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Urban and industrial growth in developing countries has increased the demand for water and the related need for more information on water and sewage treatment. This project, conducted by the University of Oklahoma, focuses on that need by developing a global network of adaptive and innovative technologies based on economic, social, political and cultural factors. A series of detailed reports have been produced that are designed to assist planners in their selection of suitable water and wastewater treatment processes appropriate to the material and manpower resource capabilities of particular countries at particular times.

"Prediction Methodology for Suitable Water and Wastewater Processes,"
George W. Reid and Richard Discenza.
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"Data Requirement," University of Oklahoma Bureau of Water and Environmental Resources Research.
PN-AAD-295

"A Mathematical Model for Predicting Water Demand, Wastewater Disposal and Cost of Water and Wastewater Treatment Systems in Developing Countries," George W. Reid and Michael I. Muiga.
PN-AAD-294

"Treatment Methods for Water Supplies in Rural Areas of Developing Countries," Ir. L. Huisman.
PN-AAD-284
PN-AAD-285

"Sewage Treatment in Developing Countries," L.W. Canter and J.F. Malina.
PN-AAD-286

"Contributions to a Mail Survey on Practical Solutions in Drinking Water Supply and Wastes Disposal for Developing Countries," International Reference Centre for Community Water Supplies, The Hague.
PN-AAD-287

"A Catalog of Water Supply and Waste Disposal Methods for Individual Units," George W. Reid.
PN-AAD-283

"Historic Implication for Developing Countries of Developed Countries' Water and Wastewater Technology," George W. Reid and Kay Coffey.
PN-AAD-288

"Evaluation of Lower Cost Methods of Water Treatment in Latin America," Odyer A. Sperandio and Jose Perez C.
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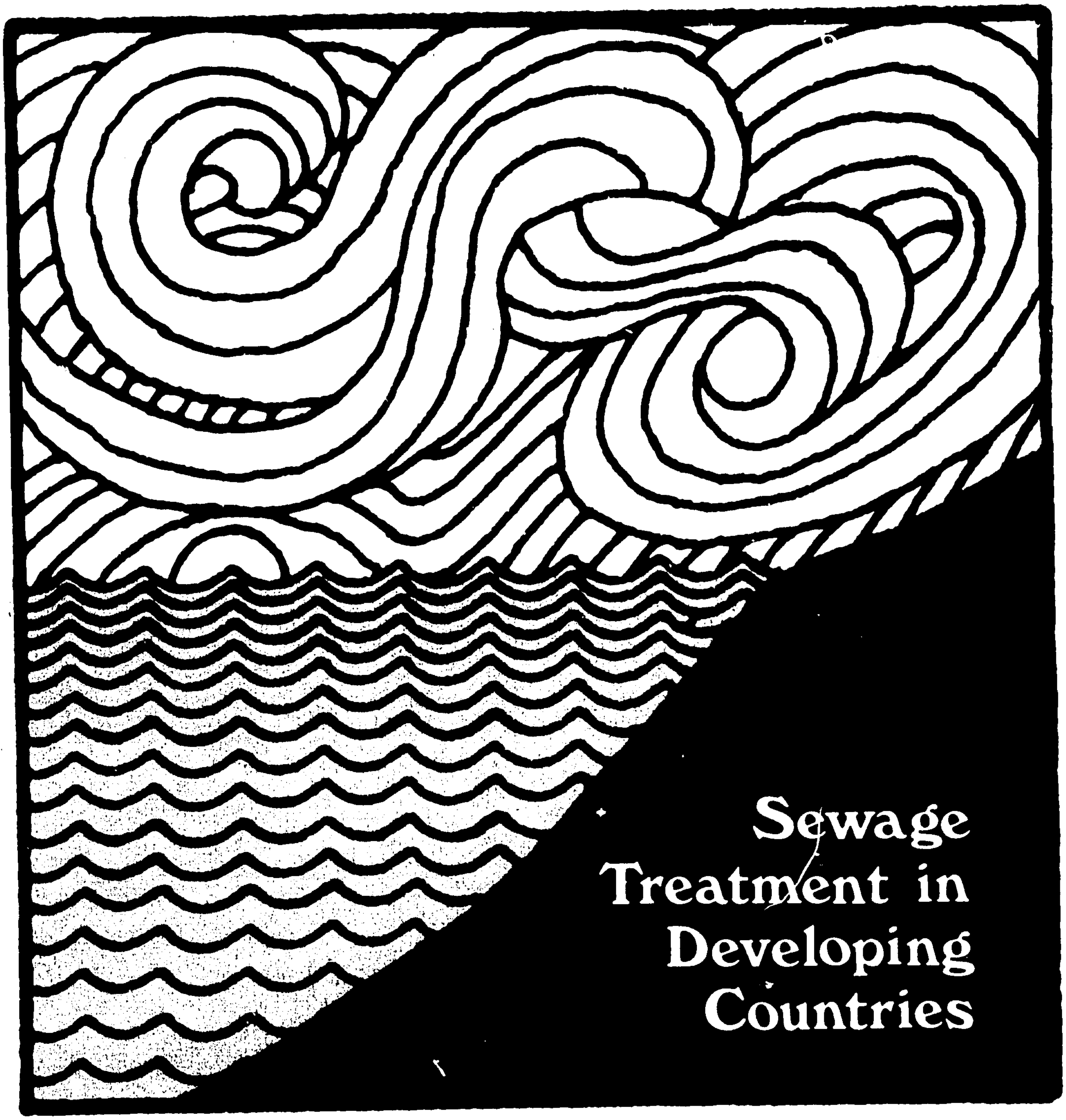
"Socio-Economic Conditions which Pertain to Cost of Construction and Operation of Water and Sewage Treatment Facilities and Quality of Water Consumption in Kenya," Erasto Muga.
PN-AAD-290

