.10	1.52	3.80	0.70	dry basis
Pig	1.95	1.29	0.34	6.58	1.10	dry basis

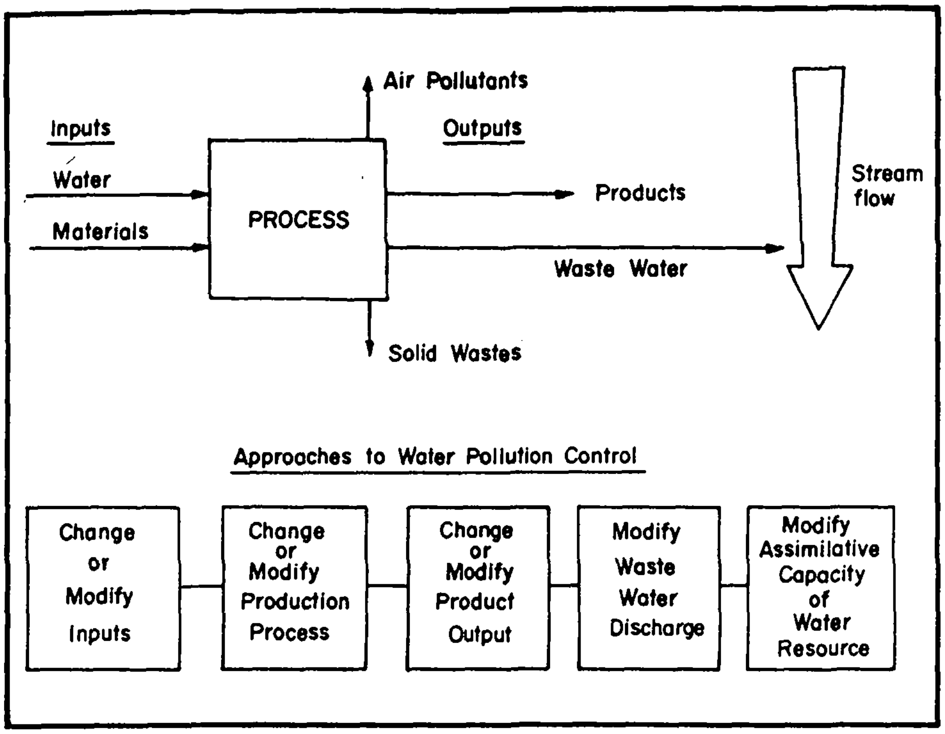

Fig. I – Cycle of Water Use and Approaches to Pollution Control (36)

Table 25. Technological Alternatives in Water Pollution Abatement (37).

Principle	Method
A. Reducing Wastes Generation	1. Change type of raw material inputs 2. Change or modify production process 3. Change or modify product outputs 4. In-plant recirculation of water 5. Segregation of concentrated waste streams 6. Waste elimination
B. Reducing Wastes after Generation	1. Materials recovery 2. By-product production 3. Waste treatment 4. Effluent re-use
C. Increasing or Making Better Use of Assimilative Capacity of Receiving Water	1. Addition of dilution water 2. Multiple outlets from reservoirs 3. Reservoir mixing 4. Reaeration of streams 5. Saltwater barriers 6. Effluent redistribution

equally applicable to municipal discharges. It is important to stress that a waste disposal problem should not be considered in isolation and the waste discharge should not be blindly accepted as the starting point in the search for a solution. However, before these technological alternatives can be evaluated, a great deal of information must be determined and their quality requirements established, data on stream flow and waste discharges must be collected to enable a mathematical model of the stream system to be developed, water use and waste generation must be examined and conservation and treatment methods considered. Whenever possible recycling and reuse of waste should be incorporated in the waste management system.

Much work has been carried out in temperate developed countries and the results have been freely published. This is not the case in tropical developing countries and their peculiar environmental conditions often make acceptance of standards and methods developed for other countries inappropriate and unwise. Hence methods which are locally applicable and which are also cost-effective should be emphasized.

(b) A General Survey of Human Waste Treatment and Disposal Systems

Waste treatment has not been widely adopted in developing countries because the costs are significant and the direct benefits to municipality have been considered zero or low. The external damages or social costs caused by wastes discharges have been also almost totally ignored. The situation with regard to municipal wastewater treatment in many developing countries is all the more complicated by the fact that conventional sewerage systems are not often found in cities. Without wastewater collection and transport to control plants, the cost advantages of large scale treatment plants cannot be achieved. However, here again, it may be necessary to think unconventionally in arriving at a solution because the capital cost of installing sewers in large cities is usually prohibitive and developing countries may not be able to afford it (36).

Only when economic processes of materials recovery, by-product production and effluent reuse fail to prevent a residual waste load from a community exceeding the assimilative capacity of a receiving water, it is necessary to adopt conventional treatment methods before discharge. In designing and operating a waste treatment plant, full advantage should be taken of the receiving water's assimilative capacity, in its original or modified state. This may mean a phased development of plant as waste residuals increase and flexible design of units to allow varying degrees of treatment efficiency to match the stochastic nature of stream assimilation capacity.

The combination of unit processes making up a treatment plant flow diagram will depend on the characteristics of the particular waste and the effluent standards imposed. Invariably, the costs of constructing and operating a wastewater treatment plant increase with the degree of treatment required and so the controlling authority should be careful to impose only those stream standards essential for downstream water uses. Table 26 shows a listing of unit processes commonly used for municipal wastewater relative to the type of polluting material present. It can be seen that most processes have an output, which generally needs further handling, and so cannot be considered complete disposal devices. Some alternatives like land treatment and landfills may be considered as complete treatment and disposal methods. The various options available for excreta, sludge and greywater treatment will be described in later sections.

The unit processes marked with an asterisk (*) in Table 26 are considered most suitable for use in tropical developing countries either by reason of their suitability for the prevailing climatic and labour conditions or because they utilize little or no imported equipment or for both reasons. It should always be

Table 26. Wastewater Treatment Unit Processes (36).

Material to be Removed or Converted	Unit Process	Output from Unit Process
Non-degradable materials		
Coarse solids	* Screening	Screenings
Suspended solids	* Sedimentation	Sludge or Slurry
	* Coagulation and Flocculation	"
	* Filtration	"
	* Flotation	"
	Centrifugation	"
	Cyclone	"
Dissolved solids	Distillation	Brine
	Electrodialysis	"
	Reverse Osmosis	"
	Dialysis	"
	Ion Exchange	"
	* Neutralization	Sludge
	* Oxidation/Reduction & Precipitation	"
Degradable organic Materials:	Aerobic Biological Treatment:	
	Activated Sludge	Sludge
	Biological Filters	"
	* Biological Disc Filters	"
	* Oxidation Ditches	"
	* Oxidation Ponds (Facultative)	Algae
	* Aerated Lagoons	"
	Anerobic Biological Treatment	
	* Anaerobic Digestion	Sludge
	* Anaerobic Contact	"
	* Anaerobic Lagoons	"
	Adsorption:	
	* Activated Carbon	-
Sludges:	Concentration:	
Inorganic and organic	* Clarifier thickening	Concentrate
	* Gravity thickening	"
	* Flotation	"
	Dewatering:	
	* Drying Beds	Dry-Cake
	* Lagoons	"
	Filtration - gravity	"
	- vacuum	"
	- pressure	"
	Centrifugation	
Organic	Digestion:	
	Aerobic	Sludge
	* Anaerobic	"
	Heat Drying and Combustion:	
	Heat Drying	Dry-Cake
	Incineration	Solid residue + gases
	Wet oxidation	Solid residue
Liquid effluents and solid residuals	Final Disposal:	
	Land fill	
	* Fertilizer	
	Stream Discharge	
	Sea Discharge	
	* Irrigation	
	Underground Disposal	

* Most Suitable for Tropical Developing Countries.

the aim to adopt methods which are particularly suited to and take advantage of prevailing environmental conditions. For example, the high temperature conditions in tropical countries promote the use of anaerobic biological treatment for organic wastes and the lack of skilled labour encourages the adoption of unsophisticated processes. It is normal to attempt to use the lowest cost solution to a waste treatment problem but this is especially important under the economic restrictions in developing countries.

While large cities eventually will be forced to adopt capital intensive systems for waste treatment, smaller cities or towns in the developing countries, must think in less conventional terms if anything in the way of pollution abatement is to be achieved. Land intensive systems like oxidation ponds, oxidation ditches, land treatment systems, etc., and particularly treatment processes utilizing limited equipment needing specialized manufacture, suggest themselves as logical methods. However, land is never cheap and land intensive treatment processes should still be designed and operated to obtain maximum efficiency from land use.

5.2 Animal Waste

The Task Committee on Agricultural Waste Management in the United States (9), in their survey of animal waste treatment systems in the U.S. reported that it is very unlikely that conventional waste treatment practices will be employed for feedlot runoff and animal wastes because of the high construction and operation costs of these processes when compared with collection, pretreatment-storage, and application techniques commonly employed as conservation techniques or agricultural production practices. Similar trends may be expected in developing countries.

The status of available disposal, treatment and utilization processes, as well as associated energy and nonwater quality aspects, in the United States are summarised in Table 27. The terms "Best Practical Control Technology Currently Available" (BPCTCA) and "Best Available Technology Economically Achievable" (BATEA) are used as given in the Federal guidelines to implement sections 304 and 306 of the Federal Water Pollution Control Act Amendments of 1972. It is to be noted that of the 20 processes listed in Table 27, 18 are still in the experimental stages.

The Task Committee on Agricultural Waste Management (9) also notes: "Animal agriculture is in an enviable position to comply with the no-discharge goal because land which is essential for both livestock production and terminal application of associated waste is generally readily available. Regardless of the particular animal type or production unit under consideration, the potential or actual waste management alternatives are similar. The overview schematic of animal waste management alternatives shown in Fig. 2 emphasizes the unifying principles inherent in animal waste management. Implementation of animal waste management techniques could be expedited if the commonality of waste streams and appropriate unit processes, overall systems, and management practices were more directive in selecting treatment methods and engineering controls."

Although the above discussion focuses on the situation in the United States, it holds good for developing countries as well, wherever such animal waste problems have been identified or are prevalent. There is a dearth of literature on animal waste management from developing countries. However, it is hoped that a summary of the existing alternatives for animal waste treatment would stimulate possible activity in countries or regions so far not practicing any pollution abatement strategies.

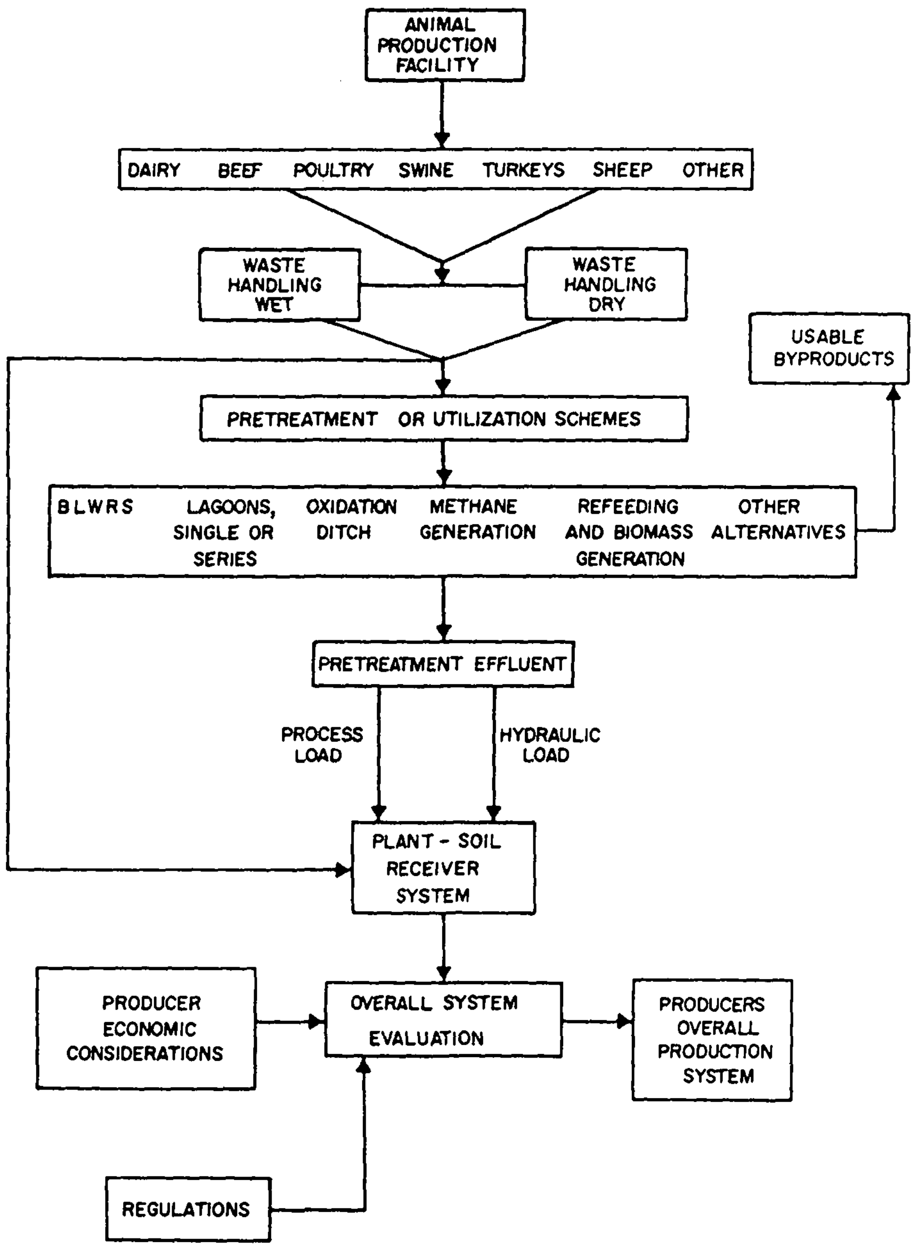

Fig. 2 – Animal Waste Management Alternative (9)

Table 27. Status of Available Processes, Their Energy and Nonwater Quality Aspects (9).

Technology	Application			Function		Status		Type of Process			Net energy usage	By-product
	Manure	Runoff	Containment	Complete treatment	Partial treatment	BPCTCA[a]	BATEA[b]	Experimental	Biochemical	Physical chemical		
Land Utilization	x	x		x		x			x		Low	None
Runoff Control		x	x			x			x		Low	None
Lagoons for Treatment		x	x		x	x			x		High	None[c]
Evaporation		x	x		x	x				x	Low	None[c]
Oxidation Ditch (spread or feed)	x				x	x (spread)	x (feed)		x		High	None[c]
Composting	x			x		x			x		High	None[c]
Dehydration (sell or feed)	x			x		x (sell)	x (feed)			x	Low	None[c]
Activated Sludge	x				x		x		x		Low	Compost
Wastelage	x				x		x		x		Low	Fiber
Conversion to Industrial Products	x			x				x		x	Low	Fiber
Aerobic Yeast Production	x			x				x	x		High	Sludge, liquid
Aerobic Single Cell Protein	x			x				x	x		High	Sludge, liquid
Anaerobic Single Cell Protein	x			x				x	x		Low	None[c]
Feed Recycle	x			x				x		x	Low	Sludge
Anaerobic Fuel Gas	x				x			x	x		Low	Ash
Fly Larvae Production	x				x			x	x		Low	Ash
Biochemical Recycle	x				x			x	x		Low	Ash
Conversion to Oil	x				x			x		x	Low	Ash
Gasification	x				x			x		x	Low	None[c]
Pyrolysis	x				x			x		x	Low	Liquid
Incineration	x				x			x		x	Low	Liquid, solids
Hydrolysis	x				x			x		x	Low	None
Chemical Extraction	x				x			x		x	Low	Sludge, liquid
BLWRS[d]		x		x				x	x		Low	Sludge
Trickling Filters		x			x			x	x		Low	Sludge, liquid
Spray Runoff		x			x			x	x		Low	Grass, liquid
Rotating Biological Contractor		x			x			x	x		Low	Sludge, liquid
Water Hyacinths		x			x			x	x		Low	None[c]
Algae		x			x			x	x		Low	None[c]

[a]BPCTCA ---- Best Practicable Control Technology Currently Available.

[b]BATEA ---- Best Available Technology Economically Achievable.

[c]Unless otherwise specifically indicated ash, salts or similar system residuals, if any, are not fully established full scale.

[d]Barriered Landscape Water Renovation System.

5.3 Potential Human and Animal Waste Treatment Processes for Developing Countries

Appropriate methods of waste treatment and disposal in developing countries are those which focus on low cost options. So far developing countries in many situations have directly adopted conventional or non-conventional methods of waste treatment as being used in the developed countries with little or no modification, with the result that in many such cases they have not been cost-effective nor efficient in treatment. Technology transfer from developed to developing countries would be feasible if they are properly modified to suit local conditions. Generally speaking, a treatment system that is simple - yet capable of satisfactory treatment at a minimum cost - should be considered for adoption.

It is interesting to study whether sophisticated technology should ever be transferred to a developing country and if it should be, what should be the constraints (38). Take for example, the case of a big metropolitan city in Asia. There should be no objection in transferring sophisticated technology like deep shaft process or oxygen aerated activated sludge process or any advanced waste water treatment process to a city of its size and nature. It has the necessary infrastructure and personnel availability to integrate such a system in its industrial environment, whereas installing a reverse osmosis plant for desalination for a small town in the brackish water area of a district which is economically a backward agriculture area would be a big mistake. It has neither the infrastructure nor the personnel available to run such a plant. Economic conditions and personnel availability play a major role in the choice of a waste treatment strategy for any particular region or area.

Another fact to be noted in considering appropriate treatment systems for developing countries is that there is a lack of data base derived from local research in these countries. Hence it is difficult to select the right treatment system for a particular situation or locality. In 1976, the World Bank, with the collaboration of the International Development Research Centre, Canada, launched a worldwide search to identify the various immediate technologies between the most primitive low cost waste management alternatives and Western sewerage systems (16). The various low cost waste management alternatives they found suitable for developing countries may be illustrated as shown in Fig. 3.

Waterborne options, i.e. sewerage systems, are as yet the only solution identified for high density, high rise housing and commercial areas. The concentration of population in these areas tends to minimize the drawbacks associated with sewerage; provision of piped water, and cost tied to intelligent water-saving and reuse practices, well managed sewerage systems can be viable options (48).

Cartage options work on the same principle as sewerage - removing wastes to locations outside of inhabited areas for disposal or treatment but without the use of pipes. Such systems consist of a household sewerage vault that is emptied periodically by vacuum trucks or smaller pumping carts. Such collection systems are more suited for certain urban areas because capital outlay is low, about a third that of sewers, the system always operates at or near capacity; is labour-intensive, and provides a high level of service when properly operated (48).

On-site options generally suitable for urban and rural application can be implemented and operated by individuals. These are basically variations of the pit privy - probably the most widely used technology for excreta disposal - with improvements to environmental and hygienic conditions. Composting toilets, wherein solid organic wastes are biologically converted into a stable, humus-like product, are a promising alternative (48).

Composting on a larger scale together with waste stabilization ponds are two other treatment possibilities that offer flexibility and low cost. Both methods are effective in destroying pathogens, and offer reuse possibilities. Waste reuse and recycling of resources are already widely practiced in developing countries, but not so much for reasons of environmental conservation, as in response to the pressure to exploit every resource potential to its fullest to meet needs. Reuse of human waste may be undertaken through fertilization of crops with treated and untreated nightsoil, irrigation with sewage and stabilization pond effluents, fish and algae production based on

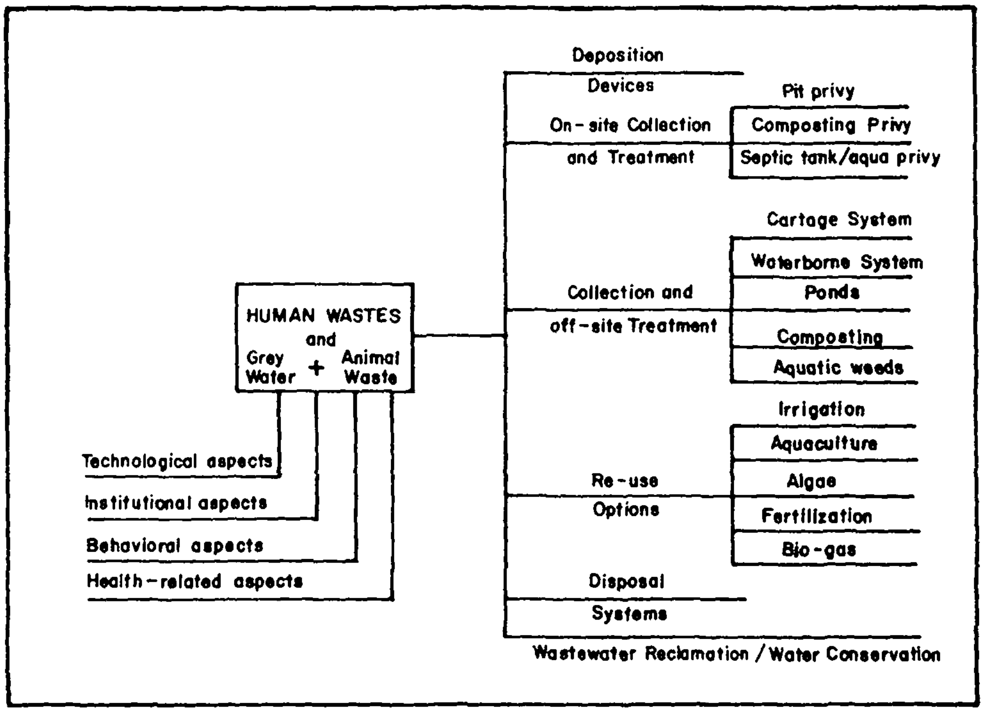

Fig. 3 Low Cost Waste Management Options for Sanitation in Developing Countries (16)

wastes, and the generation of biogas. Animal wastes may also be reused on agricultural lands, fish and algae production, for the generation of methane, etc. (48).