"A Water Sterilization Study in the Philippines," Reynaldo M. Lesaca.
PN-AAD-282

"The Study of Microbial Treatment of Nightsoil," Taiwan Institute of Environmental Sanitation.
PN-AAD-281

"Study of an Existing Water Treatment Plant on Simple Design and Operating System for Supplying Drinking Water to Rural Communities in the Lower Mekong Basin Countries," Thailand Ministry of Public Health, Department of Health, Rural Water Supply Division.
PN-AAD-280



APPROPRIATE METHODS OF TREATING WATER AND WASTEWATER IN DEVELOPING COUNTRIES

THE UNIVERSITY OF OKLAHOMA
BUREAU OF WATER AND ENVIRONMENTAL RESOURCES RESEARCH
Sponsored by: U.S. AGENCY FOR INTERNATIONAL DEVELOPMENT
WASHINGTON, D.C.

SEWAGE TREATMENT

in

DEVELOPING COUNTRIES

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Introduction

There is a major need for sewage treatment in developing countries. Untreated sewage pollutes surface and underground waters that could otherwise be useful for human and animal consumption, land irrigation, or recreation. Polluted waters spread water-borne diseases, including infectious hepatitis, resulting in sporadic epidemic outbreaks. In developing countries these diseases account for more than five million deaths each year, and about 500 million persons are suffering from them at the present time.

To serve as an example of the magnitude of sewage treatment needs, Table 1 is presented for urban communities in Latin America (Pavanello and Mohanrad, 1973). Many developing countries in Latin America and around the world have essentially no sewage treatment facilities; for example, only 5% of the population of India is served with sewerage facilities, and even lower percentages exist in Thailand and Ethiopia.

The main reason sewage treatment is minimally practiced in many countries is the high cost of construction, operation, and maintenance of plants utilizing the trickling filter or activated sludge process. These biological-mechanical systems are often too sophisticated for areas where skilled and trained personnel are scarce.

The purpose of this paper is to provide an overview of the state-of-the-art of sewage treatment in developing countries. Mention will be made of processes utilized in developing countries from the context of available treatment system technology. No attempt will be made to cover every process in detail. The paper will be oriented to treatment applied for sewered wastewaters. Individual treatment systems are discussed in a recent report by van den Berg (Internal Report, AID Project, University of Oklahoma, 1975).

Table 1

Sewage Pollution in
Urban Communities in Latin America

Facilities	Urban Population Millions	Degree of Pollution
Sewers and some form of treatment	5.7	Partial control
Sewers, but no treatment	51.7	Severe to moderate pollution of streams and coastal areas
House water-connections, but no sewers	30.0	Diffused pollution of soil and streams
Easy access to piped water, but no sewers	19.0	Some degree of land and stream pollution
No access to piped water	39.0	Little or no water pollution problems

There is very little in the literature relative to "Alternative Disposal Methods." However, since this type of treatment is beginning to find wider application we have included in Appendix II of this report an overview of current topics of interest.

Development of Findings

This paper was developed following a review of published references on wastewater treatment in developing countries. In addition, selected non-U.S. and some U.S. references for developed countries were also identified relative to wastewater treatment.

The approach used was to examine the following libraries: University of Oklahoma Library, University of Panama Library, Pan-American Health Organization Library, Library of Congress, U.S. Army Library, State Department Library, World Bank Library, and the U.S. National Academy of Science Library. In addition, personal libraries of a number of individuals have also supplied valuable reference sources. This paper only addresses those published reference sources in the above named libraries and locations. A survey of non-published information on wastewater treatment processes in developing countries is being conducted by the International Reference Center at Delft, Holland.

Table 2 is a summary of the identified reference sources, organized by treatment process. A total of 408 published references were found for the ten processes identified as the basic systems for consideration in developing countries. Additionally, 236 references dealing with general water pollution control were identified, as well as 139 references on methods other than the basic ten processes. Table 2 does not include a breakdown between developing and developed countries. The most-often cited processes were also reported in the largest number of countries, with uses in 31 countries identified for stabilization ponds and 18 countries for agricultural utilization.

Table 2

Reference Sources by Process

Process	Total References	Number References With Country Specified	Number Countries	Number References Without Country Specified
PS 1 Primary - Conventional	18	14	10	4
PS 2 - Stabilization Pond	240	178	31	61
PS 3 Sludge - Conventional	25	23	11	2
PS 4 Sludge - Advanced	3	3	3	0
PS 5 Sludge - Combined Imhoff	1	1	1	0
PS 6 Secondary - Standard Filter	14	9	3	5
PS 7 Secondary - High Rate Filter	6	5	1	1
PS 8 Secondary - Activated Sludge	59	55	16	3
PS 9 Secondary - Extended Aeration	35	32	13	4
PS 10 Disinfection	7	6	5	1
Subtotal	408			
General	236	166	45	70
Agricultural Utilization	97	81	18	16
Ground Discharge	10	7	3	3
Ocean Disposal	4	4	4	0
Septic Tanks	11	9	7	2
Tertiary (RO, IX, Combustion)	17	14	9	3
Subtotal	375			
Grand Total	783			

Table 3 contains a list of the references by country for the ten basic wastewater treatment processes identified for use in the overall AID study. Table 4 has a breakdown of these sources by process and continent, with the following continents being dominant:

PS1 Primary Treatment (conventional):	Europe
PS2 Primary - Stabilization Ponds:	Asia, Africa, North America (Canada), Middle East, and South America
PS3 Sludge - Conventional:	Europe, Africa, and Asia
PS4 Sludge - Advanced:	Europe
PS5 Sludge - Imhoff:	Latin America
PS6 Secondary - Standard Filter:	Europe
PS7 Secondary - High Rate Filter:	Europe
PS8 Secondary - Activated Sludge:	Europe
PS9 Secondary - Extended Aeration:	Europe, North America (Canada)
PS10 Disinfection:	Europe
Agricultural Utilization:	Europe
Ground Discharge:	Europe
Ocean Disposal	South America (Brazil)
Septic Tanks:	Latin and South America, Asia
Tertiary:	Europe

Therefore, the following processes are associated with developed countries: PS1 Primary - Conventional, PS3 Sludge - Conventional, PS4 Sludge - Advanced, PS6 Secondary - Standard Filter, PS7 Secondary - High Rate Filter, PS8 Secondary - Activated Sludge, PS9 Secondary - Extended Aeration, PS10 Disinfection, Agricultural Utilization, Ground Discharge, and Tertiary Treatment. Those processes which are primarily associated with developing countries include PS2 Primary - Stabilization Ponds, PS3 Sludge - Conventional (shown for both developed and developing countries), Ocean Disposal, and Septic Tanks. On the basis that ponds are the most used process in developing countries, the remainder of this report is a presentation of the use and costs of ponds and increases in treatment costs associated with the use of more sophisticated wastewater treatment processes.

Table 3 Reference Sources By Country

PS1 PRIMARY TREATMENT (CONVENTIONAL)

COUNTRY	NO. OF REFERENCES
1. Artic	1
2. Australia	1
3. Canada	1
4. England	2
5. Germany	1
6. India	2
7. Israel	1
8. Poland	2
9. South Africa	1
10. Sweden	2
Total	14

PS2 PRIMARY - STABILIZATION PONDS

COUNTRY	NO. OF REFERENCES
1. Arab Republics	2
2. Artic Circle	3
3. Australia	9
4. Belgium	1
5. Brazil	3
6. Canada	28
7. Colombia	5
8. Denmark	1
9. England	7
10. Finland	1
11. Germany	3
12. Holland	1
13. India	34
14. Israel	14
15. Japan	4
16. Malaysia	1
17. New Zealand	3
18. Niger	1
19. Pakistan	1
20. Panama & Canal Zone	6
21. Poland	5
22. Rhodesia	2
23. Russia	11
24. South Africa	16
25. South Vietnam	1
26. Sweden	3
27. Switzerland	1
28. Thailand	5
29. Tanzania	1
30. Turkey	1
31. Zambia	3
Total	178

PS3 SLUDGE (CONVENTIONAL)

COUNTRY	NO. OF REFERENCES
1. Czechoslovakia	1
2. England	3
3. Germany	2
4. India	3
5. Jamaica	1
6. New Zealand	1
7. Norway	1
8. Poland	1
9. Russia	2
10. South Africa	7
11. Thailand	1
Total	23

PS4 SLUDGE (ADVANCED)

COUNTRY	NO. OF REFERENCES
1. Czechoslovakia	1
2. Netherlands	1
3. Poland	1
Total	3

PS5 SLUDGE (IMHOFF)

COUNTRY	NO. OF REFERENCES
1. Panama	1
Total	1

PS6 SECONDARY TREATMENT (STANDARD FILTER)

COUNTRY	NO. OF REFERENCES
1. England	7
2. Germandy	1
3. India	1
Total	9

PS7 SECONDARY TREATMENT (HIGH RATE FILTER)

COUNTRY	NO. OF REFERENCES
1. England	5
Total	5

PS8 SECONDARY TREATMENT (ACTIVATED SLUDGE)

COUNTRY	NO. OF REFERENCES
1. United Arab Republic	1
2. Canada	7
3. Czechoslovakia	6
4. England	11
5. Finland	1
6. France	1
7. Germany	2
8. Holland	5
9. India	2
10. Ireland	1
11. Japan	5
12. Russia	3
13. South Africa	1
14. Sweden	2
15. Switzerland	6
16. Turkey	1
Total	55

PS9 SECONDARY TREATMENT (EXTENDED AERATION)

COUNTRY	NO. OF REFERENCES
1. Artic	3
2. Australia	2
3. Canada	11
4. Czechoslovakia	1
5. England	4
6. France	1
7. Germany	2
8. India	1
9. Japan	2
10. Panama	1
11. Poland	1
12. Russia	2
13. South Africa	1
Total	32

PS10 DISINFECTION

COUNTRY	NO. OF REFERENCES
1. Canada	1
2. Germany	1
3. Israel	1
4. Jamaica	1
5. Russia	2
Total	6