Sewerage has long been regarded as a universal solution to waste disposal. It is assumed that the technology needs simply to be introduced to produce a predetermined, predictable result. However, sanitation engineers and managers (along with others in different fields) are discovering that their accepted universals breakdown in developed country contexts. The best, and often the only solutions, arise from an understanding of the unique characteristics of the problems encountered, and take into account the local human and material resources available to solve them. A step-by-step upgrading compatible with existing conditions will prove to be the best approach. This approach - adaptation rather than just adoption - implies a dynamic process of problem solving that can produce benefits wherever science and technology are brought to bear on development (48).

The next two sections will introduce the readers to some low-cost waste management options in the context of developing countries.

6. PROMISING ALTERNATIVES FOR HUMAN WASTE MANAGEMENT IN DEVELOPING COUNTRIES

6.1 Onsite Collection and Treatment

It is unlikely that the systems that are appropriate to the rather small populations of the resource-wealthy industrialized countries will be successful in solving the formidable problems of a much poorer, and much more populous, developing country (16). A World Health Organization survey published in 1976 (39) indicated that whereas in 1970, 27% of the urban population in developing countries had sewerage connections, this figure had actually declined to 25%. Even more serious is the fact that another 25% had no access to any sanitary facility at all. This emphasizes the need for research on low cost on-site collection and treatment systems.

It has been reported (39) that only 13% of the population of the developing countries actually has piped in-house connections and that only 6.5% of the population of developing countries are connected to sewers. This means that, for the moment, the main problem of the majority of the population, which is not served by piped water, is not wastewater disposal, but excreta disposal (16). A recent report by Pickford (40) indicated that only a small proportion of Third World town people are served by a sewage works; in all the developing countries the average as of 1979 is only 3 per cent. Figs. 4 and 5 illustrate the urban water supply and urban sanitation situations in developing countries (40). From Fig. 5 it is evident that a large proportion of the people in developing countries resort to household systems of sanitation. The various options available are as follows:

(a) Pit Latrine

The pit latrine remains to date one of the most widely used technologies for excreta disposal in the tropics (16). They are the most common and the simplest sanitation system (41). They are almost universally acceptable in rural areas and are widely used in urban areas, although often not ideal. They are the cheapest system possible and the system most appropriate for self-help programs in which inidividual householders are responsible for their own sanitation. The schematic diagram of a basic pit latrine is shown in Fig. 6. The pit or borehole latrines have also been depicted in Fig. 7. Where site and ground conditions are suitable, these have great advantages (40). The major obstacles to pit latrine construction are population densities, and location of the nearest dug-well water supply (16).

Improvements can make the pit latrine more acceptable. Some of the improvements mentioned in the literature (42) are: (i) Pour-flush latrine, (ii) Chute and Pan Arrangement, and (iii) Reed's Odorless Earth Closet (ROEC). Details of these may be had from elsewhere (16, 42, 43).

(b) Composting Privies

The term "composting privies" refers to household composting systems, which may be either aerobic or anaerobic, and are sometimes referred to as "mouldering toilets", particularly in the Scandinavian literature. Composting is essentially a dry process and composting privies represent one form of dry excreta-disposal options (16). The different versions of composting privies are (16, 18, 42): (i) Double-Vault Composting Latrine, (ii) Vietnamese Double Vault, and (iii) Aerobic Household Composting System. The composting pit latrine is schematically shown in Fig. 6. The Vietnamese double-vault compost latrines and the modified Scandinavian designs like the Clivus Multrum are shown in Fig. 7. The chief advantages of a composting privy is the destruction of pathogens in the excreta during the composting period, and the reuse of the compost in agriculture and aquaculture. The drawbacks associated with the pit privy also

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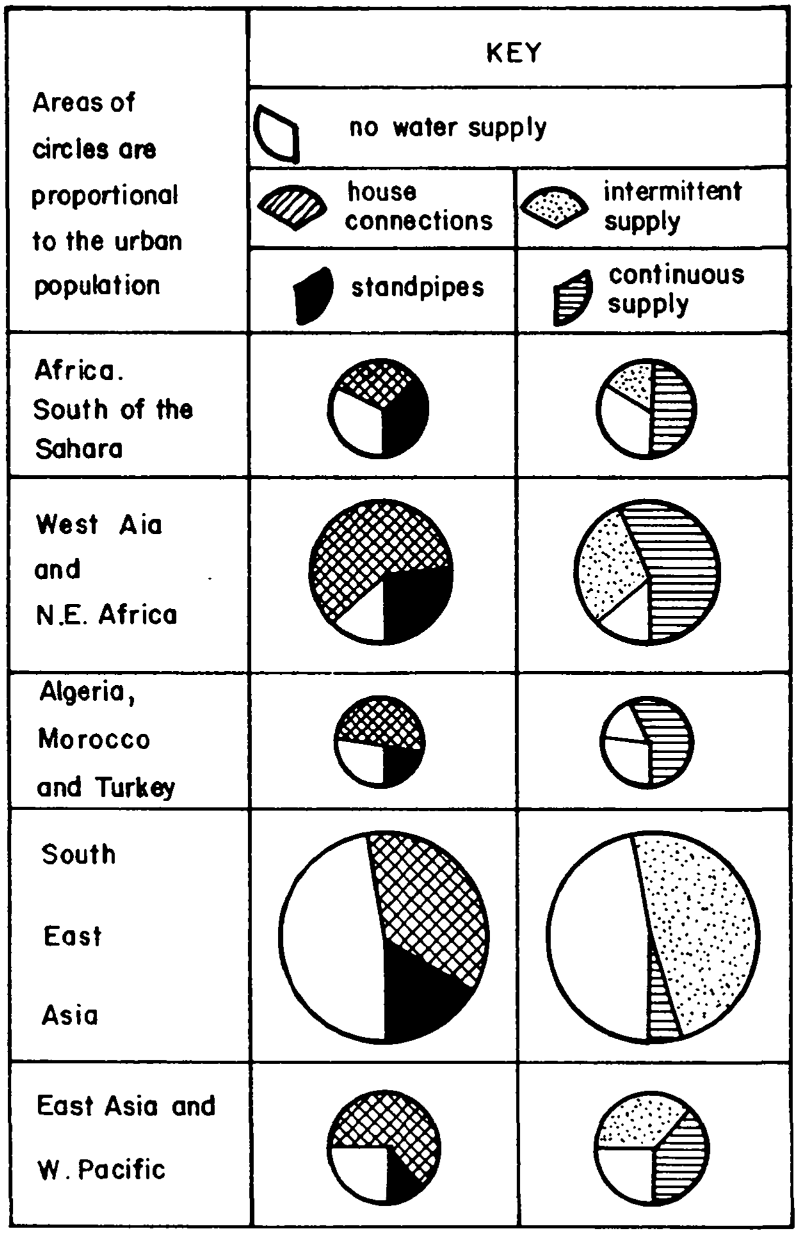

Fig. 4 Urban Water Supply Situation in Developing Countries (40)

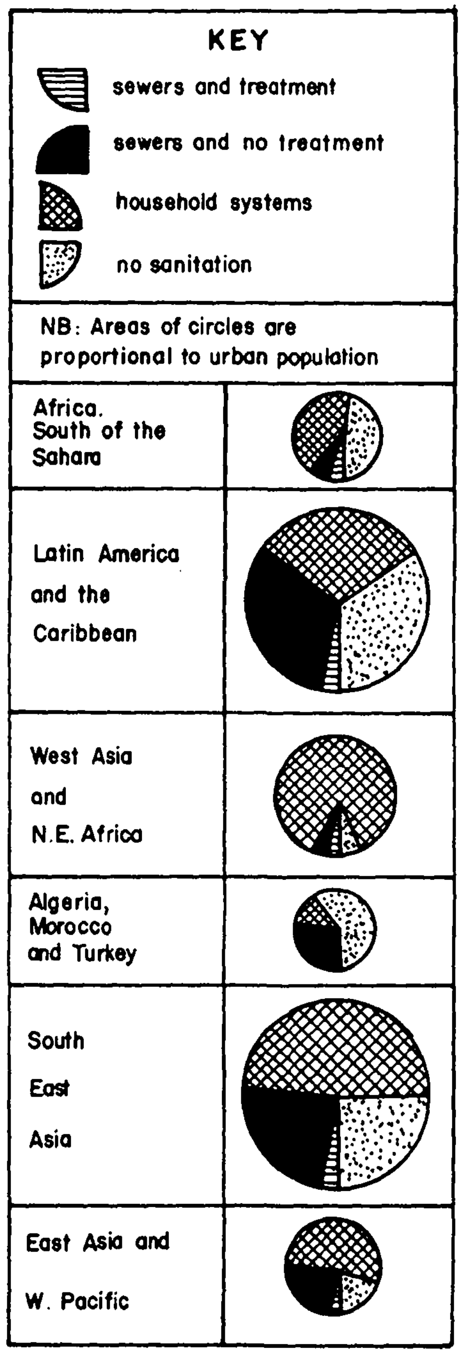

Fig. 5 Urban Sanitation Situation in Developing Countries (40)

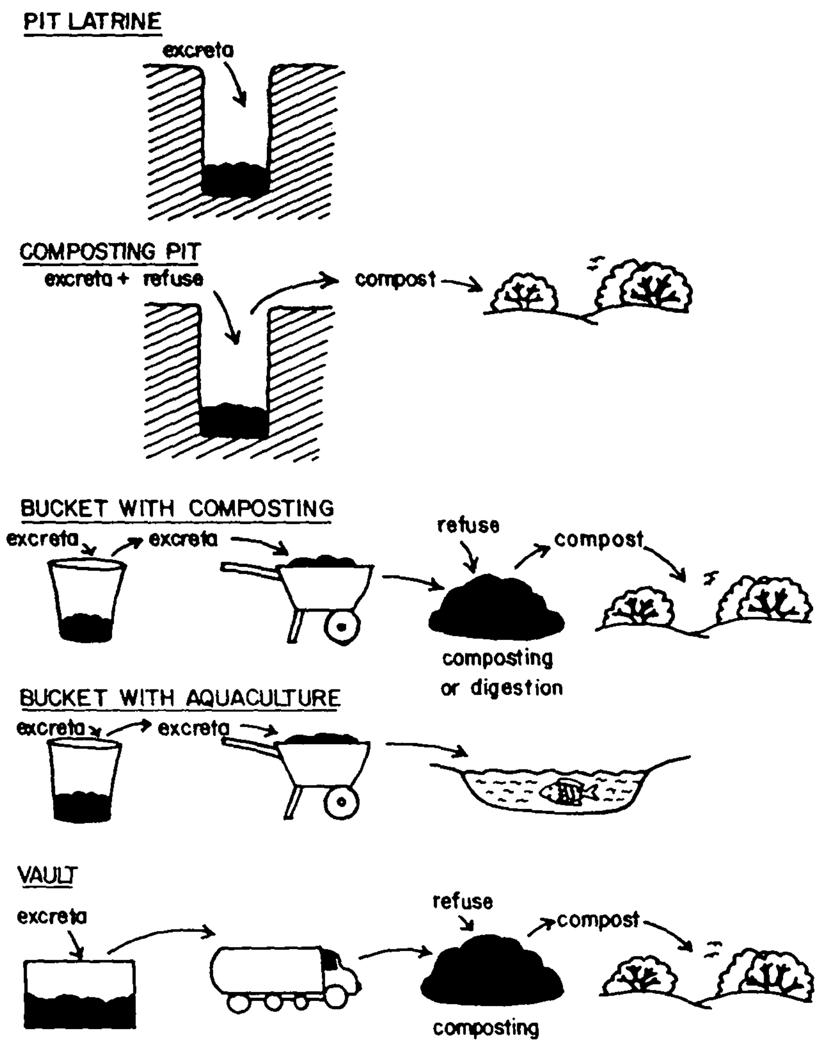

Fig. 6 'Dry' or Nightsoil Disposal Systems (41)

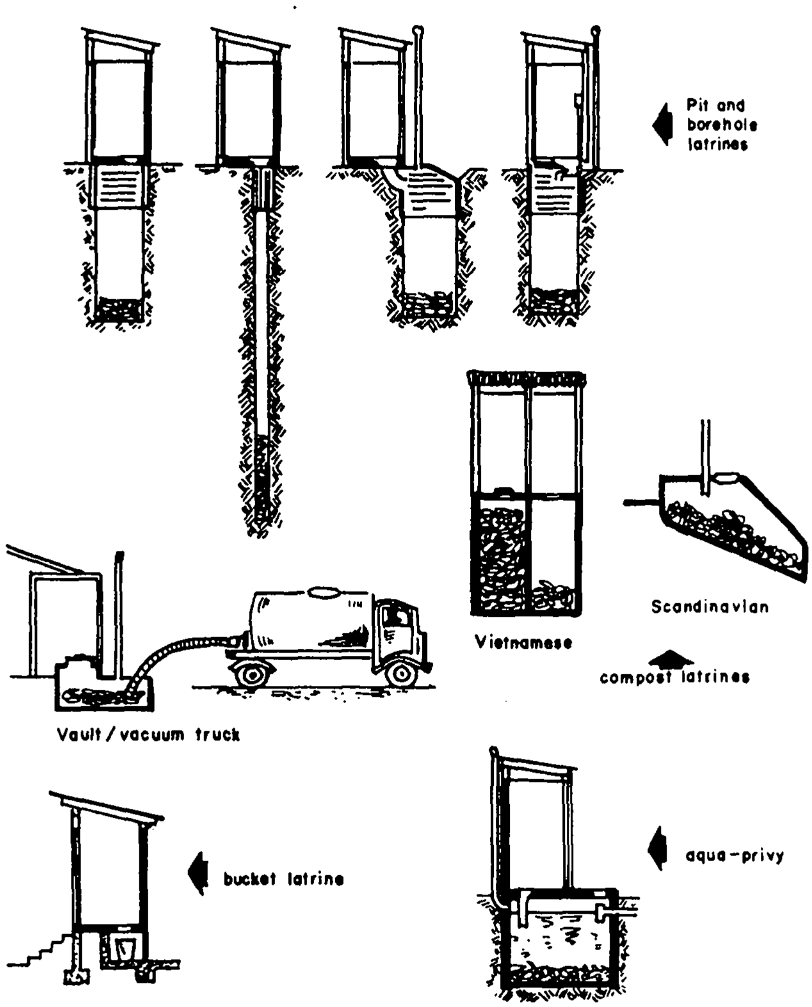

Fig. 7 Some Alternative to Sewerage Systems (40)

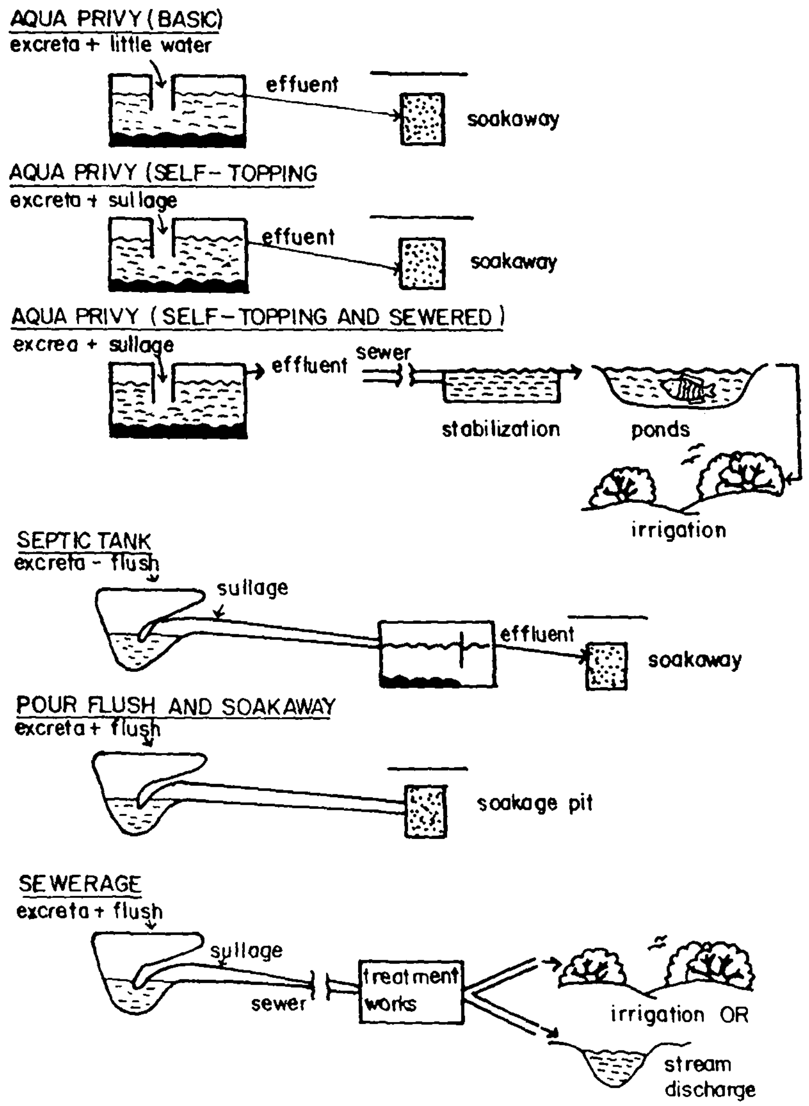

Fig. 8 'Wet' or Sewage Disposal Systems (41)

apply to composting privies (41). The composting toilets in the tropics have recently been reviewed by Kilama and Winblad (44). According to them, compost latrines are sensitive to misuses: refuse must be added regularly, overuse must be avoided and very little water must be used. Intensive health education is an important component, especially during initial use.

(c) Septic Tank

The septic tank consists of a compartmentalized vault within which settlement and some liquefaction of the solids take place, and a subterranean tile or leaching field where most of the biological treatment of the septic tank effluent occurs (Fig. 8). All the household wastewater goes into the tank in addition to the excreta and flushing water. The costs of septic tank installation, as well as periodic desludging, make them completely inappropriate for the rural population of a developing country. The extensive area required for the infiltration field severely limits their application to urban areas. There are indications that in urban areas septic tanks will often cost more on a per household basis than conventional waterborne sewerage (16, 45).

Septic tanks can be used for populations of over 300 but they are most commonly found on individual dwellings. In the tropical cities of the world, houses in relatively high-income, low density areas not having a sewerage system may successfully employ individual septic tank systems. Since the septic tank often takes all wastewater from the house, it needs a substantial soakaway (a soakaway is basically a pit or a trench filled with stones or given a lining through which water can seep. In other words it simply allows the wastewater to filter into the ground and disperse), thus rendering the system unworkable in high density areas (41).

Some causes for septic system failures have been poor soils, hydraulic and organic overloading, underdesign, high groundwater, lack of maintenance, conversion of seasonal homes to year-round use, increased density, etc. (46). Properly designed, constructed, and operated systems should not fail, but even if they fail they are controllable. Moreover, alternative septic system technologies are available to overcome soil, geological, and hydrological conditions that may limit the use of conventionally designed septic systems (47). Such alternative systems can (i) provide as good or better treatment than central systems, (iii) use less energy, and (iii) replenish groundwaters.

The disposal of effluent in soil from septic tanks serving individual or small suburban communities becomes difficult in areas of compact soil conditions, high water table, and limited availability of open land. Under these conditions, secondary treatment of septic tank effluent is accomplished by sand filters and mounds. These systems require frequent maintenance and additional pumps. In such cases, an anaerobic upflow filter may be successfully used as a simple secondary treatment device for treating septic tank effluent and settled domestic sewage, or may be used as a composite sewage treatment unit (26). Although the use of anaerobic upflow filter for industrial and synthetic waste treatment is well documented, very limited literature, to date, is available on anaerobic filter application for domestic or septic tank effluent treatment and this area warrants further investigation.

(d) Aqua Privy

The aqua-privy is a modified cylindrical septic tank, which is filled with water upon construction and replenished as necessary to maintain a water-seal. A vertical drop pipe carries waste from a toilet bowl or a squatting plate to below the water surface. As with a septic system, solids sink to the bottom of the tank; overflow is discharged to a leaching field; and the tank sludge is removed periodically. If insufficient water is maintained in the tank, the water-seal ceases to function, and flies and odors become a serious problem (42). Household wastewater (grey water) is not usually disposed of in the aqua-privy. The system has many of the same limitations as the pit latrine with respect to density of implementation and to the requirement for separate disposal of household wastewaters, although at a much higher cost (16). The advantages of aqua privy over a separate septic tank are that it uses less water and less land, and that it does not require solids to be flushed along a pipe and so is less liable to blockage (41). Figs. 7 and 8 illustrate the aqua privy system.

The choice of which excreta disposal system to adopt in a particular case will depend on many factors and no easy guide can be presented. Table 28 gives some of the important relative features of the systems available. The final decision will depend to a large degree on previous experience, both good and bad, of sanitation systems in the area (41).

Table 28. Comparison of Several Sanitation Technologies (41).

Sanitation System	Rural Application	Urban Application	Construction Cost	Operation Cost	Ease of Construction	Water Requirement	Hygiene
Pit latrines	Suitable in all areas	Not in high density suburbs	Low	Low	Very easy except in wet or rocky ground	None	Moderate
Bucket and cartage	Suitable	Suitable	Low	High	Easy	None	Bad
Vault and vacuum truck	Not suitable	Suitable where vehicle maintenance available	Medium	High	Requires skilled builder	None	Moderate
Aqua privies	Suitable	Suitable	High	Low	Requires skilled builder	Water source near privy	Good
Septic tanks	Suitable	Suitable for low-density suburbs	Very high	Low	Requires skilled builder	Water piped to privy	Excellent
Pour flush and soakaway	Suitable	Not suitable	High	Low	Requires skilled builder	Water source near privy	Good
Sewerage	Not suitable	Suitable where it can be afforded	Very high	Medium	Requires experienced engineer	Water piped to privy	Excellent

6.2 Collection and Offsite Treatment

The various options available for removal of human wastes to locations, usually outside the city or point of generation, for treatment and/or disposal are the following: (a) Cartage, (b) Waterborne, (c) Ponds, (d) Composting, and (e) Aquatic Plants.