Table 4 : References by Treatment Process and Continent

Process	Continent or Area									
	Africa	Asia	Arctic	Aus-tralia	Europe	Latin America	Middle East	North America	General	Total
1. General	14	23	2	8	83	18	8	40	31	227
2. Waste Stabiliztion Pond	29	54	3	14	34	14	20	35	42	245
3. Agriculture Utilization	--	2	-	4	70	--	4	1	16	97
4. Combustion	--	---	-	--	2	--	--	---	---	2
5. Disinfection	--	1	-	--	3	--	1	1	1	7
6. Disposal to the Ocean	1	---	-	--	---	3	--	---	---	4
7. Ground Discharge	--	---	-	--	6	--	1	---	3	10
8. Ion Exchange	--	---	-	3	2	--	--	2	---	7
9. Literature Review--Water Pollution	--	---	-	--	---	--	--	---	4	4
10. Primary Treatment--Conventional	1	2	1	1	9	--	1	1	2	18
11. Reverse Osmosis	--	---	-	--	2	--	--	1	---	3
12. Secondary Treatment--Activated Sludge	1	8	-	--	39	--	1	7	3	59
13. Secondary Treatment--Extended Aeration	1	3	3	2	12	1	--	11	2	35
14. Secondary Treatment--High Rate Filter	--	---	-	--	5	--	--	---	1	6
15. Secondary Treatment--Standard Filter	--	1	-	--	12	--	--	---	1	14
16. Septic Tank	--	3	-	--	---	6	--	1	1	11
17. Sludge - Advanced	--	---	-	--	3	--	--	---	---	3
18. Sludge - Conventional	7	5	-	1	10	--	--	---	2	25
19. Sludge - Imhoff	--	---	-	--	---	1	--	---	---	1
20. Tertiary Treatment	--	---	-	--	4	--	--	---	1	5
TOTAL	54	102	9	33	296	43	36	100	110	783

Wastewater Treatment Goals

It is useful to consider the wastewater treatment goals that have been identified for treatment practices in the United States, and then to compare these to the particular goals that can be achieved by the processes in current use in developing countries as well as those that are potentially usable. Table 5 shows the wastewater treatment goals from an historical perspective in the United States (Barth, 1971). These goals were delineated by the U.S. Environmental Protection Agency in 1971. The beginning point is identified as the year 1900, while the year 1920 was chosen to represent the approximate time of the introduction of the activated sludge process in the United States. The year 1964 was chosen since that was the year when the Advanced Wastewater Treatment Research Program of the U.S. Public Health Service was initiated.

Suggested wastewater treatment goals for developing countries should be primarily oriented to protecting public health through the control of pathogens, and secondarily oriented to the removal of oxygen-demanding materials and suspended solids. These suggested goals for developing countries are analagous to some of the historic goals of wastewater treatment in the United States. Future wastewater treatment goals for developing countries are expected to become more similar to those for developed countries. Table 6 indicates which of the treatment processes identified in Table 2 above are appropriate for meeting the suggested goals for developing countries.

References Searched

Based on the numbers of published references identified in this

Table 5

Wastewater Treatment Goals - United States

<u>1900 - 1920 Historic</u>

Remove Suspended Solids

Remove Oxygen Demanding Materials

Transform NH_4^+ to NO_3^-

<u>1920 - 1964 Contempory</u>

Remove Suspended Solids

Remove BOD_5

Protect Receiving Water from Toxicants

Control Coliforms

<u>1964 - 1972</u>

Remove Suspended Solids

Remove Oxygen Demanding Materials

Remove Phosphorus

Transform NH_4^+ to NO_3^- or Remove Nitrogen

Protect Receiving Water from Toxicants

Control Coliforms

Positive Control of Sludges and Brines

<u>Current Trend</u>

Elimination of discharge of all pollutants

Table 6: Treatment Process Applicability to
Suggested Wastewater Treatment Goals in Developing Countries

Process \ Goal	Coliform Control	Solids Removal	Oxygen Demand Removal	Sludge Control	Phosphorus Removal	Nitrogen Control	Toxicant Control
PS1 Primary - Conventional		x					
PS2 Primary - Stabilization Pond	x	x	x				
PS3 Sludge - Conventional				x			
PS4 Sludge - Advanced				x			
PS5 Sludge - Combined Imhoff		x	x	x			
PS6 Secondary - Standard Filter		x	x	x			
PS7 Secondary - High Rate Filter		x	x	x			
PS8 Secondary - Activated Sludge		x	x	x			
PS9 Secondary - Extended Aeration		x	x	x			
PS10 Disinfection	x						
Agricultural Utilization	x						
Ground Discharge	x						
Ocean Disposal				x			
Septic Tanks	x	x	x	x			
Tertiary (RO, IX, Combustion)					x	x	x

study, attention was given to literature dealing with waste stabilization ponds, as well as screening of references originally identified as general references. The focus given to waste stabilization ponds is appropriate since this is the primary treatment process in use in developing countries at the current time.

A total of 472 (240 on ponds and 232 on general control) out of 783 identified references were reviewed in this study. A listing of all 783 identified references is in Appendix I. A breakdown of the usable and nonusable references out of the 472 is shown in Table 7. A total of 167 useful references were identified (35%), while 110 references were found not to be useful due to reasons such as orientation to industrial wastes, drinking water or sewerage systems. A total of 195 references were not found in the library sources searched in conjunction with this study. Many of these references were from specific conferences that had been held throughout the world and were simply unavailable from the library sources examined.

State-of-the-Art References

In the process of searching the identified references useful in this study, 11 sources were identified as providing general state-of-the-art information on waste stabilization ponds. Nine of the 11 references were primarily oriented to developing countries, and are listed as follows:

Agency for International Development, Sewage Lagoons for Developing Countries, Ideas and Methods Exchange No. 62 302/2/1, Sewage Lagoons, Department of Housing and Urban Development, Washington,D.C., 20410, January, 1966, 35 pages.

Table 7: Summary of References* Searched

Summary	Number of References
Useful references	167
Not useful	110
Not found	195

* Includes 240 from stabilization pond category (PS2) and 232 from general references category.

Arceivala, S. J., "Rational Design of Stabilization Ponds", In: Proceedings of a Symposium on Waste Treatment by Oxidation Ponds, Nagpur, 1963, Nagpur, Central Public Health Engineering Research Institute, 1964.

Eckley, Louis E., Canter, L. W., and Reid, George, Operation of Stabilization Ponds in a Tropical Area Final Report, U. S. Army Medical Research and Development Command, Contract No. DADA17-68-C-8137, Gorges Memorial Institute, Washington, D.C. 20406, 1974, 284 pages.

Gloyna, Earnest F., "Waste Stabilization Ponds", World Health Organization Monograph Series No. 60, Geneva, Switzerland, 1971, 175 pages.

Hopkins, G. J. and Hopkins, O. C. Waste Stabilization Lagoons Symposium on Waste Treatment by Oxidation Ponds, Central Public Health Engineering Research Institute, Nagpur, India, 1961.

Marais, G. V. R. "New Factors in the Design, Operation and Performance of Waste Stabilization Ponds", Bulletin of the World Health Organization, Vol. 34, No. 5, 1966, pp. 737-763.

Marais, G. V. R. "A Rational Theory for the Design of Sewage Stabilization Ponds in Tropical and Sub-Tropical Areas". In: Symposium of Hygiene and Sanitation in Relation to Housing, CCTA/WHO, Niamey, 1961, London Commission for Tech. Cooperation in Africa, 1963, 67 pages.

McGarry, M. G., and Pescond, M. B., "Stabilization Pond Design Criteria for Tropical Asia", Second International Symposium for Waste Treatment Lagoons, Kansas City, Missouri, 1970. pp. 114-132.

Talboys, Albert P., "Stabilization Ponds Installation in Latin America", Pan American Center for Sanitary Engineering and Environmental Science, Lima, Peru, July, 1971, 39 pages.

Two of the state-of-the-art references basically describe the use of waste stabilization ponds in the United States, these are:

Barsom, George, "Lagoon Performance and the State of Lagoon Technology", Report No. EPA-R2-73-144, U.S. Environmental Protection Agency, Washington, D.C., June, 1973, 214 pages.

Missouri Basin Engineering Health Council, "Waste Treatment Lagoons - State of the Art", Report No. 17090 EHX 07/71, U. S. Environmental Protection Agency, July, 1971, 152 pages.

History of Pond Usage in Developing Countries

Man-made stabilization lagoons for sewage treatment, fish production, and land irrigation have been used in Asia for centuries. In Europe, fish ponds were built by the Greeks in Agrigantum, Sicily, before modern times (Gloyna, 1971). Stabilization ponds were rapidly adopted as a method of sewage treatment by other countries of the world, but it was not until the early sixties that significant field data appeared in the literature. Ponds have been used in India for a considerable period of time, however, "engineering ponds" are associated with the last 15 years (Siddiqi and Handa, 1971). The use of ponds was reported in Marandellas, Southern Rhodesia, in 1960 (Hodgson, 1964). By 1967, ponds were in use in at least twenty-six developing countries (Gloyna, 1971), including Argentina, Bolivia, Brazil, Colombia, Costa Rica, Cuba, Ecquador, Ghana, Guatemala, India, Israel, Kenya, Mauritus, Mexico, Nicaragua, Nigeria, Pakistan, Peru, Saudi Arabia, South Africa, Southern Rhodesia, Thailand, Uganda, United Arab Republic, Venezuela, and Zambia. This list of countries was extended by the Latin American study by

Talboys (1971), and should include Chile, El Salvador, Panama, Barbados, Honduras, Dominican Republic, and Uruguay. This literature review has found references from these additional developing countries that should be included in the list: Malaysia, South Vietnam, and Tanzania; thus making a total of at least 36 countries that are using ponds for stabilization of organic wastes.

Biology of Waste Stabilization Ponds

Figure 1 shows common interactions in a waste stabilization pond (Zajic, 1971). Aerobic, facultative, and anaerobic bacteria are found in ponds. Predominant bacteria under aerobic or facultative conditions include *Pseudomonas*, *Achromobacter*, *Flavobacterium*, and *Alcaligenes* (McKinney, 1962; Zajic, 1971; Gann, et al, 1968; Oswald, 1968-1). Jourdan (1969) reported the presence of *Achromobacter*, *Psuedomonas*. and *Flavobacterium* in a Colombian sewage pond. Eckley, et al, (1974) confirmed the presence of *Pseudomonas* and *Alcaligenes* in Panamanian ponds. Under anaerobic conditions the genus *Clostridium* predominates, but sulfate-reducing and methane-forming bacteria can also be present. Four genera of the methane-forming bacteria have been recognized: *Methanobacterium*, *Methanobacillus*, *Methanococcus*, and *Methanosarcina* (Mitchell, 1974).