(a) Cartage

There are a series of options available for removal of human wastes that accomplish this without the use of underground pipes, but by some form of cartage, either handcarts, trucks, or vacuum trucks, depending on the level of sophistication (16). Some of these are depicted in Figs. 6 and 7. This option would be appropriate only on a fairly large scale due to the financial and organizational problems associated with running a fleet of vehicles. This would be most appropriate for a town or city with an efficient and established municipal administration (41). Cartage is widely practiced throughout the cities of developing countries. Widespread practice has been reported in China (49), Japan (50), Taiwan (51), etc. The costs of cartage systems vary from case to case depending on the frequency of collection, and the distance from vault to disposal point.

Little work has been done on reducing the cost of vacuum trucks, or on low cost methods for night-soil treatment. Vacuum truck systems from relatively advanced countries such as Japan will have to be adopted to the conditions in the poorer developing countries. Smaller-scale vehicles, such as hand-operated vacuum carts (52), which could be locally fabricated, would make the cartage system much more adaptable to incremental adoption by the informal sector.

The disadvantage of the cartage option, as mentioned earlier, is the high degree of efficient central organization required for successful operation. The chief advantages are: (i) it can be used to upgrade conditions in existing built-up areas, where the construction of underground sewers would be impossible, and (ii) it can be used in conjunction with on-site systems. In Jakarta, Indonesia (53), and in Bangkok, Thailand (126), existing cesspools have been made operable by periodic pumping out, in spite of high groundwater and poor soil conditions. The problems of odour, uncleanliness, and unpleasantness associated with the pail or bucket systems may be avoided by using the vacuum truck, or the smaller scale version vacuum cart, into which the nightsoil can be sucked directly from the vault.

(b) Waterborne

When the Western engineers design urban waste disposal systems for a less developed nation, they almost invariably base their design on waterborne sewage transport. This involves dilution of the waste in its most concentrated form with potable water solely for transportation. The resulting sewage, mostly water, is flushed through a system of subterranean pipes and pumping stations to one discharge point. Because direct discharge of large volumes of waste is detrimental to the receiving water, the objective then becomes one of repurifying the water and reconcentrating and treating the waste. In short, diluting waste for transportation and then concentrating it at a treatment plant do not make sense economically or in terms of resource conservation (12).

Sewers and treatment plants are expensive. On a per-household basis, they are far more expensive than color television sets. Developing countries are having considerable difficulty providing urban wastewater management services, because the technology they are trying to apply is inappropriate. Sewerage transferred from industrialized states is capital intensive during construction and labor-conserving during operation: quite the opposite of required economic characteristics. Therefore some researchers (42) are of the opinion that sewers are not appropriate for developing nations. Others (54) also argue that when only 13 percent of the population of developing countries enjoys a piped water supply and internal plumbing, the major problem is one of excreta disposal.

Although the above discussion seems to be quite logical, sewerage seems to be the only solution for waste disposal in high-density, high-rise housing and commercial areas (16). It seems that, for the moment at least, underground sewers are the only solution for the central business district or for those areas where housing is in the form of high-rise buildings. Under these situations sewerage reduces two drawbacks usually associated with waterborne sanitation: first the required piped water is usually available in high-rise housing, and second the concentration of population significantly reduces the unit cost of sewerage. Fig. 8 illustrates a sewerage system.

To overcome the problem of clogging associated with sewerage in low-density areas in tropical climates due to insufficient water usage, a waterborne alternative, called the aqua-privy/sewerage system, has been proposed as can be seen in Fig. 8. This has also been reported to be economical (55).

One distinct advantage of waterborne systems is the reuse potential of wastewater. With these systems it is possible to recoup at least some of the capital cost of the sewerage system by the development of algae production and fish ponds and secondary use of water for irrigation. Long term benefits of reuse is gaining increasing importance in the present-day waste management programs.

(c) Ponds and Oxidation Ditches

Many years of field experience have established the waste stabilization pond as a relatively inexpensive and reliable method of wastewater treatment. Recently, various adaptations have been made in the design of pond systems, including the use of pretreatment units such as anaerobic ponds and the addition of mechanically aerated lagoons. Either of these pretreatment units may be used successfully to assist the facultative waste stabilizaiton pond or other biological treatment units. Also, the use of maturation or polishing ponds following facultative ponds has become more prevalent, particularly as a means of controlling the bacteriological count (56).

A facultative waste stabilization pond provides an aquatic environment in which photosynthetic and surface oxygenation provides an aerobic zone in the upper strata, a facultative zone throughout most of the depth and an anaerobic bottom layer. This type of pond may be designed to operate separately; follow an aerobic waste stabilization pond, a mechanically aerated pond, or various types of biological treatment units. Also, a facultative waste stabilization pond can provide pretreatment for a polishing waste stabilization pond (Fig. 9). Ponds have also been used in association with other recycling alternatives (57, 58).

Environmental conditions in tropical countries are ideal for the biological processes which occur in these ponds. Essentially, organic water is broken down by bacteria in the ponds as in conventional biological treatment processes, aerobically in the upper layer and anaerobically at the bottom. The oxygen requirements of the bacteria in facultative ponds are provided mainly by algal photosynthesis, while algae proliferate as a result of the carbondioxide released by bacterial respiration. Ponds can be very cheap to construct, being formed by earth embankments and not requiring lining if built on relatively impervious soil. The chief advantages of oxidation ponds is their ease of operation and low maintenance costs (36).

Ambient temperature has a significant effect on pond performance and on the maximum organic loadings which they can tolerate. Facultative ponds in tropical regions can be loaded upto about 450 kg BOD per ha-day without lowering the BOD removal per unit of area, while anaerobic ponds or lagoons have been operated upto 50,800 kg BOD per ha-day with high efficiency (59). Anaerobic systems are particularly suited to tropical conditions and anaerobic ponds are the cheapest possible form of anaerobic treatment. The cost of treatment using oxidation ponds depends on both the efficiency of land use (which depends on climate) and on the cost of land (which depends on location).

Oxidation ponds are an extremely flexible system of waste treatment. If originally designed as a number of facultative ponds in series, the first pond or ponds can be allowed to go anaerobic as loading increases and no further land is required. If the loading further increases, later ponds in the series system can be aerated using floating surface aerators to increase their treatment capacity and yet maintain aerobic conditions. If eventually an urban area has grown to the point where land value is too high to justify excess use for waste treatment, the land occupied by oxidation ponds is a reclaimable asset which can

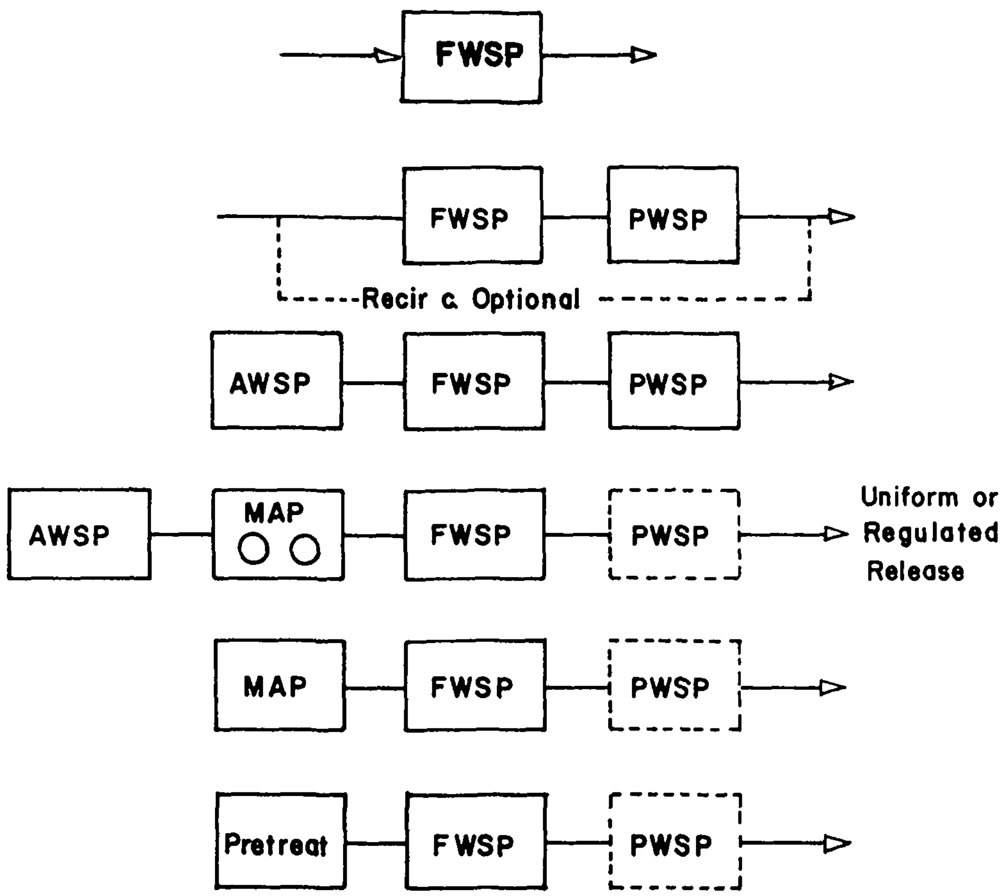

Fig. 9 Possible Treatment Trains Associated with Facultative Waste Stabilization Ponds

<u>Note</u>
FWSP = Facultative Waste Stabilization Pond
AWSP = Aerobic Waste Stabilization Pond
MAP = Mechanically Aerated Pond
PWSP = Polishing Waste Stabilization Pond

offset the costs of providing alternative secondary treatment. Ponds hold a lot of promise for waste treatment in developing countries.

An alternative process to oxidation ponds which has been used for small communities is the oxidation ditch. In fact, this process is an extended aeration activated sludge process designed for a retention period of about 24 hours rather than the conventional activated sludge detention time of 6 hours. Land use is much less than for oxidation ponds which are usually designed for a minimum detention of 10 days for treatment of sewage, to allow a greater die-off of pathogens.

The process has great appeal in developing countries because construction is simple and the only equipment necessary for a basic plant is an aeration rotor, which can be made locally. Operation is simple, maintenance cost is low and efficiency of BOD removal is high. Ditch construction can be cheap but is more costly than for oxidation ponds. Oxidation ditch treatment would not normally be adopted for large waste flows because of the high retention time in the plant. Cost of treatment using this method would generally be of the order of a regular secondary treatment plant because of the size.

(d) Composting

Composting has been defined as "a biological process for converting organic solid wastes into a stable, humus-like product whose chief use is as a soil conditoner". Composting has long been a traditional method for the recycling of farm wastes, and more recently it has been used for the treatment of nightsoil and sewage sludge.

Nightsoil may be mixed with organic wastes and refuse and composted. Composting takes place in piles or in pits, and not under water. If the compost is frequently turned to allow air into it, it will not produce offensive odours. Temperatures of 50-60 Celsius degrees are reached and efficient composting will take 1-4 months. This combination of time and temperature will cause most pathogens to be destroyed and will produce an inoffensive material suitable for agricultural use.

In China, composting of nightsoil is an important component of rural health programs (61). Two kinds of aerobic composting are used: pit composting where air is channeled through trenches at the bottom of the pit, and pile composting where air is introduced into holes made by the removal of sticks. The composted material is used in agriculture. Aerobic composting of city refuse mixed with nightsoil is also prevalent in India (16). In India, a method known as the "Bangalore process" is practiced on a communal basis. This process is probably aerobic for a short period after piling and after each turn, and anaerobic during most of the remainder of the composting period (62).

Composting of a mixture of human waste together with other organic works like leaves, etc., is also feasible and it helps to optimise the C/N ratio. A study conducted at the Asian Institute of Technology, Bangkok, Thailand (17,63), to study the feasibility of utilizing nightsoil and water hyacinths as raw materials in composting showed that composting is not only a solution to the treatment and disposal of nightsoil and water hyacinth, but it also results in the production mainly of fish feed for Tilapia, and possibly of a valuable organic fertilizer which is in great demand for agricultural uses throughout tropical regions. The "ground-surface continuous aerobic composting" proved to be effective, easy to maintain, and able to retain valuable nutrients while eliminating health hazards. The data in Table 29 shows that this composting method is feasible and suitable for adoption in developing countries because of its ability to retain most of the nitrogen, phosphorus and potassium in the compost, and attain a satisfactory degree of composting within a relatively short period of time, i.e. 30 days.

Some important factors to be considered in composting are toxic substances, aeration, water content, carbon to nitrogen ratio, mineral nutrients, composition of organic wastes, the availability of nutrients, moisture content, size of heap, particle size, and the degree of aeration and agitation.

Composting of sewage sludge is practised in developed countries like the United States and may also be an option in developing countries where sludge is produced in treatment facilities. The methods used in the U.S. are either the windrow technique or the forced aeration method. The former requires turning the pile at specified intervals, usually done by specially designed machines (16). The "aerated pile composting method" is one such method developed by the U.S. Department of Agriculture (5) which is particularly suitable for land application of sludge, since the product has little odor, practically no

Table 29. Average nutrient content of compost piles (Nightsoil + water hyacinth + leaves) at C/N ratios of 20, 30 and 40 at the initial period and during the 30 - 60 days of composting (17).

	C/N = 20		C/N = 30		C/N = 40	
	Initial	30-60 day*	Initial	30-60 day*	Initial	30-60 day*
% N dry weight	2.0	2.2	1.3	1.9	1.3	1.9
% P dry weight	0.3	0.6	0.2	0.4	0.3	0.3
% K dry weight	1.0	1.0	0.6	0.6	0.6	0.6

* = Average of 5 samples taken during that period.

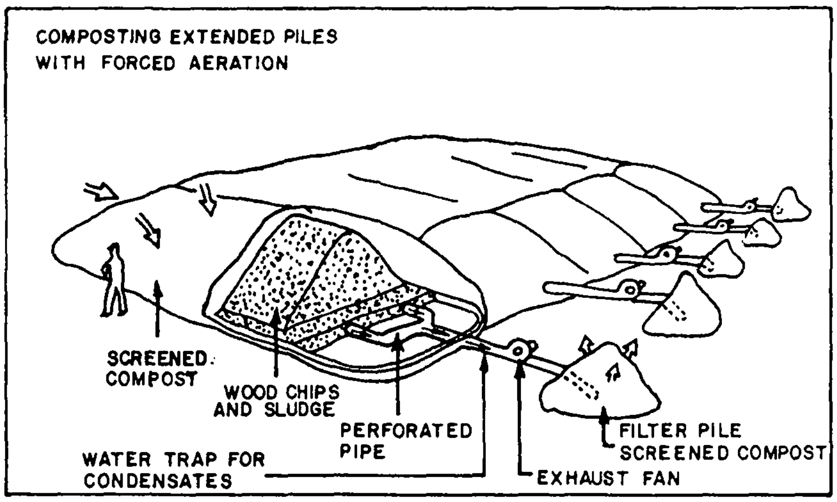

Figure 10 Sludge Composting for Land Application (5).

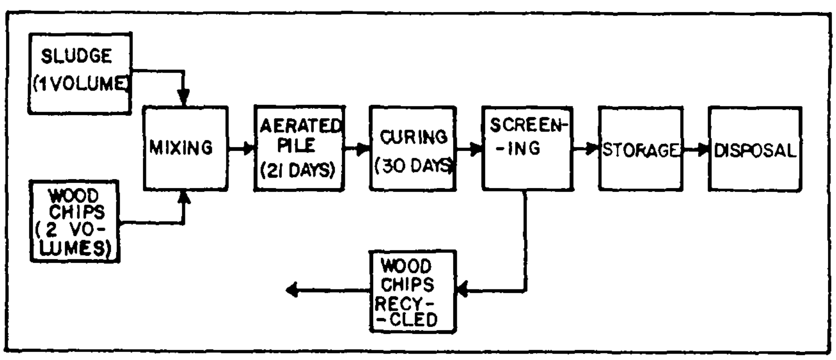

Figure 11. Aerated-Pile Composting Processes (5).

pathogenic organisms, and is dry enough to be stored easily. This method is depicted in Figs. 10 and 11 (5). The forced aeration method relies on mechanically induced air movement through the pile (16).

(e) Aquatic Plants and Weeds

The potential environmental benefits derived from utilizing treated municipal wastewater for wetland restoration and enhancement and the feasibility of using wastewater-wetland complexes as an alternative among economical wastewater treatment systems for small communities has been studied in the United States (64,65). These systems also demonstrate a reuse method that combines wastewater and wildlife management for optimum results. Wetlands systems created and maintained with treated wastewater are cost effective and low in energy requirements. In fact, solar energy is the primary element supporting the plants and higher organisms that remove pollutants from the wastewater. A California study (64), in which a balanced and healthy wetlands ecosystem composed of pond and marsh areas was successfully created using secondary treated wastewater, has revealed the following: (i) the wildlife habitat actively supports 67 species of plants, 21 species of animals, 85 species of birds and 34 species of aquatic invertebrates; (ii) mosquito breeding has been reduced to a minimum through the use of natural predators, and avian botulism and odors have been avoided, (iii) nitrate removal is consistent and BOD and SS removal is seasonal - if algae were not regarded as a component of SS, they would then be consistently lowered.

Most of the scientific investigation of aquatic weeds and plants has taken place in America and Europe, but this concept can successfully be applied to developing countries also, which abound in wetlands and marshes and have a tropical climate with bright sunshine most of the year. Care however should be taken in adapting this technology to tropical conditions and its health implications under the tropical conditions of developing countries should be investigated thoroughly.

Water hyacinths are reported to be used for sewage treatment in the United States where they are harvested for animal feed (16). However, it appears that such an option may not be economically viable at the present moment. Water hyacinths can also be used to produce biogas with or without the use of any extra materials. In Thailand, water hyacinth is available in plenty and investigations are underway at the Asian Institute of Technology, Bangkok to utilize these for biogas production and composting. In Vietnam and throughout Southeast Asia, aquatic weeds are grown in ponds to which nightsoil is added and the harvested weeds are used for animal feed (66). This option for human waste treatment holds a lot of promise for developing countries and scientific investigations must be launched to exploit the technique.

6.3 Reuse

We are now moving towards a "recycle society" - a society in which virtually all materials are reused indefinitely. Secondary materials will become our major resources, and our natural untapped resources will become our backup supplies. Human wastes are usually "resources out of place" and should be re-used wherever practicable.

The World Health Organization Expert Committees on Environmental Sanitation, at its third session in 1952 stated that "the Committee recognizes the widespread use, in many parts of the world, of human excreta as fertilizer... With the growing world population and the limited extent of world resources, all efforts to utilize sanitary by-products and return them to the soil should be encouraged. The necessity of controlling these activities in such a way as to reduce to an absolute minimum their inherent public health hazards cannot be too strongly emphasized".

Recycling, or reuse, of resources is widely practised in developing countries, not so much for reasons of environmental control (as in the West) as out of dire necessity. Further to the pressures of their population explosion, developing countries face a situation where their limited resources must be stretched a long way indeed (16). With the increasing consciousness for environmental sanitation in these countries coupled with the realization of the immense benefits associated with waste recycling, it is expected that reuse of human wastes will gain tremendous importance in the waste management programs in developing countries.

The chief resource recovery systems that show a lot of promise in the developing countries are: (a) Irrigation, (b) Aquaculture, (c) Algae, (d) Fertilization, and (e) Biogas.

(a) Irrigation

Land treatment of sewage, either raw or treated, can be used in developing areas where land is available. Although land treatment is not a new technique, it has not received the acceptance or recognition it deserves in the Third World. One reason might be that only 6.5% of the population of developing countries has access to a sewerage system. However, it should be borne in mind that sewerage remains one of the few effective options for centre city locations, and this option has been chosen already in a number of cities. Moreover, stabilization ponds are generally considered as one of the most appropriate methods of waste treatment for tropical climates and pond effluents can be effectively used for irrigation. One reason for the reluctance in considering this option in the developing countries is due to the public's fear of diseases and heavy metal hazards associated with sewage irrigation. The public should be informed about processes that are being used in properly managed land treatment systems to protect public health, in order to allay their fear of disease transmission, and they can also be informed that as yet there are no cases of toxic element poisoning of humans associated with land treatment (4).

The word 'irrigation' in this section is used to refer to land treatment of sewage or pond effluent, as differentiated from fertilization', which is used to refer to land application of nightsoil and sewage sludge. Fig. 12 illustrates the different methods which can be used for land application of sewage (4). Details of these systems can be obtained elsewhere (4, 67).