Algae in waste stabilization lagoons have been grouped as green algae, diatoms, and blue-green algae by Gloyna (1971). On the other hand, Palmer (1962) and Eckley, et al (1974) have grouped them as blue-green algae, green algae, diatoms, and pigmented flagellates. A representative list of report algal genera in stabilization ponds in developing countries is contained in Table 8. From Table 8 the most common genera are *Chlorella*, *Oscillatoria*, *Chlamydomonas*, and *Euglena*.

Figure 1: Schematic Diagram of Waste Stabilization Lagoons Operation

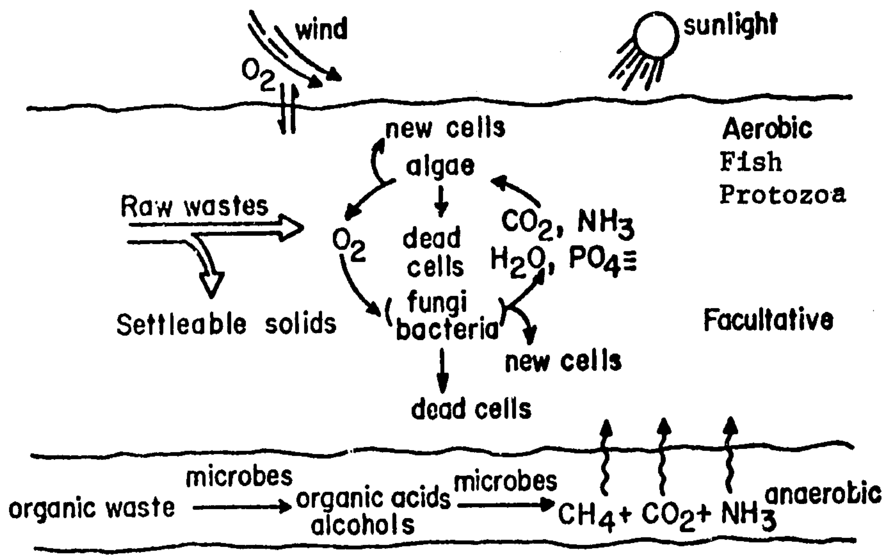

Table 8: Algal Genera Observed in Stabilization Ponds in Developing Countries

Country	Algal genera	Reference
Brazil	Chlorella	Talboys, 1971
Colombia (Cali)	Chlorella Carteria Euglena Chlamydomonas Lepocinclis Nitzchia	Canter, 1969
Colombia (Palmira)	Chlorella Euglena	Canter, 1969
India (Ahmedabad)	Arthrosphira Oscillatoria Chlorella	Jayangoudar, et al, 1970 Amin and Ganapati, 1972
India (Madras)	Eudorina Oocystis Pandorina Merismopedia Oscillatoria Spirulina	Purushothaman, 1970
Mexico (Durango)	Chlorella Scenedesmus Euglena Oscillatoria Phacus	Talboys, 1971
Panama (Canal Zone)	Chlorella Chlamydomonas Euglena Anacystis	Longley, et al, 1970 Eckley, et al, 1974
Peru (Lima)	Chlorella Euglena	Talboys, 1971
Rhodesia (Mandarellas)	Golenkinia Scenedesmus Closteriopsia Micractinium	Hodgson, 1964
Thailand	Chlorella	McGarry, 1970
Zambia (Lusaka)	Micractinium Ankistrodesmus Euglena Chlorella	Marais, 1970

Protozoa, rotifers, and fungi occur in ponds and are important in obtaining effluents with minimum turbidity (Calaway, 1968, Ruttner, 1973; Gloyna, 1971; Cubillos, 1970; Canter, 1969; Purushothaman, 1970; and Amin and Ganapati, 1972). Rotifers are of special interest because they feed on small organic particles as well as on bacteria and algae (Pennak, 1953; Ruttner, 1973; McKinney, 1962). The role of fungi in waste treatment resides in their capacity to assimilate a wide range of complex organic materials, and their ability to produce bactericidal substances (Carpenter, 1969; Vennes, 1970; and Zajic, 1971).

At least two orders of crustaceans have been found in waste stabilization ponds: Clodocera and Copepoda. The genus Daphnia belonging to the former, and Cyclops belonging to the latter, have been identified in many stabilization lagoons. Like rotifiers, clodocerans and copepods feed on bacteria and algae, and are important to the clarification of pond effluents (Vennes, 1970; De Noyelles, 1967; Tschortner, 1968, and Hodgson, 1964).

Snails in waste stabilization ponds can act as vectors in the transmission of schistosomiasis. Pond detention time is important since Hodgson (1964), while investigating a pond in Mandarellas, Southern Rhodesia, found that snail vectors were not capable of survival for more than ten weeks in a pond environment.

Aquatic insects such as mosquitoes can be a problem in ponds with no routine maintenance program. (Kimmerle and Enns, 1968). Periodic removal of peripheral vegetation is generally required for acheiving positive control (Longley, et al, 1970; Eckley, et al, 1974; and Marais, 1966).