Many people equate land treatment with landfills, dumps, odorous overloaded sites and the like. Land treatment is not dumping or simply disposal. It is a managed competently designed approach that utilizes the most current engineering and scientific information. The result is a system that uses and conserves the resources in wastes (water, nutrients, organic matter) to enhance the soil and crop production rather than simply treat and dispose of the wastes. Most of the research in this field is being carried out in the developed countries where land treatment is being viewed as an effective waste treatment method based on scientific and engineering principles. The "Werribee Farm' near Melbourne in Australia is probably one of the world's best examples of the benefits to be derived from the use of reclaimed water (68). The farm currently covers an area of some 10,800 ha. and treats an average of 200,000 ML (200 million cu. m) of wastewater per year. Of this, approximately 20 percent (40,000 ML/a) is used for land irrigation during the summer period, the remainder being treated in lagoons or by grass filtration during winter. Approximately 80 percent of the sewage used for irrigation is applied to the land without prior treatment. Sewage is

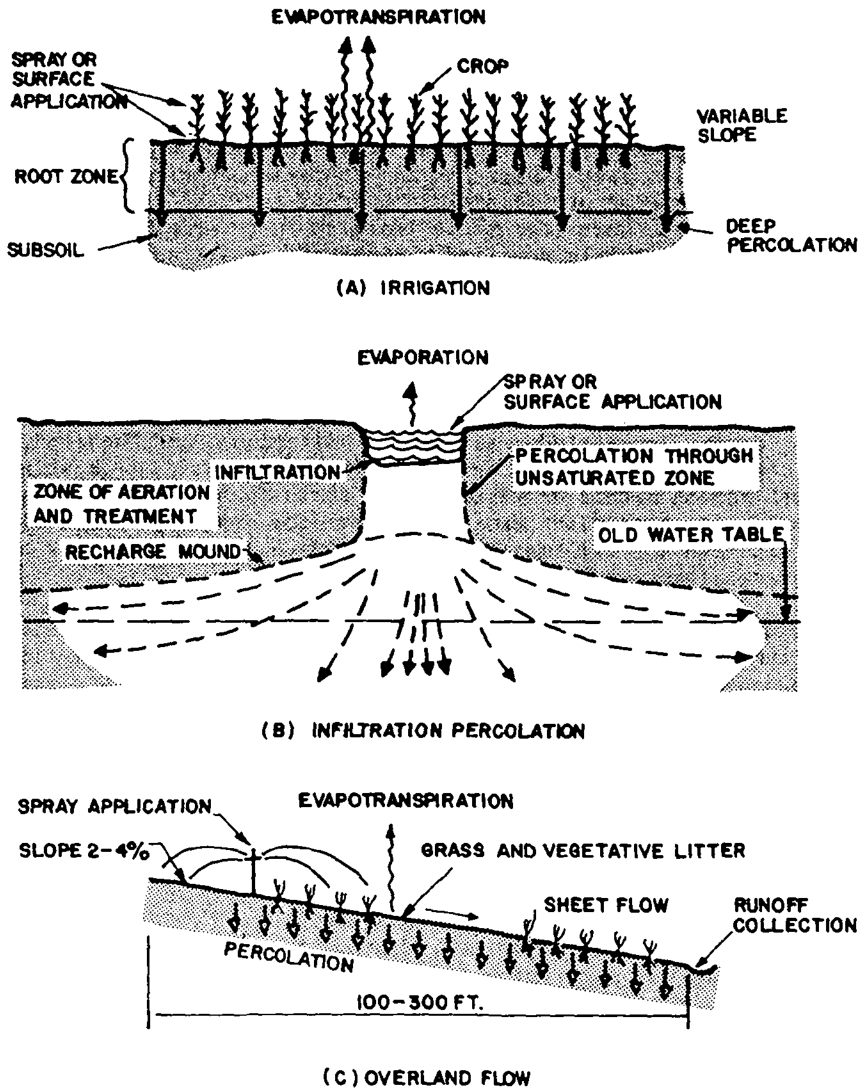

Figure 12 Methods of Land Application (4)

applied at a rate of 100 mm every 18 days (68).

The widest use of sewage for irrigation in a developing country is in India, where untreated sewage is used directly on the soil. It is reported that almost a third of the sewage produced by about 25 million people (1% of the total population) is utilized for irrigation (69). Sewage farming, as it is known in India, is generally practiced under organized conditions and on a specific range of crops to reduce health hazards to workers as well as to consumers in the case of edible crops (70). Recently there have been reports of reuse of municipal wastewater on land from other countries like Iran (71), Israel (72), and South Africa (73). The use of stabilization pond effluent has agricultural, sanitary, and environmental benefits, and considerable work has been done in many countries on land treatment of pond effluents.

According to Pickford (40), irrigation with crude sewage under controlled conditions may be the most appropriate method of treatment and disposal for developing countries. Not much research has been done on land treatment of sewage or stabilization pond effluents in South East Asia, although some successful studies have been undertaken at the Asian Institute of Technology, Bangkok, on land treatment of industrial (74) and agro-industrial wastes (75). With a view to stimulate more scientific research in the field in the developing countries, ENSIC has recently compiled a state-of-the-art on land treatment of municipal wastewater (4).

(b) Aquaculture

This is a resource recovery system that shows tremendous possibilities in the developing countries. Cultured fish are a major source of animal protein in China, Japan, Taiwan, India, Indonesia, the Philippines, and Thailand, and fish culture is also practiced in Bangladesh, Hongkong, Malaysia, Pakistan, and Sri Lanka. The most common method of fertilizing these fish ponds is to use organic manures. There are basically two techniques for reusing human wastes in aquaculture, either by fertilization of fishponds with the waste or by rearing fish in waste stabilization ponds (16).

In Southeast Asia, where nightsoil is added to fishponds, the accent is on fish production rather than waste treatment. The nightsoil-fertilized The consumer produces nightsoil, which is introduced to the fish pond and provides the main source of nutrients for bacterial growth. The by-products from this process are the primary nutrients for the algae, which in turn are the basic food form for the fish, which in turn are food for the consumer (16). Further, fisk also directly consume human feces.

The second technique for combining human waste reuse and aquaculture is to introduce fish into the secondary ponds in a waste stabilization pond system, where the accent is on waste treatment. The presence of fish improves the functioning of the pond with regard to algal removal, reduction of suspended solids, as well as reduction of fecal coliform bacteria in the final effluent (16).

Recently there have been many research investigations on using human waste for aquaculture in Thailand (26, 76, 77, 78,79), China (52), India (80), Hongkong (81), and other developing countries. Throughout Southeast Asia, nightsoil is added to fishponds and the accent is on fish production rather than waste treatment: 6000 hectares of fishponds are fertilized with nightsoil collected in the city of Tainan (52); in Calcutta, sewage is diverted into fishponds (122); and in the many domestic installations, latrines are actually built out over the ponds (122). Studies are presently underway at the Asian Institute of Technology, Bangkok (79) to develop engineering guidelines for the construction of recycling systems for human waste for urban and rural Asia, using sewage, and nightsoil and septic tank sludge. The system is developing into a presentable example of integrated waste management. The system has been described by Edwards (79) as given below and is illustrated in Fig. 13.

Sewage used in one project was treated and recycled into fish and maize. The system consisted of three stages. The sewage was fed into a shallow, high rate stabilization pond in which the waste was rapidly treated and converted into algae. The algal laden effluent was then pumped into a pond containing Tilapia nilotica, a fish that filters the algae out of the water. Although the fish grew rapidly, significant amounts of algae passed through the fish ponds in the water flowing through the system. To fully recycle the nutrients contained in the waste, the effluent from the fish pond was used to fertilize maize. In

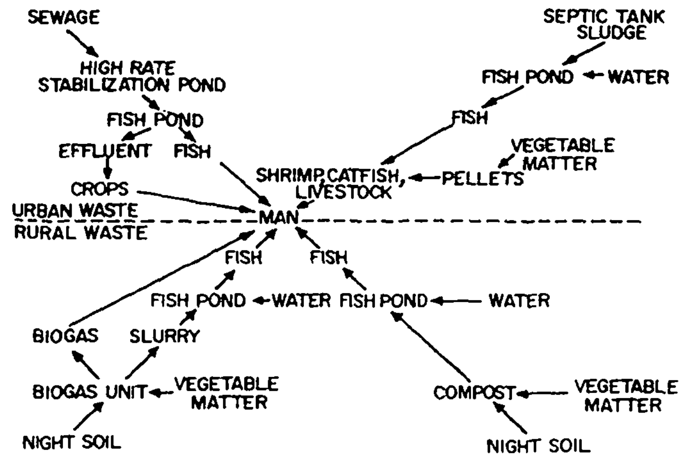

Fig. 13 – Schematic Diagram of Research in Thailand to Recycle Urban and Rural Human Wastes to Cultivate into Fish (79)

another project, septic tank sludge from Bangkok was recycled into fish. The septic tank sludge was added to a single stage stabilization--fish which the nutrients in the waste were converted into plankton which were harvested by Tilapia nilotica. Such a system could have a large impact on current unsanitary methods of sludge disposal in Bangkok and much of Asia. Yields of 20,000 kg/ha-year of fish may be possible in the system. However, a thorough analysis would be needed for determining the economic feasibility of the system.

Systems to treat and recycle nightsoil into fish suitable for rural areas are also being developed in Thailand (Fig. 13). One system composts nightsoil with vegetable matter using the ground surface continuous aerobic composting method as described in section 6.2 (d). The compost is added to a small 200 sq.m. fish pond and its efficiency in fish production is being determined. A second system for rural areas involves the use of nightsoil in biogas production, using a low cost biogas digester unit with provision for mixing the contents of the digester. In the present study the use of the slurry for fish production is being assessed. Pathogen destruction takes place during composting in one system, in biogas production in the second system, and during the cultivation of fish in both systems. A final pathogen attenuation step when the fish are cooked should render the fish safe for human consumption.

Two potential problems relating to the consumption of fish raised on human wastes are the social acceptability of the fish and the potential for transfer of diseases of insanitation. These can be solved by public education, by removing the fish intestines and washing and cooking the flesh thoroughly before consumption, by treating the wastes prior to use in fish culture and/or by feeding waste-grown fish to other animals which can then be consumed by humans so that the fish raised on waste are not consumed directly by humans (79). These areas are at the moment being widely studied.

(c) Algae

Waste stabilization ponds can be designed specifically to maximise algae production by reducing the pond depth to 20-40 centimetres to improve sunlight availability throughout. Under these conditions, the conversion of sewage nutrients to algae is extremely rapid, taking 3-4 days, and the resulting pond is usually referred to as a high-rate pond, or sometimes as an algae pond. A recent publication by Shelef and Soeder (127) gives quite up-to-date information on these algae ponds.

High-rate algal growth pond systems for waste treatment and resource recovery are usually less expensive to construct and operate than conventional waste treatment systems (81). Oxidation ponds have been designed to maximize the growth of algae as well as provide a high degree of sewage treatment (83). Subsequent harvesting of the algae has produced a by-product containing approximately 50 percent protein which can be used to replace fishmeal in the diets of poultry, cattle, swine and sheep. Marketing of the algal product will affect the cost of sewage treatment and the clear liquid effluent may be reused in agriculture.

Successful investigations are underway in many countries on the use of algae to remove nitrogen components from domestic sewage for water reclamation purposes. After algal harvesting and further treatment by filtration, activated carbon adsorption and chlorination, the water quality meets the World Health Organization (WHO) international standards for drinking water. Again, the algal by-product may be marketed to help offset the treatment cost.

One of the problems encountered with algae as an animal feed has been the low digestibility of the nonprotein component - the cell walls. A solution would be to use algae as fish feed since algae constitute their natural food and their digestive system is assumed to be more adapted to algae. This also offers the flexibility of using the algae for animal feed.

Pilot scale algae production is currently practiced in several regions of Asia. The intensive algal wastewater treatment system (IAWTS) as developed and studied at the Technion, Haifa (Fig. 14) provides high quality effluent which can be reused for unrestricted irrigation of agricultural crops or can be safely discharged into receiving bodies of water with high quality requirements. It simultaneously produces approximately 150 tons per hectare per year of proteinaceous feedstuff for animal (poultry, fish, etc.) with protein content of over 45% (28,29). A municipality of 100,000 inhabitants producing 20,000 cu.m./day of raw sewage can produce over 2,500 tons per year of dry proteinaceous animal feed-stuff and 7 million cu.m. per year of reusable irrigation water (Fig. 15). According to Shelef, et al. (28), the benefits of basic treatment, production of reusable water and production of animal feed surpass by a wide margin the cost of the system with respect to both operational and capital recovery.

In pilot scale studies at Manila, Adan and Lee (82) reported an average algal production of about 47 metric tons/ha per year. It has been reported (84) that commercial production of algae is not feasible for a poor, developing country like Bangladesh, and only production at the rural level is possible where "producers will be the consumers". Algal production from human waste has also been reported from India (85), Singapore (86), etc.

The climate in the tropics is very conducive for algae production in stabilization ponds and holds a lot of promise in the developing countries.

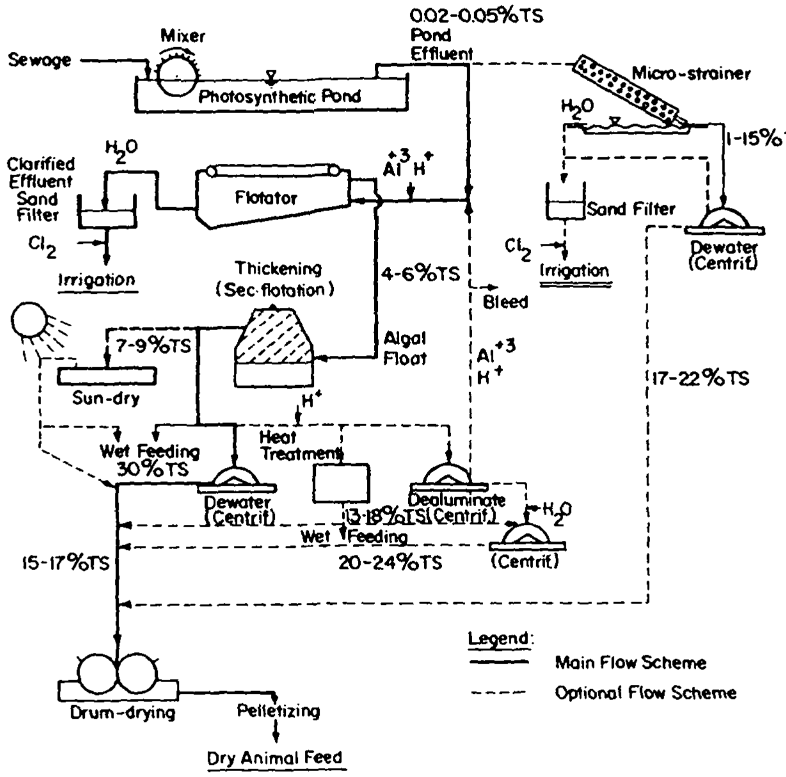

Fig. 14 - Flow Scheme of the Intensive Algal Wastewater Treatment System (IAWT) showing the Main Process (Thick Line) and Optional Process (Dotted Line). Percent of Total Solids of Biomass are Denoted by %TS (28)

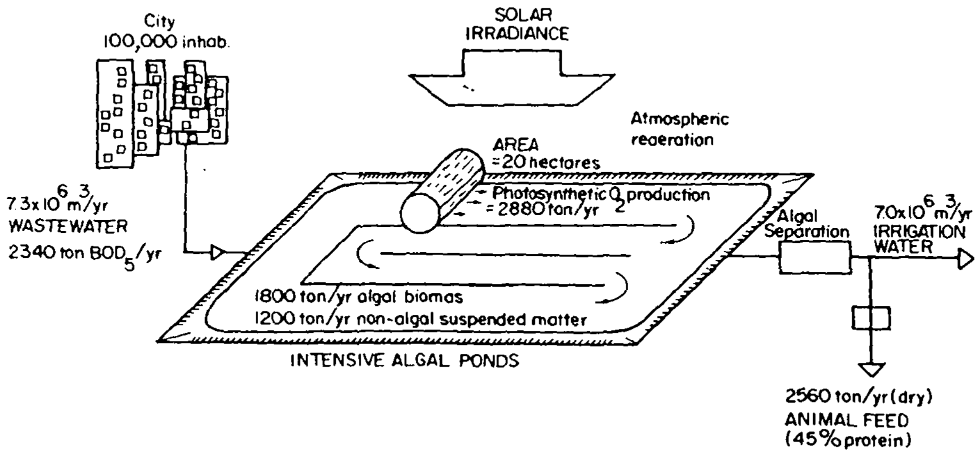

Fig. 15 - A Scheme for the Overall Material Balance of a Model City of 100,000 Inhabitants Based on Experience Gathered in the Technion and Haifa Bay Studies. (28)

(d) Fertilization

Nightsoil contains the three main plant nutrients nitrogen (0.6%), phosphorus (0.2%), and potassium (0.3%) (87). The most widespread reuse of human wastes, now as in the past, is direct fertilization of crops with untreated nightsoil. This technique is practised by farmers throughout Southeast Asia, particularly in Korea, China, and Taiwan, and to a lesser extent in Japan, Thailand, the Philippines, Indonesia, and Malaysia (16). The most outstanding example is to be found in China, where nightsoil has been used for this purpose from time immemorial and is still being used for agricultural development, thereby providing a positive monetary incentive for pollution control (4).

In China, nightsoil has been collected and used for the fertilization of crops for centuries and as we have seen already, is a rich source of plant nutrients (19). From the viewpoint of conservation and utilization of natural resources, the practice is commendable, although for health reasons strict controls have to be carried out. Since nightsoil is considered a valuable source of crop nutrients, its application to the fields could not be banned on the grounds of being a public health hazard lest ill health be replaced by famine. After the Chinese Liberation, practical modifications were made to existing practices in China. The principle of giving priority to prevention has been adopted and there have been health campaigns aimed at the extermination of pests and diseases. The commune members in China were exhorted to store nightsoil in properly designed closed storage chambers for a four-week period to destroy hookworm and schistosomia ova prior to its application. The storage chambers are now widely used in rural areas. Another method gaining importance in China is to pass nightsoil through biogas plants where it is subjected to anaerobic digestion which effectively kills parasitic micro-organisms. In cities, nightsoil is efficiently collected and despatched to the rural areas in closed carts or by boat and is mixed with city or crop wastes for high temperature composting, or it is stored in covered pits for about 1-2 months before being distributed to production brigades/teams. An idea of nightsoil fertilization in China can be had from Fig. 16.

Feachem and Cairncross (41) are also of the opinion that direct application of nightsoil as an agricultural fertilizer involves very substantial health hazards to agricultural workers and to the consumers of crops grown, and they recommend that nightsoil should be either digested, or composted with organic refuse and vegetable matter, before application to the land. In addition to China, anaerobic composting of nightsoil has also been reported in India and in Vietnam, and in the latter case seems to be practiced on a wide scale (16). Besides the nutrient value of nightsoil, it is also a soil conditioner due to its high humus value. Controlled and properly managed fertilization of lands with nightsoil seems to be a viable resource reuse system for developing countries, especially in view of the energy crises and the skyrocketing prices of oil and consequently, the prices of chemical fertilizers.

(e) Biogas

The anaerobic decomposition, or fermentation, of human excreta produces a combustible gas referred to as swamp gas, gobar gas, dung gas or biogas. All anaerobic processes produce this gas (a mixture of about two-thirds methane and one-third carbon dioxide) but specific installations known as "methane digesters" or "biogas plants" have been designed to optimize gas production. Biogas plants on a large rural scale have found application in a number of Asian countries since development began in India in 1938. At present there are millions of biogas plants in China (89), 36,000 in India, 27,000 in Korea (88), 7,000 in Taiwan (45), and smaller numbers in the Philippines, Nepal, Pakistan,

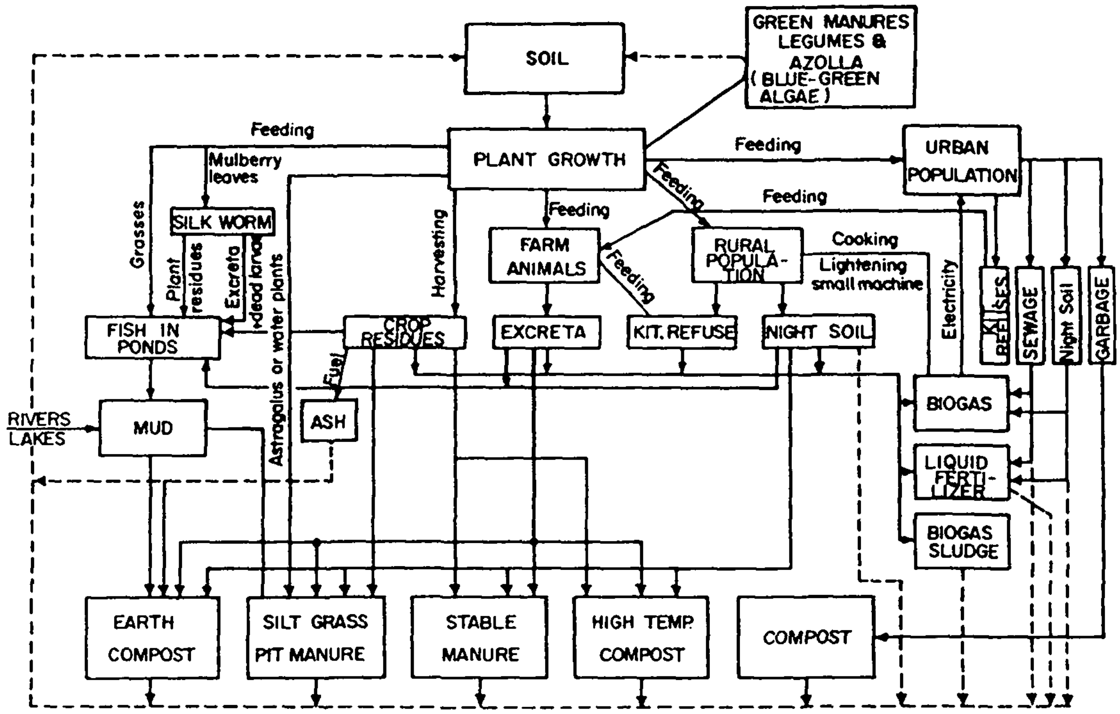

Fig.16 – Recycling of Organic Wastes in the People's Republic of China.

Bangladesh, Thailand, Indonesia, and Japan.

The world is presently experiencing an unprecedented energy shortage which is particularly severe for developing countries, which usually lack capital to purchase sufficient oil. Although there are various alternative sources of energy available such as solar and wind, the technology required to make them widely-applicable to the developing countries is still being developed (90,91). Biogas is conveniently renewable and it has a vital role to play as a future source of energy (92).