Fish in waste stabilization ponds can be used for insect control algae control, and production of protein for animal and human consumption. Protein production and sewage treatment may have conflicting purposes since sewage can be treated and passed through ponds at a rate greater than that at which maximum fish growth takes place (Mortimer and Hickling, 1954). Fish in waste stabilization ponds have been reported in Java, Thailand, Burma, Malaya, Sumatra, the Philippines, Formosa, Ceylon, British West Indies, India, Rhodesia, China, Trinidad, Borneo, Pakistan, Puerto Rico, and Hawaii (Swingle, 1960; Mortimer and Hickling, 1954; Hodgson, 1964; McGarry, 1970; and Duffer, 1974).

Climatic Factors Affecting Pond Performance

Temperature, solar radiation, wind speed, evaporation, and rainfall are the principal climatic factors which affect pond performance. Temperature affects photosynthetic oxygen production, rate of organic degradation, and chemical and biochemical reactions occurring in the pond. The optimum temperature for a pond system is between 25-32°C.

Thermal stratification can occur in ponds as a result of liquid temperature differentials. If stratification persists, non-motile algae below the thermocline cannot enter the photic zone and die due to lack of light (Marais, 1970). Thermal stratification can also cause short-circuiting, resulting in reduced effluent quality (Barsom, 1973).

Solar radiation affects the water temperature of ponds, and is also the energy source for photosynthesis. Probable values of visible solar energy are given in Table 9 (Oswald and Gotaas, 1955). Table 9 indicates that the predicted minimum and maximum values of visible solar energy for tropical areas are 120 and 270 Langleys, respectively. Measured values for ponds in tropical areas often exceed 270 Langleys

Table 9: Probable Values of Visible Solar Energy as a Function of Latitude and Month

Latitude		Month											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
0	max	255*	266	271	266	249	236	238	252	269	265	256	253
	min	210	219	206	188	182	103	137	167	207	203	202	195
10	max	223	244	264	271	270	262	265	266	266	248	228	225
	min	179	184	193	183	192	129	158	176	196	181	176	162
20	max	183	213	246	271	284	284	282	272	252	224	190	182
	min	134	140	168	170	194	148	172	177	176	150	138	120
30	max	136	176	218	261	290	296	289	271	231	192	148	126
	min	76	96	134	151	184	163	178	166	147	113	90	70
40	max	80	130	181	181	286	298	288	258	203	152	95	66
	min	30	53	95	125	162	173	172	147	112	72	42	24
50	max	28	70	141	210	271	297	280	236	166	100	40	26
	min	10	19	58	97	144	176	155	125	73	40	15	7
60	max	7	32	107	176	249	294	268	205	126	43	10	5
	min	2	4	33	79	132	174	144	100	38	26	3	1

*Values of S in Langleys, cal/(cm^2) (day)

Correction for cloudiness:

$$S_c = S_{min} + r(S_{max} - S_{min})$$

where:

r = total hours sunshine/total possible hours sunshine

Correction for elevation up to 10,000 ft.:

$$S_c = S(1 + 0.01e)$$

where:

e = elevation in hundreds of feet

(Gloyna, 1971; Marais, 1970; Eckley, et al, 1974; Canter, 1969; and Hodgson, 1964). According to Marais (1970), solar radiation in tropical areas does not seem to be a critical factor for algal growth and oxygen production.

Wind is a prominent factor affecting the performance of waste stabilization ponds. Wind causes reaeration in the top layer, and induces mixing in the whole body of water. Mixing is of special interest because it overcomes stratification, distributes oxygen generated in the top layers to the bottom layers, maintains non-mobile algae in suspension, enhances algae growth, and increases the organic capacity of ponds (Marais, 1970). Wind can also cause de-aeration under supersaturated conditions of dissolved oxygen (Canter, 1969), and during periods of excessive windspeed settleable solids might become suspended, thus reducing light penetration and consequently reducing photosynthetic activity. Excessive windspeed may also cause erosion along the edges of ponds (Callaway and Wagner, 1966).

To avoid short-circuiting from inlet to outlet and retardation of the normal flow, the pond layout should be planned in a way to prevent having the prevailing wind direction along the line of flow (Callaway and Wagner, 1966). Prevailing wind direction is also an important consideration in the location of lagoons with respect to housing. A minimum of one-quarter mile from the housing area to the pond location is suggested (Ibid.)

Evaporation and rainfall are interrelated, and in various ways are affected by temperature, solar radiation, and wind speed. In tropical areas, evaporation might play an important role in determining the level of water maintained in the lagoon (Callaway and Wagner, 1966).

Evaporation loss should be considered in lagoon design, or supplemental water should be provided to compensate for the evaporation loss (Barsom, 1973). Oswald (1968) reported that algae converting light into heat accelerates the rate of evaporation in ponds. Evaporation in algae cultures is at least 10% greater than in plain water. Rainfall is important due to hydraulic design considerations for ponds. A heavy rain can increase reaeration, induce mixing, contribute high DO water, and in some cases, break down stratification in ponds.

Design Practice for Ponds

The majority of waste stabilization ponds are designed on the basis of organic loading, depth, and detention time (Zajic , 1971). Other factors influencing the design of ponds are temperature, light, volumetric loading, bottom sediment accumulation, toxicity of waste, size and shape of pond facilities, hydraulic principles, and mode of operation (Gloyna, 1965). As Canter (1969) proposed, two approaches to designing waste stabilization ponds are: (1) use of design criteria based on usage; and (2) use of empirical design equations based on experimentation.