The benefits of biogas are the following (93):

(i) The gas produced, being largely methane with upto 30% carbon dioxide, is a clean and convenient fuel;

(ii) Use of the gas as fuel saves other fuels such as kerosene, wood and coal, and eliminates the need to burn other valuable natural resources;

(iii) The gas provides a convenient and cheap source of power not only for cooking, but for lighting, heating and running farm machinery, irrigation pumps and so on;

(iv) The effluent and sludge, remaining after digestion has taken place, are a rich and effective manure;

(v) Due to the removal of carbon during digestion, the organic material remaining is richer in nitrogen and phosphorus than the opriginal material and is thus a superior fertilizer to normal compost;

(vi) The less obvious benefits relate principally to control of environmental pollution. The process turns offensive waste materials from humans (and animals) into useful and innocuous products and is an ideal method of waste disposal.

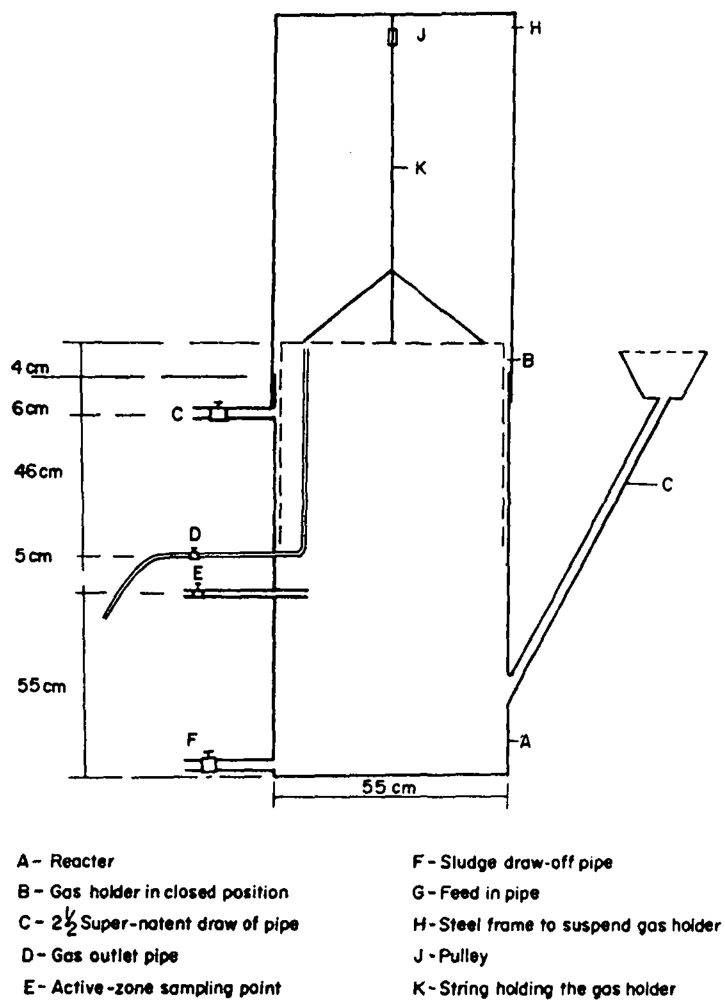

Fig. 17 – The Floating - Cover Type – Indian System (90)

Although several modifications have been tried, presently there are two types of biogas digesters in use (Figs. 17 and 18) (90): the floating-cover type (Indian system), and the fixed-cover type (Chinese system). The advantages and disadvantages of both the systems have been discussed elsewhere (90) and it has been pointed out that the latter system is more economical in construction and easier in operation and maintenance. Some important factors affecting biogas production are: ambient temperature, organic loading, pH, ammonia toxicity,

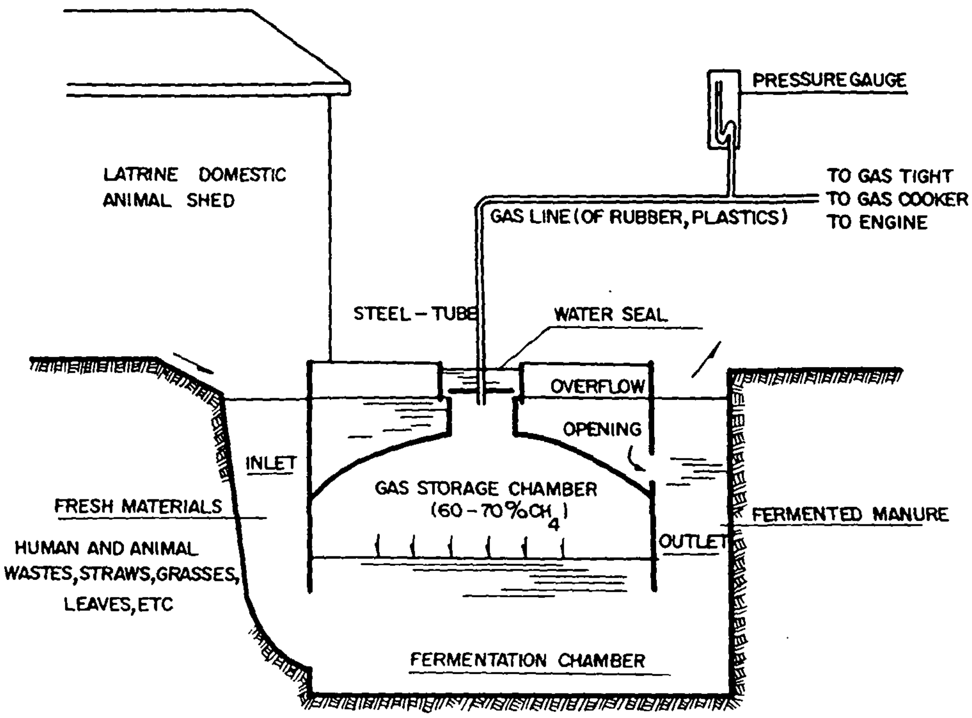

Fig. 18 - The Fixed-Cover Type - Chinese System (90)

viscosity of the slurry, and stirring.

To date, several developing as well as developed countries have sponsored biofuel research and development programs and these are shown in Table 30. Most biogas applications have to date been in rural areas where animal manure is available, fertilizer may be required, and electricity is usually lacking. Nevertheless, several urban plants and research biogas plants are operating in Manila (88,95). Although it is possible to generate biogas using human excreta alone (88), most of the literature pertains to treatment of settled sewage sludge by anaerobic digestion in large scale sewage treatment plants.

At present, research is being conducted at the Asian Institute of Technology, Bangkok, to explore the feasibility of utilizing a mixture of nightsoil and water hyacinth as raw material for biogas. The results obtained so far indicate that such a system looks attractive to countries like Thailand where aquatic weeds are available in plenty. However, the economic viability of the system will have to be carefully looked into. Anaerobic digestion is also effective in destroying pathogens in human wastes.

Biogas can also play an important role in the overall economic development of developing countries by helping in the generation and acquisition of energy, development of food crops, production of protein via the growth of algae and fish in oxidation ponds, hygienic disposal of sewage and a tangible counteraction of environmental pollution (Fig. 19) (94).

The Drinking Water Supply and Sanitation Decade of 1981-90 will provide some incentive to experiment with low-cost alternatives including reuse systems.

Table 30. Research and Developments Related to Bio-gas in Various Countries (94).

Place	Purpose and General Remarks
Bangladesh	Development of rural community-size plants for energy and fertilizer production
Barbados	Bio-energy and fertilizer production
China, People's Republic of	Fertilizer; framily-size plants
Guyana	Bio-energy production
Fiji	Integrated farming with algal and fish ponds for protein and fertilizer
India	Bio-gas used for households in rural areas
Indonesia	Experimental and training
Jamaica	Bio-energy production
Japan	Pollution control
Korea, Republic of	Feed and fertilizer
Lesotho	Rural development
Malaysia	Develop bio-gas technology for rural electrification
Nepal	Bio-energy; fertilizer
Pakistan	Fertilizer
Papua New Guinea	Fertilizer
Philippines	Algal ponds; fertilizer
Singapore	Experimental and training
Sri Lanka	Rural development
Thailand	Rural cooking and electrification
Trinidad	Bio-energy; fertilizer
Tanzania	Fuel and Fertilizer production
Upper Volta	Village development scheme

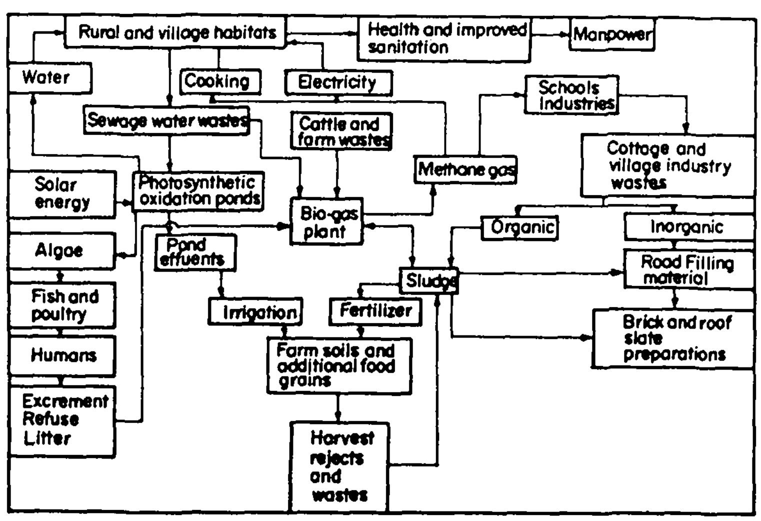

Fig. 19 - Interactive Loop of Rural or Village Farming System based on Biogas Economy (94)

The international assistance organizations such as the World Bank, the Asian Development Bank, as well as the U.N. and bilateral agencies can play a leading role in this respect. This would best come in the form of carefully designed and carried out demonstration projects at the community level such as the World Bank and UNDP are currently planning. These should be closely monitored to provide feeedback information for adaptation and improvement before the approaches are implemented in full-scale projects. Once concrete examples are established and recognised, the task of convincing local authorities of the benefits of reuse should be much easier. Thus, in the future waste management may well become looked upon as a profit-making venture instead of a subsidized burden on the community (96).

6.4 Grey Water Management

Dry excreta disposal systems like pit latrines, composting privies, vacuum truck and vault, or wet systems such as aqua-privies do not dispose of household wastewater, which is usually referred to as sullage or grey water. Grey water is simply disposed of around the house and allowed to soak into the ground in the rural areas. In typical urban areas, grey water is disposed of in street drains or storm sewers. It is obvious that a tradeoff must be made between the beneficial effects of improved excreta disposal for large numbers of people, and the adverse effects of using storm drains, surface or underground, to transport kitchen and washing water (16).

Although the successful application of alternative toilet systems and segregated treatment strategies (separation of grey water from toilet wastes) requires the handling of all waste fractions, the effective management of the grey water fraction has often been disregarded. According to Siegrist (32), characterization studies in the United States have demonstrated that the grey water fraction is not innocuous and must be properly managed. However, the management of the grey water may be simplified over that of total household wastewater due to a reduced flow volume; a reduced mass of pollutants to be removed, particularly suspended solids and nitrogen; and a reduced potential for pathogenic contamination. Laak (111) has reported that the COD/5-day BOD ratio of grey water is considerably less than this ratio in sewage and in black water. This may mean that the grey water and not the individual constituents is more biodegradable. According to him, another advantage of separateing grey water is that the toilet paper and faeces, both soil clogging materials, are eliminated. The total wastewater flow is decreased by about 40%. The probable potential health hazard from excreted pathogenic organisms is decreased; however, laundering of soiled diapers is a direct source of fecal matter. One of the disadvantages of grey water is that it has more soluble 5-day BOD, approximately about 60%, whereas sewage has about 50 to 55% soluble 5-day BOD. The grease concentration and temperature of the grey water is high. Even though there is a flow reduction in grey water systems, a corresponding decrease in flow surges will not occur (111).

Although diverse strategies have been proposed especially in developed countries for grey water management, rigorous research/development and field evaluations to properly assess the feasibility of these systems have not yet been conducted.

The most commonly employed method of grey water treatment and disposal has involved a conventional septic tank-soil absorption field. However, in light of the reduced flow and pollutant load of the grey water, more innovative management schemes may be feasible. A diverse array of management strategies, including innovative techniques, devices and systems are under various stages of development and/or application. Siegrist (32) has summarized several grey water management alternatives which have been conceived, promoted and/or applied by various individuals and organizations as presented in Table 31.

Table 31. Example Grey Water Management Alternatives (32).

I. Conventional Septic Tank - Soil Absorption Systems
II. User-Contrived Low Technology Systems
III. Modified Conventional Septic Tank - Soil Absorption Systems
    A. Modified Pretreatment
        1. Reduced Septic Tank Sizing
        2. Alternatives
            a. Coarse Stone Filter
            b. Septic Tank-Anaerobic Upflow Filter
    B. Modified Soil Disposal
        1. Reduced Soil Absorption Area Sizing
        2. Shallow Subsurface Irrigation
IV. Surface Disposal/Reuse Systems
    A. User-Contrived Low Technology Systems
    B. Sedimentation - Irrigation
    C. Septic Tank - Sand Filter Systems

The list presented is for illustrative purposes only. It is by no means all-inclusive and the inclusion of a particular alternative or the lack thereof should not be construed as a positive or negative recommendation by the author.

To enhance the limited data base, intensive field evaluations are required. Preliminary studies conducted with septic tank-sand filtration system at Wisconsin, U.S.A. (32) have indicated the feasibility of this system. Two major field scale studies have also been planned (32).

Laak (111) has proposed design details for a grey water treatment system which consists of the following: (i) A grey water pretreatment tank to remove grease and some soluble 5-day BOD (Fig. 20), (ii) A fixed media upflow filter (Fig. 21) to reduce the soluble 5-day BOD loadings or sand filters and on leaching fields, and (iii) Soil treatment system or leaching field system.

The data on grey water is slim and particular care should be taken when applying the results of research from an industrialized country to conditions in a developing one. For example, in Sweden and in the United States, it has been reported that the share of total phosphorus in grey water is high, mainly due to automatic dishwashers and clothes washers, whereas there is no comparable study of grey water characteristics in a developing country, although it has been reported that the phosphorus levels in Indian sewage are upto 10 times lower than those reported in Swedish grey water. Similarly, the grey water production in Western countries varies from 60 litres to 120 litres, per person per day, whereas in a developing country it is lower, probably 15-40 litre per person per day (16).

Hence, in proposing suitable grey water management strategies for developing countries, site-specific field assessments must be made and appropriate sytems may be recommended.

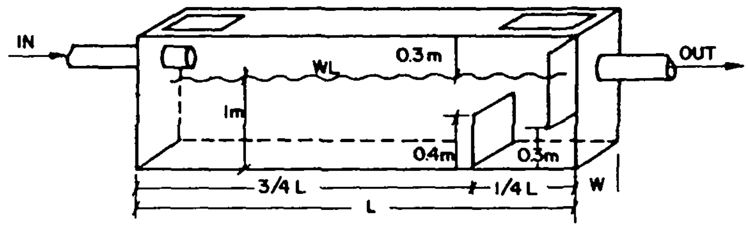

Fig.20 - Greywater Pretreatment Tank. (III)

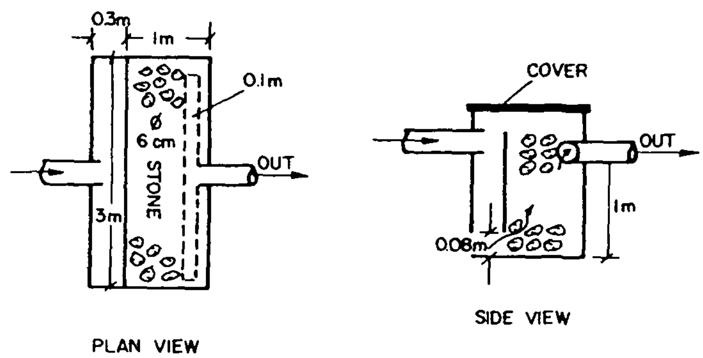

Fig. 21 - Fixed Media Anaerobic Upflow Filter (For 6 Persons) (III)

7. PROMISING ALTERNATIVES FOR ANIMAL WASTE MANAGEMENT IN DEVELOPING COUNTRIES

As mentioned already, animal waste disposal has received very little attention in the developing countries. There are very few intensive livestock systems with low stocking rates prevailing in most of the areas. In most of these regions the waste is viewed as a resource out of place and is used as manure on farmlands for crop production, or is dried and used as fuel for cooking. This is especially so in the case of cowdung.

Runoff could be a problem in both confined or unconfined livestock production. Runoff characteristics are significantly affected by the livestock production conditions. For example, warm and moist conditions enhance biological degradation. Seasonal and geoclimatic conditions influence gaseous volatilization of waste nitrogen and carbon compounds. In climates where manure dries out rapidly, the conservation constituents remain essentially constant (9). According to Loehr (97), pollution from an uncovered livestock area is related to the amount of precipitation that becomes runoff and reaches surface streams. Runoff amount is directly affected by the original condition of the manure on the production facility as well as the slope of the facility.

In the developed countries, extensive research is being conducted to device treatment and utilization methods in addition of engineering controls for animal waste management (99,100). Some of the strategies outlined in the United States for feedlots (9) have been set out in Fig. 2 and Table 27. Loehr (98) is of the opinion that even though historically animal wastes have been recycled through the soil environment with a minimum of direct release to the water environment, the gradual change to intensive livestock production facilities will necessitate improved animal waste cóllection, transportation, treatment, disposal, and utilization systems. He has outlined some treatment alternatives for enclosed, confined animal production operations as can be seen in Fig. 22.

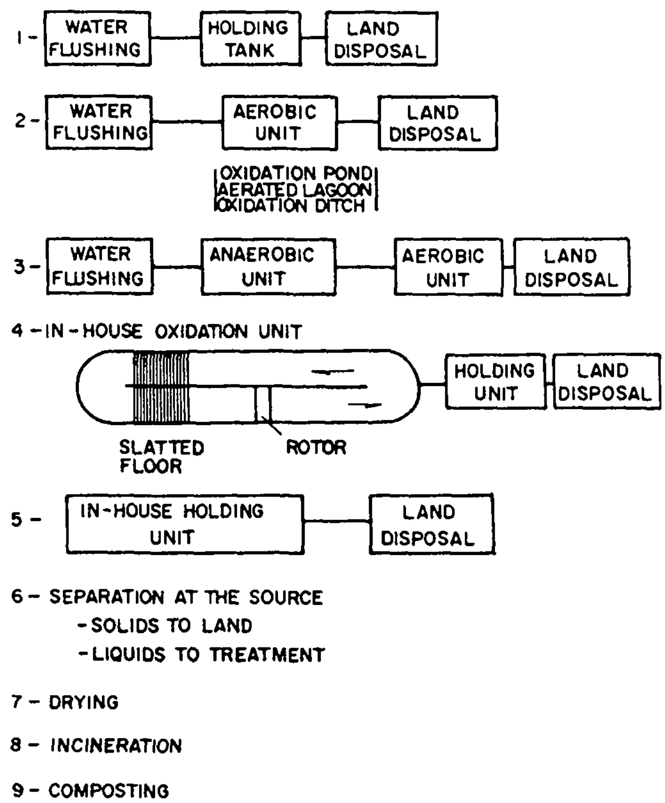

Fig. 22 – Systems for Treating Wastes from Enclosed Confined Animal Production Operations (98)

According to Taiganides, et al. (101), animal waste utilization and recycling is a highly developed art in Asia. It includes the use of waste in pisciculture, in aquaculture, in biogas energy recovery, crop production, refeeding, etc. However, the practice has been confined to small farming operations. This art of waste utilization needs to be developed into a science if it is to survive modern methods of animal production, i.e. intensive animal production. Since there is lack of capital for investment in developing countries, it is sensible to combine waste treatment with resource recovery processes, as shown in Figs. 2 and 23 and Table 27.

In intensive animal production systems using feedlots, the management of animal wastes includes the waste handling systems inside the feedlots and other housing facilities as well as any pretreatment prior to terminal disposition (9). The two sets of systems may be classified as "in-process" and "end-of-process" technologies.

7.1 In-Process Waste Handling

In-process technologies are useful for assessing the operational and physical characteristics of the feedlots and their impact on waste management. The following aspects should be considered for feedlot site-selection (9):

(i) isolation from receiving waters and natural drainage and sufficient distance above the flood plain to provide adequate space to install waste control facilities;

(ii) isolation from population or urban centers, preferably downwind (5 miles);

(iii) location in a moisture deficit, temperate, and low precipitation region;

(iv) mild 2-6% feedlot slope, preferably on South exposure to enhance evaporation benefits;

(v) available land disposal area sufficient to assimilate all liquid and solid wastes from the feedlot;

(vi) suitable soil having good permeability, high water-holding capacity, high nutrient assimilation capacity, and a deep mantle; and

(vii) a water table well below the depth of any settling basin or retention pond.

Low density production units represent a zero level of waste handling and pretreatment, along with the recovery of full fertilizer value, whereas waste from high-density confined operations approaches the excreted load, necessitating considerable management. Two primary factors control the amounts and concentrations of waste from a livestock production facility (9): (i) total liveweight of animals present and (ii) amount of wastewater used. However, before any control measures are proposed, it is necessary to individually review each situation.

Significant differences in the type and quantity of waste to be handled can also be brought about by the type of production facility (9). In cases where rainfall exceeds evaporation and areas of cooler weather, enclosed facilities are generally better suited, since the hydraulic load can be controlled and secondary pollution such as flies and odors can be minimized. The initial cost of such facilities is, however, very high compared to open lots. The nature and quantities of wastes and nuisance odors is also significantly affected by good housekeeping practices, including maintenance and cleaning of equipment, pest control, and removal of animal wastes.

Animal waste handling systems may be classified as (9): (i) wet handling systems, and (ii) dry handling systems. Wet systems use water to reduce labor and facilitate transport, but have the potential disadvantage of increasing the amount of polluted water. Dry systems, on the other hand, decrease the water

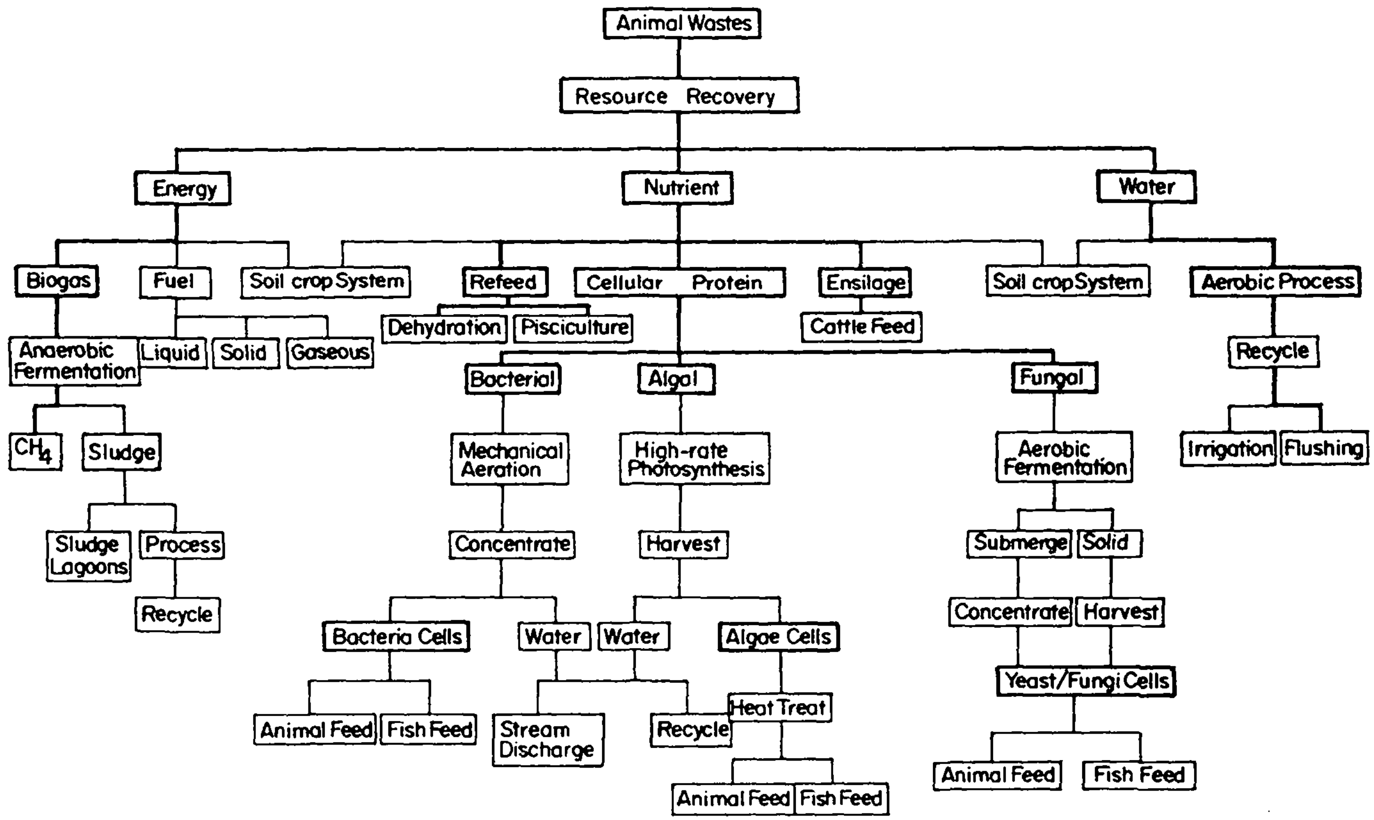

Fig.23 – Promising Pathways of Animal Waste Utilization (101)

volume to be handled.

Liquid systems may use water to flush the waste so that the waste is carried from the housing area to a collection tank prior to direct land irrigation or further treatment and land application. Housing units may, in some cases, use slotted floors for waste passage to underfloor storage pits. The storage pit slurry may then be either pumped into a tank vehicle for surface or subsurface field spreading or discharged by gravity to a sump of lagoon. In houses with manure storage pits, an underfloor ventilation system can provide a more controlled environment because gases and odors are exhausted before reaching the animal and human atmosphere above the slots. In moderate climates, where the emphasis is on steady-state pretreatment and land application, seasonal manure storage is not a major problem (9).

In-house treatment systems, such as the oxidation ditch, air injectors, or mixers, have been incorporated into the underfloor manure storage pit design to enhance pretreatment and control odor prior to terminal land application. Although management ease and biological degradation of waste constituents limiting land application is achieved by in-house or external liquid pretreatment systems, it is the experience in some developed countries that energy requirements and some malfunctions resulting in animal death have restricted widespread endorsement of these units and motivated many producers to separate mechanical treatment systems from housing facilities (9).

7.2 End of Process Treatment, Utilization and Engineering Controls

7.2.1 Land Treatment (or) Soil Utilization of Animal Wastes

The use of animal waste as a fertilizer and soil conditioner has been practised for centuries in Asia. In these regions animal waste has been considered as a resource out of place and has been recycled into cropland as a source of nutrients. Land application can be easily adopted because equipment is readily available and this approach is generally understood by the agricultural community. There are several reports of animal waste use on land in Asian countries like China (19), Bangladesh (102), Burma (11), India (12), Indonesia (103), Malaysia (14), Sri Lanka (104), Thailand (105), etc.

However, the application of animal wastes to croplands for the purpose of waste treatment and disposal is a relatively new idea. Extensive research is being conducted in several developed countries (99,100,106) to assess the viability of land treatment of livestock waste as a waste treatment alternative.

The use of animal wastes and wastewaters for crop fertilization and soil amendment has been recommended as the most effective way of utilizing organic waste materials by Taiganides (33). According to him, utilization of the wastes in soil-crop systems, however, must be based on the following principles:

(i) Environmental health protection by preventing soil and water contamination and pollution.

(ii) Application at rates suited to the soil type and not in excess of what can be effectively utilized by the crops.

(iii) Maintenance of animal numbers in balance with the area of cropland available for effective utilization of the waste.

(iv) Provision of sufficient storage so as to apply wastes during periods of the year when utilization is most effective and to avoid losses of nutrients in storage and/or through runoff, leaching, volatilization, etc.

Fig.23 - Promising Pathways of Animal Waste Utilization (101)

(v) Application methods which minimize odour and pollution, conserve nutrients and maximize the availability of the waste nutrients.

Application rates of animal waste on land may be determined by several criteria such as (33):

(i) The amount of nutrients, mainly N, which can be effectively utilized by the crops grown.

(ii) The amount of salts, mainly potassium salts, which could be tolerated without causing excessive salt build-up; this criterion is critically important in semi-arid to arid regions and in irrigated soils of poor drainage.

(iii) The amount which would be at levels which may not lower seed germination and seedling growth rate; to avoid this problem, it is recommended that waste be applied well ahead of planting time, and that the waste be thoroughly mixed with the soil avoiding pockets of high concentration of manure.

(iv) The amount that can be physically deposited or incorporated into land. Dry wastes of less than 50 percent MC (moisture content) can be applied at rates as high as 2,000 tons/ha. With slurry or liquid manure (around 10 percent TS (total solids) or 90 percent MC) application rates may be limited to 200 tons/ha for each application. Applying and incorporating liquid manure and reapplication after several months could facilitate a 300 to 400 tons/ha-year application rate. Details of application limits and application methods have been described elsewhere (33).

Where land is used for terminal application, pretreatment may be employed to reduce limiting constituents so process and hydraulic loading rates become more equivalent, thus making it minimum attention during terminal application (9). Each waste must be evaluated to assess concentrations of potentially harmful or process limiting constituents. Ultimately, the most economical approach is to balance the process load with the hydraulic input by selective pretreatment to reduce limiting constituents so that the application rate for both the hydraulic and process loads become more equivalent attendant to minimum acreage requirements.

The plant-soil system is the most cost-effective receiver for animal waste (9). Pretreatment techniques pursuant to land application have been developed for animal wastes that are compatible with producer capabilities. Treatment of animal waste for stream discharge is not recommended because land-based systems can more effectively and economically remove constituents, such as nitrogen and phosphorus, than contemporary tertiary treatment. The major role of pretreatment processes is for waste handling, storage and constituent conservation, or degradation, depending upon land availability. However, in tropical developing countries, waste utilization technologies as shown in Figs. 2, 16, 19 or 23 may be employed before terminal land application. In countries where there is no land available for the disposal of animal wastes like Singapore, combined waste treatment-resource recovery processes like the systems outlined in Fig. 23 may be successfully adopted (101).

7.2.2 Runoff Control

Feedlot runoff is unpredictable and wastewater quality is variable, although strong in organic constituents. Feedlot site selection must take into consideration the runoff control facilities (9). Runoff control may include diversions, collections systems, retention structures, conveyance systems, and terminal application equipment. It is very unlikely that conventional waste treatment practices will be employed for feedlot runoff and animal wastes because of the high construction and operation costs of these processes when compared with collection, pretreatment storage and application techniques commonly employed as conservation techniques or agricultural production practices. Hence, provisions for applying liquids and solids to land are very important.

Dike or ditch systems may be constructed around feedlots for diversion of outside runoff. Collection of rainfall runoff in holding ponds pursuant to land application by contemporary irrigation technique for slurries or liquids can eliminate direct discharge. Detailed information on feedlot design and runoff control may be obtained elsewhere (107).

7.2.3 Treatment of Animal Wastes

Animal waste treatment is expensive, and the elimination of pollutant discharges from feedlots could best be achieved by recycling and disposing feedlot wastes on cropland. However, in cases where there are several limitations to land application, such as land availability in large enough tracts, accessability at times of waste disposal, soil pollution potential, nuisance and pollutant runoff potential from landspreading, treatment of animal feedlot wastes and wastewaters might become inevitable, even if the wastes are to be applied on land after treatment (33). Some animal waste treatment methods are described below:

(a) Lagoons: The current trend towards confined livestock feeding all over the world requires the development of integrated, mechanized and automated waste handling systems. Where sufficient land is available, lagoons are often used in modern livestock feedlots since they fit into an automated liquid waste handling system (108). The design criteria of such lagoons are based upon size or loading rate recommendations to achieve maximum nitrogen conservation or degradation and odor control. Such criteria allow that lagoon size should be based upon management goals and odor control requirements which will vary for each general situation (9).

The design and operation of livestock waste lagoons must include the disposal of effluents and solids. According to White (108), the main disposal method is to spread lagoon contents on cropland for utilization of the fertilizer elements and for irrigation water. Additionally, extensive treatment is necessary where the contents are discharged into a stream. In some cases, the effluent is recycled and used as flushing water to transport the manure from the feedlot to the lagoon. In cases where lagoon evaporation exceeds rainfall, water will need to be added to prevent accumulation of salts to levels toxic to the microflora of the lagoon (108). Lagoons used for animal waste management may be (i) aerobic-algal lagoons, (ii) aerated lagoons, (iii) facultative lagoons, and (iv) anaerobic lagoons. These have been detailed elsewhere (108).

The evaluation of livestock waste lagoon performance must be done on the basis of public health, aesthetics, ecology, and economics in addition to pollutant removal efficiency (108).

In general, both aerobic and anerobic lagoons are safe from the standpoint of public health, provided they are properly managed. The principal aesthetic problem is odours. Aerobic lagoons meet this condition completely. Anaerobic lagoons can cause an odour nuisance. However, with proper design, operation and management, the odour level can be reduced to an acceptable level and then only for a brief period in the spring warm-up. The construction and operation of lagoons are usually the most cost effective methods of livestock treatment, with the exception of direct land treatment. With the high cost of energy, the facultative and anaerobic lagoons are being looked at more favourably than aerated lagoons except when odour is a potential problem (108).

The expected reductions of wastewater parameters for aerated and anaerobic single-stage lagoons as reported in the American literature are shown in Table 32. Multiple cell lagoons may also be used for livestock waste treatment.

Table 32. Expected Performance of Single-Stage Feedlof Waste Lagoons (108).

Parameter	Aerated lagoon				Anaerobic lagoon		
	Influent range (ppm)	Effluent range (ppm)	Reduction range		Influent range (ppm)	Effluent range (ppm)	Reduction range (%)
			Unclarified (%)	Clarified (%)			
TS	1000-10000	300-3500	40-75	60-85	2000-15000	1000-3000	50-75
TVS	700-7500	200-2400	40-75	60-85	1200-10000	300-4000	60-90
TSS	300-6000	150-3000	50-80	70-95	500-8000	100-3000	60-90
BOD_5	400-3000	150-1200	60-80	70-95	600-3500	200-1500	60-90
COD	1200-8000	400-3000	60-75	70-95	1500-9000	450-3000	60-90
N_{total}	400-5000	300-2400	40-70	50-80	500-6500	200-1200	60-85
P_{total}	80-1500	60-1200	20-30	70-85	100-1800	20-200	70-95

(b) Evaporation: In areas where annual evaporation rates exceed annual precipitation by a reasonable margin, and where large areas of land are available, evaporation is an effective alternative to wastewater disposal by land irrigation. Evaporation rates are a function of exposed surface area, relative humidity, ambient temperature, air movement, solar energy, and wastewater characteristics (9).

Generally, in geographic regions where the evaporation rates are high, wastewater usually represents a valuable resource for crop irrigation, and is so used. Hence, this method will be more applicable to arid regions in the developing countries.

(c) Oxidation Ditches: The feasibility of using oxidation ditches for aerobic treatment of livestock waste has been studied, particularly in developed countries (109). The oxidation ditch, as mentioned before, is a modified form of the activated sludge process where an aeration rotor continuously circulates wastewater around an open circular channel. In this process, solids removal is generally required in order to maintain an optimum level of mixed liquor solids. The processed slurry may be used as a partial protein and mineral supplement in the feed ration of ruminants (9).

According to the Task Committee on Agricultural Waste Management in the United States (9), raw manure additions to the oxidation ditch can be on a continuous or batch basis. Water is added to maintain ditch depth or solids concentration at a constant level. The oxidation ditch offers near odorless operation, reduced labor costs, and solids reduction of 34%-90%. High denitrification levels can be achieved if oxygen input is controlled. However, the system has high power and maintenance requirements, and offensive gases may be released during shutdown periods. While it is sometimes used in enclosed, slotted floor operations, external treatment processes are preferred because of potential hazards to animals associated with offensive gases formed during shutdown periods and equipment malfunction.

(d) Composting: In composting, mixing and aeration are provided to maintain aerobic conditions and permit adequate heat development. The decomposition is done by aerobic organisms, primarily bacteria, actinomycetes, fungi and protozoa (33). Like human wastes, composting of animal wastes before application on land is a common practice in many Asian countries like China (19), Indonesia (103), Nepal (110), India, Sri Lanka, Burma, Thailand (13), etc. Composting is an attractive treatment method for animal wastes since the end product may be used as a soil conditioner and organic fertilizer. The rate and type of decomposition during composting depends on oxygen availability, particle size, moisture content, temperature, pH, initial carbon to nitrogen ratio, and size and shape of the mass. Animal waste can be composted by using a turned compost windrow, aerated compost-windrow or an aerated rotating drum. The process time varies from as low as 36 hours in continuously rotating drums to 30 days in windrowing. A post composting curing time is generally necessary (9).

For agricultural or farm uses, compost does not need to age. However, if the compost is to be marketed for greenhouses or for home garden use, aging for several months is advisable (33).

The primary constraint for a successful operation of composting is an adequate local market for the end product (9). Before any composting equipment is installed, it is necessary to identify a market area and develop a network for marketing the end-product. A good end product with uniform quality is essential to maintain the market and hence the composting system should be engineered to meet the intended use of the end product (112).

(e) Dehydration: Drying and selling dehydrated waste for use directly as fuel, fertilizer or animal ingredient is a viable disposal alternative. In certain developing countries like India, raw cowdung is dried under the sun and used directly as a fuel for cooking or heating purposes. Nowadays, commercial driers are available in developed countries in which the manure is pulverized in a hammer mill, and injected into the drier (9). The product is an odorless, fine, granular material when dried to less then 10% moisture. The process can be successfully used if a market for the product exists at an adequate price.

(f) Other processes: A number of other processes for treatment or disposal of animal wastes, or both, are being developed as shown in Table 27, some of which may be useful in developing countries. An interesting concept, which may have encouraging prospects in developing countries, is the Barriered Landscape Water Renovation System (BLWRS) (9). The process represents a modified soil plot for wastewater filtering and stabilization. In this system, organic materials are oxidized and nitrogenous materials converted to nitrates in the upper aerobic zone, while in the lower anaerobic saturated zone, nitrates are converted to nitrogen gas by biological denitrification. Carbon or energy is required for biological denitrification. This can be injected into this zone in some convenient form, such as molasses.

7.2.4 Utilization of Animal Waste for Energy and Nutrient Recovery

Although technologies for animal waste utilization are being developed, it must be borne in mind that technologies offering solutions for pollution-related problems must get first priority. However, integrated systems may be used to achieve both these objectives in developing countries.

(a) Biogas Digestion: Biogas recovery from animal wastes has been reported in many developing countries like Korea (113), Thailand (13,114), Burma (11,13), Bangladesh (102), Fiji (35), India (12,13), Nepal (110), Sri Lanka (13,104), Singapore (101), China (45) and Taiwan (45). This is a technology that has been transferred from the developing countries to the developed nations, which are exploring the feasibility of such systems to their particular conditions (9,115). Current problems with the bioconversion of animal wastes are the handling and subsequent utilization of this gas. Residues from any such reactor would have to be returned to the land (9). In places like Singapore, where there is no land available, efforts are underway to design systems to recover energy as methane gas, nutrients in the form of cellular protein and treated water for reuse as shown in Fig. 23 (101).

Table 33. Approximate Quantities and Heat Value of Biogas from Animal Wastes (33).

Waste	TLW Kg.	Gas Production		Methane %	Heat Value Kcal/day
		1/kg TVS	1/day/animal		
Human	50	450	37	70	225
Laying Hen	2	450	11	70	62
Fattening pig	50	630	180	65	900
Dairy cow	500	330	1200	70	6850

According to Taiganides (33), anaerobic digestion of animal wastes is a highly complex process, but it results in the production of methane gas, renders the manure inoffensive and enhances its fertilizer value. The volume of biogas produced from animal wastes and its characteristics are shown in Table 33. Loading rates of 1 to 3.5 kg total volatile (organic) solids (TVS)/cu.m.-day have successfully been used to digest poultry, pig and cattle wastes. Dentention time is in the range of 10 to 60 days. The lower range is used for high rate digestion, whereby rigorous mixing and good temperature control are maintained. Optimal environmental conditions for digestion are temperature in the range of 35 Celsius degrees, pH in the neutral zone, volatile acids around 300-1,000 mg/l, totally enclosed tank, and gas mixing. Design alternatives and combinations of digestion systems available for animal wastes include complete mix, batch type, plug flow digesters, digesters in series, digesters in parallel, etc.

Properly managed biogas digesters show promise for animal waste treatment and resource recovery in developing countries.

(b) Ensilage or Wastelage for Refeeding: Ensiling poultry litter, cattle manure and other semi-dry animal wastes with grasses or other plant materials at ratios as high as 1:1 has resulted in no adverse effects when the silage is fed to ruminant animals at proportions as high as 40 percent of the total feed intake (33). This ensiling process greatly reduces the salmonella, coliform counts, and nematodes. The feed to be mixed with the manure is determined to a large extent by the moisture content of the fresh manure as the resultant moisture content should not be more than 50%. It must be borne in mind that only 25-40% of manure produced by cattle can be fed back to the same cattle. Refeeding, therefore, is not a waste reduction process but can only be justified as a viable process when it leads to higher energy, protein and mineral recovery from the wastes than is possible through alternate processes such as land disposal.

In Singapore (101), poultry litter is collected from broiler houses and also layer-replacement units which use sawdust or woodshavings as bedding materials. Freshly collected litter is mixed with cane molasses and ensiled for 21 days in hermetically sealed concrete silos. The ensiled product is used together with a concentrate supplement containing cassava chips, ground leaf-meal, molasses, minerals and micronutrients. The growth performance of the 115 cattle fattened since 1973 is summarised in Table 34.

Table 34. Reefeeding Ensiled Poultry Litter (Wastelage) to Cattle (101).

Wastelage in diet[a] (% dry mater basis)	Wastelage quality		Cattle[b] head	Trial time (days)	Av. gain (kg day^{-1})	Av. feed conversion ratio
	pH	Lactic acid (%)				
25	5·7	2·3	20	174	0·8	7·6:1
25	5·1	2·9	10	51	0·6	8·2:1
25	5·1	2·9	8	153	0·6	7·8:1
33	5·0	2·7	30	166	0·7	7·9:1
33	5·1	2·3	20	330	0·6	—
33	5·1	2·3	8	162	0·6	—
33	5·1	2·3	8	141	0·6	8·5:1
33	5·4	2·7	11	71	0·8	—
40	5·1	2·9	9	69	0·6	10·6:1

[a]The remainder of the diet comprised cassava chips, ground beef-meal, rice-bran, molasses, minerals and vitamin A and D supplements. No. fodder or grazing were available.

[b]Cattle used in these feeding trials are the local cross-breed type with weights ranging from 140 to 400 kg.

(c) Dehydration (or) Direct Refeeding: There are reports (33) that poultry manure, being relatively low in moisture content, is more amenable to dehydration and refeeding than other animal wastes. Well dehydrated poultry waste (DPW) should be free of pathogens, should be stable when stored in dry places, and concentrated enough (up to 30 percent crude protein) to compete with other protein ingredients.

The best animals for the utilization of poultry waste energy and nitrogen content are cattle and poultry. Monogastric animals make relatively poor use of poultry manure compared with ruminant animals.

There are also reports of refeeding dehydrated pig faeces to pigs from Singapore (101). Pig faeces were collected, dried and fed to fattening pigs at 10,15 and 20% of the diet. Although digestibilities of diets with higher dried pig faeces (DPF) were lower, pigs on these diets showed no difference in live weight gains and feed conversion ratios.

(d) Aquaculture or Pisciculture: This is also a method of refeeding or recycling animal wastes. The use of animal manure in fish farming has been well reviewed by Wohlfarth and Schroeder (116) and Edwards (79). The need for and economic implications of using manures for fish farming in the Far East as compared to the West is well brought out by Fig. 24.

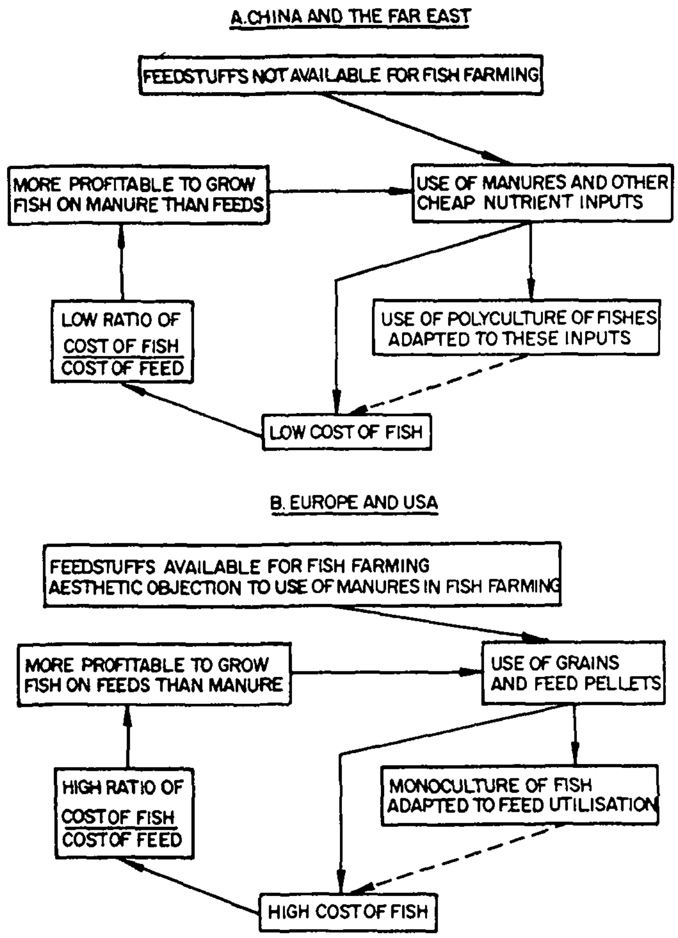

Fig. 24– Factors Influencing the Choices of Inputs in Fish Farming in China and the West (116)

The potential for recycling animal wastes into fish has been demonstrated by the Chinese who use animal manure as the main fertilizer in fish culture. All farms undertake animal husbandry to supply fertilizer for fish farming (79). Wohlfarth and Schroeder (116) are of the opinion that when manure is a regular input in aquaculture, problems of manure disposal are largely avoided and integrating aquaculture with animal husbandry appears to result in the most rational manure utilization.

According to Edwards (79), in integrated animal husbandry-fish farming systems, it is necessary to enclose the livestock so that the wastes from feeding and the excreta can be collected. The change to closely confining animals in feedlots rather than allowing them to roam freely on pasture is a recent innovation, but has rapidly gained popularity in the tropics and this will have the additional advantage that wastes can be readily collected and recycled. In integrated systems, the livestock quarters should be either situated adjacent to the fish pond to minimize transportation costs or built above the pond. The latter practice has the additional advantage of better utilizing space where land is in short supply. In Singapore, where land is in short supply, fish ponds are aerated to reduce the fish pond requirements per pig (101).

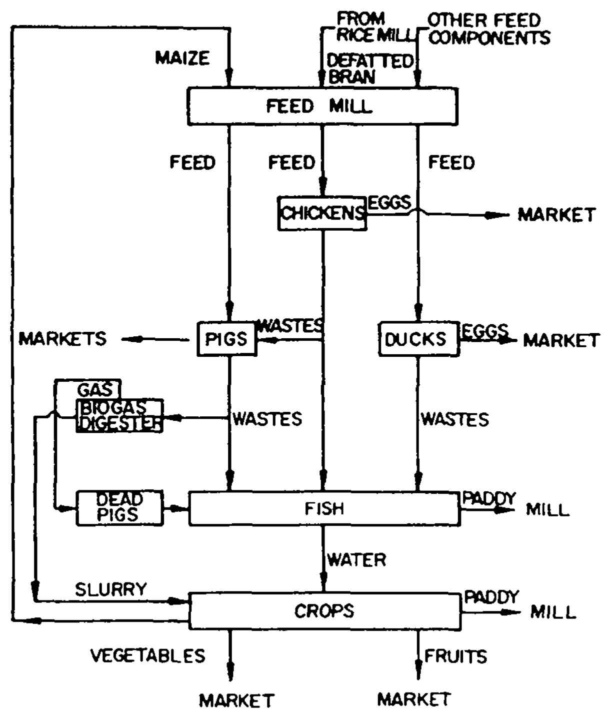

Fig.25 - Schematic of Kirikan Farm, Thailand, in which Livestock, Crops and Fish are Integrated (79)

There are reports of integrated fish farming from many Asian countries like China, Taiwan, India, indonesia, Malaysia, Singapore, the Philippines, and Thailand (79, 101, 117, 118). In Thailand, a systems study was made of the largest integrated operation which had a sophisticated system of animal waste recycling (Fig. 25) with several thousand chicken, ducks, and pigs and over 1 million fish (79). The chicken coops were built over the pigs in the nearby 1-km long feedlot, so that the bird droppings supplemented the pig feed. The pig manure was collected and used to raise catfish which received no other feed input. Dead pigs were also recycled since they were cooked using biogas generated from pig manure and fed to catfish.

(e) Algae Single Cell Protein (SCP) Production: The use of algal high rate ponds for animal waste treatment and utilization is fast gaining popularity and seems to have tremendous possibilities in developing countries, wherever land is available in plenty. Animal wastes constitute an excellent media for algae when diluted with water and they provide carbon source (through bacterial aerobic degradation which produce carbon dioxide), nitrogen, phosphorus and trace elements to sustain rich algae production. High rate algae ponds can combine efficient pollution abatement with a high potential for resource recovery in the form of algal protein. The work in Israel constitutes one of the most comprehensive studies on high-rate algal pond. This has been described by Shelef, et al. (29). The nutritional evaluation of pig wastewater grown algae has recently been described by Ngian and Thiruchelvam (119). In studies conducted on the production of algae from pig wastewater in high rate ponds in Singapore, Lee and Dodd (34) found gross biomass productivity ranged from a maximum of 25 g/sq.m.-d to a minimum of 4.4 g/sq.m.-d in spite of adverse weather and severe zooplankton predation. Removal of BOD in the absence of predators at a detention time of 16 days was greater than 90%. The demonstration-scale project is shown in Fig. 26 (101). The algae will be used for feeding pigs and poultry. Cattle wastes are also amenable for microbiological conversion (33) to SCP.

(f) Bacterial Single Cell Protein (SCP) Production: Pig and cattle wastes are also amenable to microbiological conversion to bacterial SCP by aeration (33). In Singapore, bacterial SCP has been produced from pig wastes by mechanical aeration of the wastewater falling through slatted floors into an oxidation ditch underneath the pig pens (101). A mixed liquor (ML) of excellent quality developed as shown in Table 35. Solids settled out readily, producing a clear supernatent. The mixed liquor suspended solids is fed to pigs, which are mainly bacteria. The composition of the solids, on a dry matter basis, was 48% crude protein, 8.6% crude fibre, 31% ash, 3.6% phosphorus and 2.8% calcium.

(g) Fungal SCP Production: In Singapore, studies are also underway to convert animal wastes into cellular protein by growing yeast and fungi (101). Since animal wastes do not have a balanced carbon to nitrogen to phosphorus (C:N:P) ratio to support optimum aerobic fermentation by yeast and/or fungi, additional sources of carbon like tapioca starch residues, pineapple waste, molasses, etc., may be added. Pig wastewaters are being used in these studies and the fermentations are being carried out in both the solid state and as submerged cultures (Fig. 22).

(h) Others: In addition to the methods outlined above, other techniques for animal waste utilization are being developed. Additional biological conversion schemes for nutrient recycling have been conducted, such as propagation of water hyacinths in lagoons and of fly larvae containing about 63% protein and 15% fat from inoculated manure (9). Earthworms may also be used as a biological machinery to recover nutrients from cattle manure as shown in Fig. 27 (120). Earthworms may be used as a source of protein for both animals and humans and provide a new dimension in animal waste utilization (120). Symbiotic growth of algae increased conservation of waste components because end products of bacterial metabolism are incorporated into algal cell mass (9).

7.2.5 Odor Control

Certain odorous gases emanating from livestock production facilities can be toxic to humans and livestock, but the primary concern is human nuisance. Hence most rules and regulations about livestock odors are based on the concept of nuisance. Odor control should be a major consideration in the location of an animal feedlot. According to the Committee on Agricultural Waste Management in

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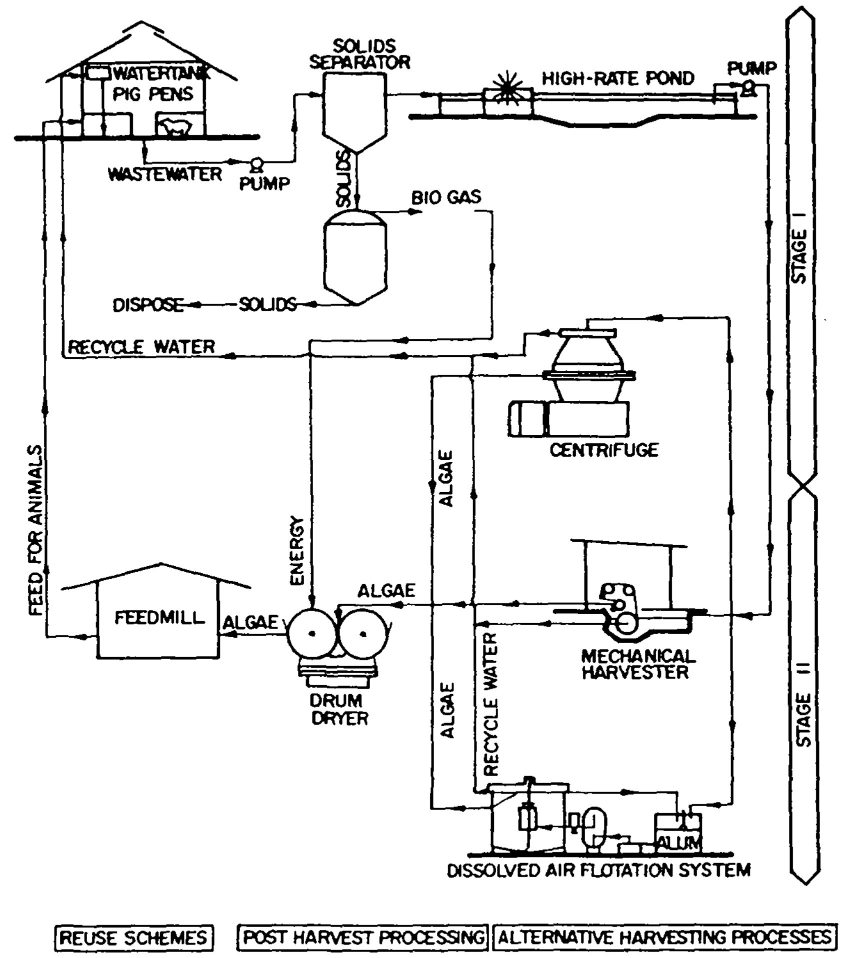


Fig.26 - Schematic of Algae SCP Production System (101)

Table 35. Typical Data from Pig Waste Processing in an Oxidation Ditch (101).

	Parameter	Mixed Liquor	Effluent
Biochemical Oxygen Demand (BOD); (mg $litre^{-1}$)	Mean	790	70
Biochemical Oxygen Demand (BOD); (mg $litre^{-1}$)	Range	230 - 1200	7 - 220
Chemical Oxygen Demand (COD); (mg $litre^{-1}$)	Mean	6450	330
Chemical Oxygen Demand (COD); (mg $litre^{-1}$)	Range	3020 - 9200	200 - 450
Total Suspended Solids (TSS); (mg $litre^{-1}$)	Mean	6560	—
Total Suspended Solids (TSS); (mg $litre^{-1}$)	Range	3200 - 8400	0 - 200

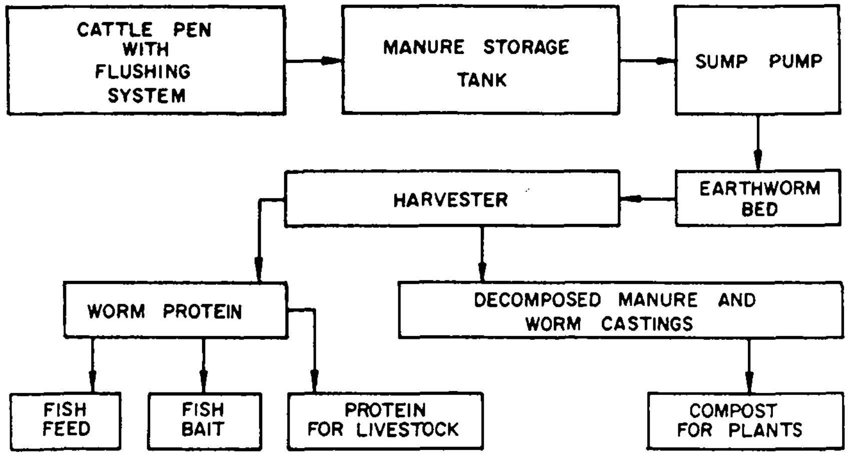


Fig. 27 – Growing Earthworms in Animal Waste (120)

the U.S.A. (9), complete odor elimination around livestock operations is not currently technically or economically feasible. However, the following seven principles may be adopted to minimize odor complaints (9):

(a) Locating a livestock operation such that close proximity to residential areas is avoided. Although no maximum distances have been established beyong which complaints are not valid, it is desirable to stay away from an urban area, 1,600 m (one mile) from housing developments and 800 m (one-half mile) from neighboring residences. Wind direction and topography are of some importance in most areas. However, in some areas there is sufficient fluctuation in wind direction to make this factor of little help.

(b) Feeding areas and animal pens should be kept dry. The primary source of odor from a livestock operation is that of anaerobic manure decomposition. By keeping manure-covered surfaces dry, this decomposition can be minimized. This same procedure not only is helpful as an odor control scheme, but also is beneficial in the control of water pollution due to runoff and is an aid in fly and insect control.

(c) Manure management systems should be designed to prevent dirty, manure-covered animals. The warm body of an animal, when covered with wet manure, makes an area of accelerated bacterial growth and odor production. Once produced, the odorous by-products of manure decomposition are quickly vaporized into the air by animal heat.

(d) Appropriate selection of manure storage and treatment devices can be helpful. The use of aerobic systems in general will reduce odor production. Other measures to inhibit anaerobic decomposition such as dry manure storage, chlorine or lime addition, or a closed storage system will reduce odorous gas production.

(e) An orderly scheme of runoff collection and manure handling not only avoids opportunity for water pollution but also promotes better drainage, thus minimizing areas of odor production. In addition, an orderly appearing operation is effective in suggesting a nonoffensive situation.

(f) Dead animal disposal must be according to a definite plan to avoid odors, flies, and severe health risks. Prompt handling, with removal from the site within 24 hr, is required in most areas. Pickup by rendering works is the preferred disposal method where quickly available; otherwise, burial or incineration may be considered.

(g) Odor control chemicals have achieved limited use in livestock operations. Because of the lack of an effective means of evaluating the performance of these materials and their expense, odor control chemical use has been generally limited to short-term applications or used only in particularly offensive areas, such as a manure storage pit immediately before hauling.

8. GENERAL CONSIDERATIONS

8.1 Technology Selection

Once the different treatment and disposal technologies have been compared with each other on a technical basis, the one most appropriate to the needs and resources of the community may be chosen. This selection is usually based on a combination of economic, technical, and social criteria. The situation eventually boils down to the question: which is the cheapest, technically feasible technology that the users can afford and maintain, prefer to cheaper alternatives, and the local authority is institutionally capable of operating? Some critical information items needed for selection and design of sanitation systems were outlined by Kalbermalten, et al. (123) and these are set out in Table 36. They have also presented algorithms (Figs. 28, 29 and 30) that can be used as a guide to the selection of the most appropriate sanitation technology for any given community in developing countries (123, 124, 125). The algorithm is meant only as a guide to the decision making process. Its main virtue is that it prompts engineers and planners to ask the right sort of questions, which perhaps they would not otherwise ask; some answers can only be obtained from the intended beneficiaries. The algorithm should not be used blindly in place of engineering judgement, but rather as a tool to facilitate the critical appraisal of the various sanitation options, especially those for the urban and rural poor. The algorithm is most useful when there are no existing sanitation systems, other than communal facilities, in the community under consideration.

Once a tentative selection of the most appropriate technology has been made, several questions should be asked again as checks. These are (123):

(a) Is the technology socially acceptable? Is it compatible with cultural and religions requirements? Can it be maintained by the user and, if appropriate, by the municipality? Are municipal support services (e.g. educational, inspectional) required? Can they be made available?

(b) Is the technology politically acceptable?

(c) Are the beneficiaries willing (as well as able) to pay the full cost of the proposed facility? If not, are user subsidies (direct grants or 'soft' loans) available? Is foreign exchange required? If so, is it available?

(d) What is the expected upgrading sequence? What time frame is involved?

Table 36. Critical Information Items Needed for Selection and Design of Sanitation Systems (123)

Climate conditions

Temperature ranges; precipitation, including drought or flood periods.

Site conditions

Topography.
Geology, including soil stability.
Hydrogeology, including seasonal water table fluctuations.
Vulnerability to flooding.

Population

Number, present and projected.
Density, including growth patterns.
Housing types, including occupancy rates and tenure patterns.
Income levels.
Locally available skills (managerial and technical).
Locally available materials and components.
Municipal services available, including roads, power.

Environmental Sanitation

Existing water supply service levels including accessibility and reliability, and costs.
Marginal costs of improvements to water supply.
Existing excreta disposal, sullage removal and storm drainage facilities.
Other environmental problems such as garbage or animal wastes.

Socio-cultural factors

People's perceptions of present situation and interest in or susceptibility to change.
Reasons for acceptance/rejection of any previous attempts at upgrading.
Level of hygiene education.
Religious or cultural factors affecting hygiene practices and technology choice.
Location or use of facilities by both sexes and all age groups.
Attitudes towards resource reclamation
Attitudes towards communal or shared facilities.

Institutional framework

Allocation of responsibility, and effectiveness of state, local or municipal institutions, in providing the following services:

- Water
- Sewerage, Sanitation, Street cleansing, Drainage
- Health
- Education
- Housing and urban upgrading

Note: *The priority between various items will vary with the sanitation options being considered; the list above indicates typical areas which should be investigated by planners and designers.*

Figure 28. First-stage Algorithm for Selection of Sanitation Technology (123).

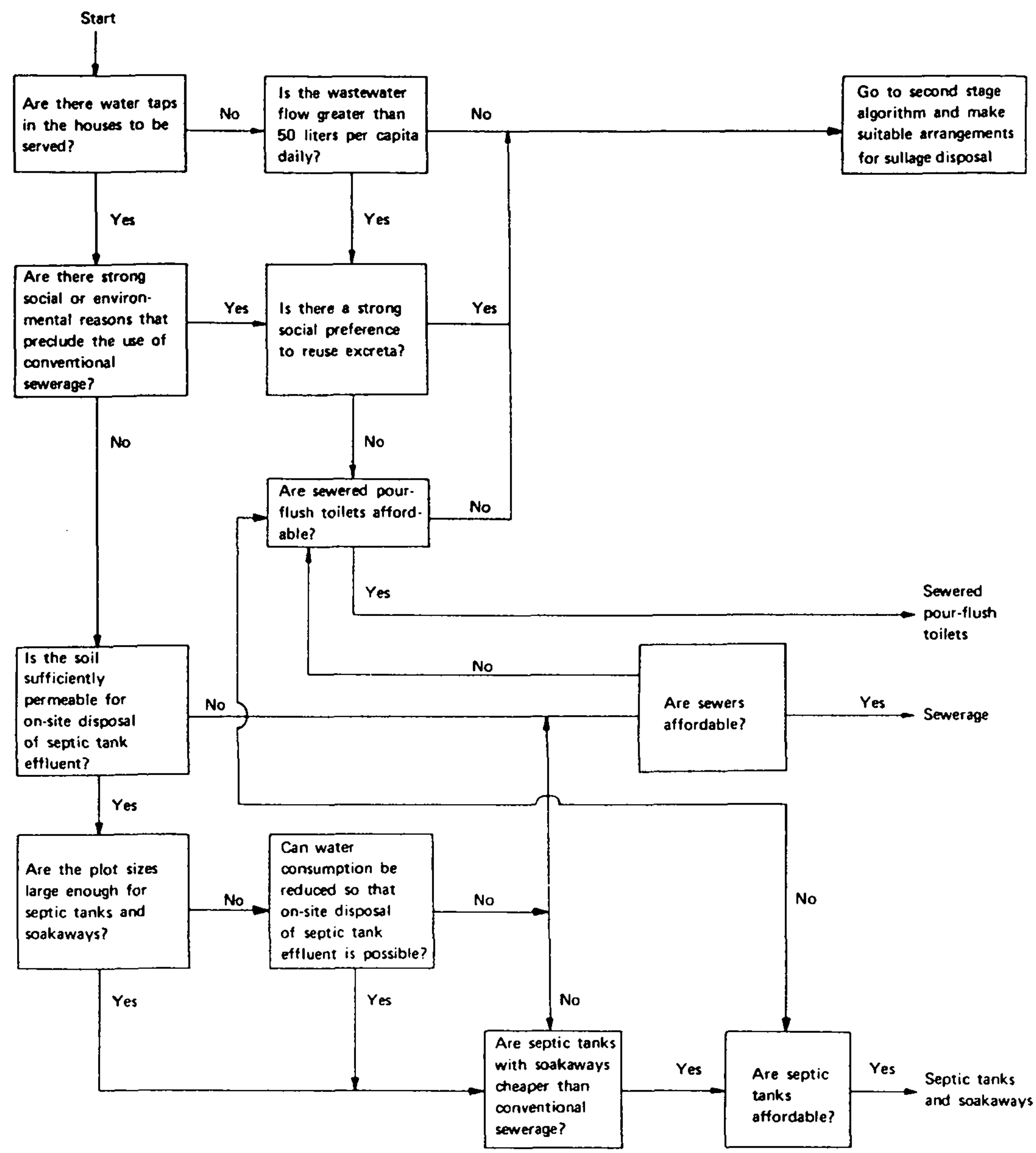
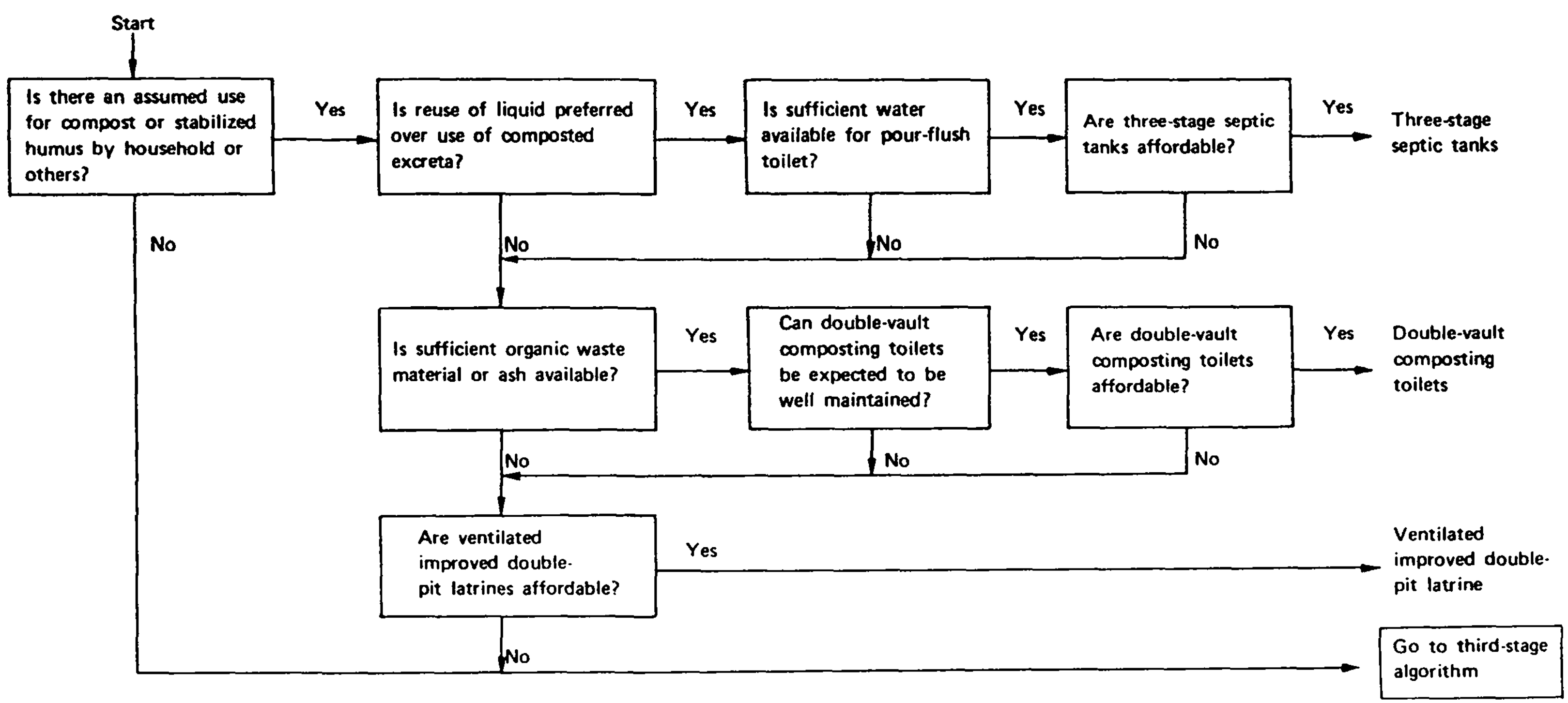


Figure 29. Second-stage Algorithm for Selection of Sanitation Technology (123).



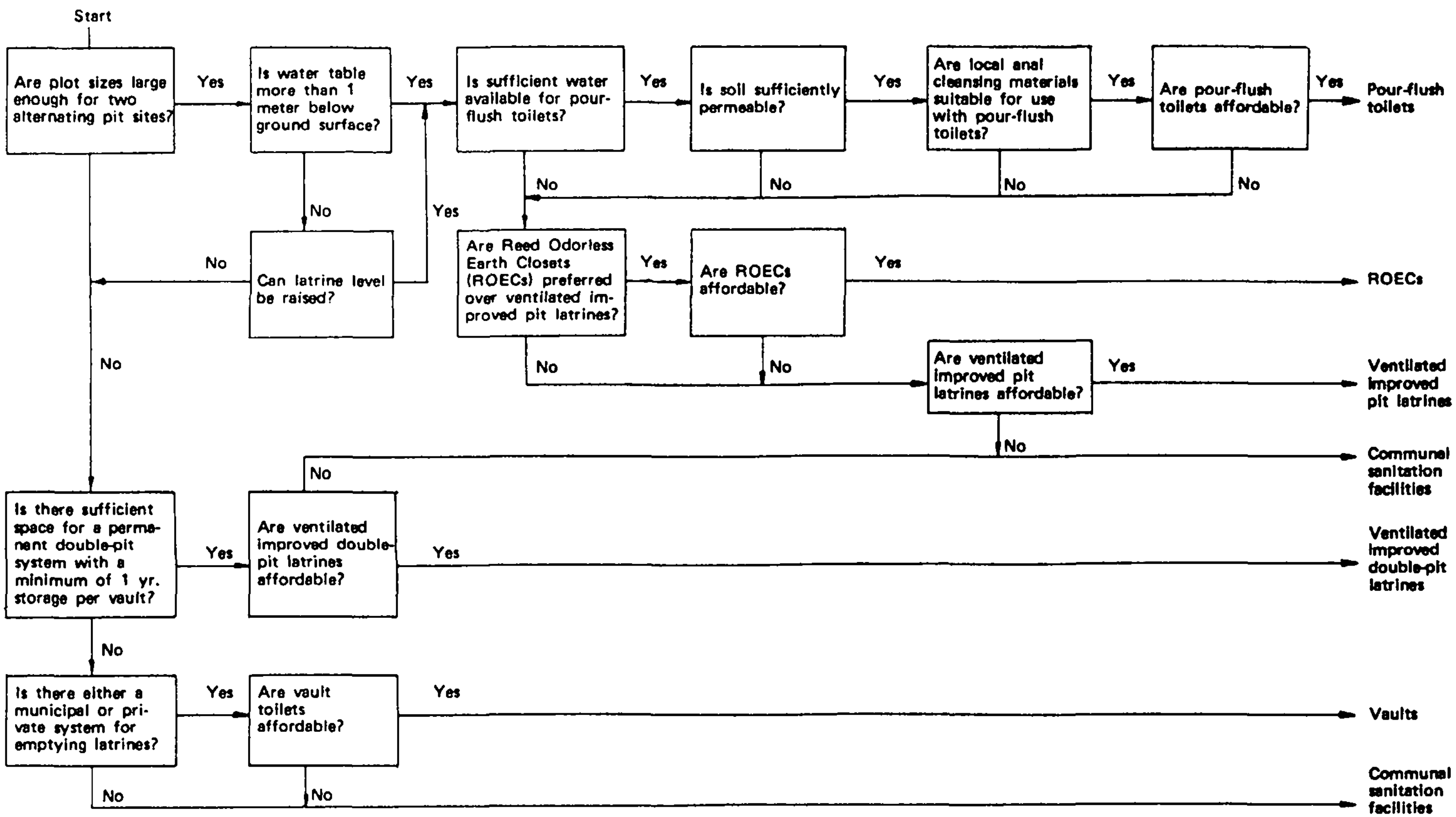


Figure 30. Third-Stage Algorithm for Selection of Sanitation Technology (123).

Is it compatible with current housing and water development plans? Are more costly technologies in this upgrading sequence affordable now?

(e) What facilities exist to produce the hardware required for the technology? If lacking, can they be developed? Are the necessary raw materials locally available? Can self-help labor be used? Are training programe required?

(f) Can the existing sanitation system, if any, be upgraded in any better way than that shown in the algorithm?

(g) Is there a neighbouring area whose existing or planned sanitation system makes a more costly alternative feasible? (e.g. small sewers discharging to an existing sewer system).

(h) What is the potential for reuse? If low, would the adoption of a technology with a higher reuse potential be economically justifiable?

(i) If the selected technology cannot deal with sullage, what facilities for sullage disposal are required? Is the amount of sullage water low enough or could it be reduced sufficiently, to preclude the need for sullage disposal facilities?

8.2 Economic Considerations

According to Kalbermatten, et al. (125), comparative costing lies at the heart of the analysis of alternative sanitation technologies. The scoring measure commonly used in project evaluation is some variation of the benefit/cost ratio. Unfortunately, the impossibility of meaningful benefit measurement for sanitation projects precludes its use in this case. There also exist unquantifiable costs associated with alternative sanitation technologies. While it is generally possible to qualitatively assess the environmental consequences of installing a particular system, it is very difficult to quantify them since no 'market' for such public goods exists. It is even more difficult to compare them with the environmental situation that would develop without the project in order to determine net benefit or net cost figures.

In general, there is no completely satisfactory scoring system for comparing alternatives with unquantifiable benefits. Only in the case of mutually exclusive alternatives with identical benefits can apply a cost minimization rule. However, where there are differences in the output or service, the least-cost project will not often be the economically optimal one. Alternative sanitation systems provide a wide range of benefit levels. While most properly selected systems can be designed to provide the potential for full health benefits (i.e. to assure pathogen destruction), the user convenience offered by an indoor toilet with sewer connection is hard to match with a pit privy. Many benefits exist in the mind of the user, and varying qualities of service result in varying benefit levels. For this reason a least-cost solution will not provide sufficient information to select among sanitation alternatives. Nonetheless, if properly applied, it will provide an objective common denominator that reflects the cost trade-offs corresponding to different service standards. Once comparable cost data have been developed, the consumers or their community representatives can make their own determination of how much they are willing to pay to obtain various service standards. Thus the economic evaluation of alternative sanitation technologies comprises three components: comparable economic costing, maximizing the health benefit from each alternative through proper design, and allowing the user to make the final benefit cost determination. A study conducted by the World Bank (125) revealed that the single most useful figure for cross technology cost comparison is the total annual cost per household (TACH). It includes both investment and recurrent costs, properly adjusted to reflect real opportunity costs, and averaged over time by the average incremental cost method. Table 37 summarizes the TACH obtained for ten technologies included in the World Bank study. Detailed information on comparative costing for developing countries may be obtained elsewhere (124, 125).

Table 37. Average Annual On-Site, Collection, and Treatment Costs per Household (125). (1978 U.S. dollars)

Facility	Mean TACH	On-site costs	Collection costs	Treatment costs
Low Cost				
PF toilet	18.7	18.7	–	–
Pit privy	28.5	28.5	–	–
Communal toilet	34.0	34.0	–	–
Vacuum-truck cartage	37.5	16.8	14.0	6.6
Low-cost septic tanks	51.6	51.6	–	–
Composting toilets	55.0	47.0	–	8.0
Bucket cartage[a]	64.9	32.9	26.0	6.0
Medium Cost				
Sewered aquaprivy[a]	159.2	89.8	39.2	30.2
Aquaprivy	168.0	168.0	–	–
Japanese vacuum truck	187.7	128.0	34.0	26.0
High Cost				
Septic tanks	369.2	332.3	25.6	11.3
Sewerage	400.3	201.6	82.8	115.9

[a] To account for large differences in the number of users, per capita costs were used and scaled up by the cross-country average for six persons per household.

8.3 Operational Aspects

It must be borne in mind that prior to choice of technology based on algorithms outlined in Section 8.1, a matrix as shown in Table 38 may be used to define comparative criteria and to display performance according to the established criteria. Ranking technologies by means of subjective weighting produces a numerical comparison of spurious precision. Moreover, in any given community there are always basic physical and cultural attributes that - in conjunction with the existing level of water supply service and the community's general socioeconomic status - considerably limit the choice of technologies, irrespective of the overall scores achieved in a comparison by numerical matrix of all possible technologies. The most useful function of a matrix, therefore, is to exclude certain technologies in a given situation, rather than to select

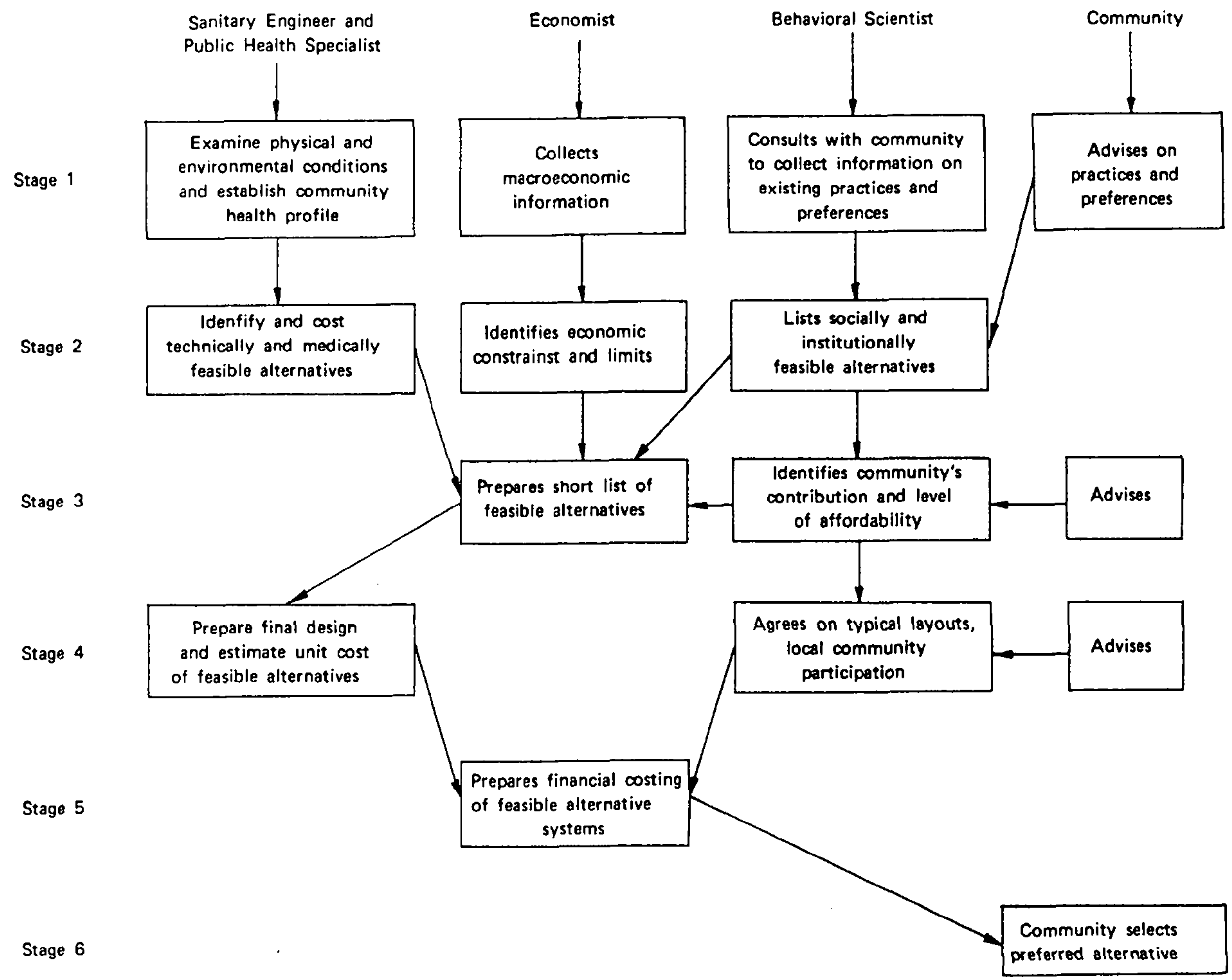
Table 38. Descriptive Comparison of Sanitation Technologies (124).

Sanitation technology	Rural application	Urban application	Construction cost	Operating cost	Ease of construction	Self-help potential	Water requirement	Required soil conditions	Complementary off-site investments[a]	Reuse potential	Health benefits	Institutional requirements
Ventilated improved pit (VIP) latrines and Reed Odorless Earth Closets (ROECs)	Suitable	Suitable in low/medium-density areas	L	L	Very easy except in wet or rocky ground	H	None	Stable permeable soil; groundwater at least 1 meter below surface[b]	None	L	Good	L
Pour-flush (PF) toilets	Suitable	Suitable in low/medium-density areas	L	L	Easy	H	Water near toilet	Stable permeable soil; groundwater at least 1 meter below surface[b]	None	L	Very good	L
Double Vault composting (DVC) toilets	Suitable	Suitable in very low-density areas	M	L	Requires some skilled labor	H	None	None (can be built above ground	None	H	Good	L
Self-topping aquaprivy	Suitable	Suitable in low/medium-density areas	M	L	Requires some skilled labor	H	Water near toilet	Permeable soil; groundwater at least 1 meter below ground surface[b]	Treatment facilities for sludge	M	Very good	L
Septic tanks	Suitable for rural institutions	Suitable in low/medium-density areas	H	H	Requires some skilled labor	L	Water piped to house and toilet	Permeable soil; groundwater at least 1 meter below ground surface[b]	Off-site treatment facilities for sludge	M	Very good	L
Three stage septic tank	Suitable	Suitable in low/medium density areas	M	L	Requires some skilled labor	H	Water near toilet	Permeable soil; groundwater atq least 1 meter below ground surface[2]	Treatment facilities for sludge	M	Very good	L
Vault toilets and cartage	Not suitable	Suitable	M	H	Requires some skilled labor	H (for vault construction)	Water near toilet	None (can be built above aground)	Treatment facilities for night soil	H	Very good	VH
Sewered PF toilets, septic tanks, and aquaprivies	Not suitable	Suitable	H	M	Requires skilled engineer/builder	L	Water piped to house	None	Sewers and treatment facilities	H	Very good	H
Sewerage	Not suitable	Suitable	Very high	M	Requires skilled engineer/builder	L	Water piped to house and toilet	None	Sewers and treatment facilities	H	Very good	H

[a] On or off-site sullage disposal facilities are required for nonsewered technologies.
[b] If groundwater is less than 1 meter below ground, a plinth can be built.
L, low; M, medium; H, high; VH, very high.

[a] On or off-site sullage disposal facilities are required for nonsewered technologies.
[b] If groundwater is less than 1 meter below ground, a plinth can be built.
L, low; M, medium; H, high; VH, very high.

Figure 31. Recommended Structure of Feasibility Studies for Sanitation Program Planning (124).



the best.

Besides the above mentioned factors, sociocultural and health factors also affect the choice of technology. These are described in detail elsewhere (123, 124, 125, 126).

It has already been mentioned that the final step in identifying appropriate sanitation technology must rest with the eventual beneficiaries. Those alternatives that have survived technical, health, social, and economic tests are presented to the community with their corresponding financial price tags, and the users must decide the level of service they are willing to pay for.

How the technical, health, social, and economic aspects of technological choice are actually coordinated is shown in Fig. 31, although the stages in the figure should not be interpreted too literally. The relations between the various boxes in Fig. 31 warrants close working association among the different actors in the planning process.

9. CONCLUSION

This report has attempted to pinpoint some of the techniques that may be adopted for human and animal wastes management in developing countries. Some of these methods are already prevalent in some developing countries. It is hoped that this document will stimulate work in other parts also. Although several methods have been outlined, both for human and animal wastes, the selection of a strategy for a particular region will depend on many factors like economic feasibility, manpower availability, availability of suitable equipments, public acceptability, site suitability, availability of land, etc.

Management of human and animal waste has become a significant problem in the developing countries today and unless rational measures are adopted to tackle the situation, the problem may become acute. The major thrust of the strategy to be adopted in developing countries should be directed to low cost options, should be in keeping with the local availability of material resources, and researches in developing appropriate methodologies should be conducted. Further, appropriate man-power training will form another important facet of the strategy, since an efficient waste management program will require skilled personnel to carry out the operations (128). In summary, it may be said that transfer of technology from developed to developing countries whould not conflict with locally appropriate technology. Adaptation, rather than just adoption, should be the watchword and the waste problem in the developing countries should be solved using indegenous technology.

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