Design criteria based on usage should be given preference depending on satisfactory operating experiences and similar climatic conditions prevailing in the area. While in the United States organic loadings for facultative ponds of 50 lb. BOD_5/acre/day or less are mostly used (Canter, Englande, and Mauldin, 1969), tropical areas can receive three to seven times this loading with successful results. Table 10 presented by Gloyna (1971) shows organic loadings for facultative ponds that have been used in various geographical locations with good results. Table 11 summarizes some design loadings used on pond

Table 10.

BOD Loadings Per Unit Area Per Day Under Various Climatic Conditions

Surface Loading ($LB\ BOD_5$/Acre/day)[a]	Population Per Acre[b]	Detention Time (Days)[c]	Environmental Conditions
Less than 9	Less than 80	More than 200	Frigid zones, with seasonal ice cover, uniformly low water temperature & variable cloud cover.
9 - 45	80 - 405	200 - 100	Cold seasonal climate, with seasonal ice cover & temperate summer temperatures for short season.
45 - 134	405-1,215	100 - 33	Temperate to semi-tropical occasional ice cover, no prolonged cloud cover.
134 - 313	1,215-2,834	33 - 17	Tropical, uniformly distributed sunshine & temperature, & no seasonal cloud cover.

[a] These estimates are based on the assumption that the effluent volume is equal to the influent volume, i.e., the sum of the evaporative and seepage losses is not greater than rainfall.

[b] Assuming a contribution of 0.11 lb BOD_5 per person per day in developing areas.

[c] Based on an influent volume of 260 gallons of waste per person per day.

Table 11 : Areal Loadings Used in Tropical Areas

Location	Loading ($lb\ BOD_5/acre/day$)	Depth (Feet)	No. of Lagoons	Remarks	Source
Latin America					
Canas, Costa Rica	213	3-5	2	Facultative, Parallel	1
Lima, Peru	254	2.3-40	1	Facultative	2
Lima, Peru	241	5.5[a]	21	Facultative, series	2
Mexicali, Mexico	1062	15[a]-4.6[b]	N.D.	Anaerobic-facultative, series	2
Brasilia, Brazil	536[a]-80[b]	65[a]-33[b]	2	Anaerobic-facultative, series	2
Canal Zone, Panama	150	6[a]-4[b]	3	Anaerobic-facultative, series	3
Palmira, Colombia	150	3-5	3	Facultative, series & parallel	4
Asia					
Madras, India	180	2.75[a]-5[b]	5	Anaerobic-facultative, series	5
Ahmedabad, India	200-250	3-4	2	Facultative, series	6
Ahmedabad, India	325	4	1	Facultative	7
Nagpur, India	185[a]	3.5[a]	2	Facultative, series	7
Nagpur, India	417[a]-394[b]	5[a,b]	2	Facultative, parallel	7
Bangkok, Thailand	5000	3	N.D.	Anaerobic	8
Bangkok, Thailand	200-400	08-15	24	High rate, parallel	9
Danang, Viet Nam	220	N.D.	2	Facultative, series	10

Continued on the next page

Table 11 (Continued): Areal Loadings Used in Tropical Areas

Location	Loadings (lb BOD_5/acre/day)	Depth (Feet)	No. of Lagoons	Remarks	Source
Africa					
Mandarellas, Southern Rhodesia	168^a	4^a-3^b	6	Facultative, series	11
Nairobi, Kenya	91.5^a-57^b	$5.7^{a,b}$	2	Facultative, series	12

Sources:
1. Saenz (1969)
2. Talboys (1971)
3. Eckley et al (1974)
4. Canter (1969)
5. Purushothaman (1970)
6. Jayangoudar et al (1970)
7. Dave and Jain (1966)
8. McGarry and Pescod (1970)
9. McGarry (1970)
10. Duttweiler and Burgh (1969)
11. Hodgson (1964)
12. WHO and Government of Kenya (1973)

[a] Primary ponds

[b] Secondary Ponds

N.D.- No Data

systems in Latin America, Asia, and Africa.

Empirical design relationships have been developed by several investigators. These will be presented for anaerobic ponds (Vincent), facultative ponds (Marais and Shaw, Herman and Gloyna, McGarry and Pescod, Siddiqi and Handa), and aerobic ponds (Oswald, and Zajic).

McGarry and Pescod (1970) presented an empirical formulation recommended by Vincent for anaerobic ponds in tropical areas. Complete mixing and a pH range between 6.8 and 7.2 must be assumed. This empirical formulation is presented in Equation 1, as follows:

$$P = \frac{P_o}{6(\frac{P}{P_o})^{4.8} R + 1} \qquad \text{(Equation 1)}$$

where: P = Pond and effluent five-day, 20°C BOD, mg/l

P_o = Influent five-day, 20°C BOD, mg/l

R = Retention time for completely mixed separate pond system (days)

Marais and Shaw developed an equation for facultative ponds in southern and central Africa (Gloyna, 1971). Complete mixing and reduction of BOD according to a first-order reaction were assumed. The equation is as follows:

$$L_p = \frac{600}{(0.18d + 8)} \qquad \text{(Equation 2)}$$

where: L_p = Effluent BOD_5 (mg/l)

d = Depth (m.)

and if the initial BOD and detention time are known:

$$L_p = \frac{L_o}{0.17\ R_T + 1} \qquad \text{(Equation 3)}$$

where: L_o = Influent BOD_5 (mg/1)

R_T = Detention time at temperature T

Herman and Gloyna also proposed an equation particularly useful for temperate and warmer areas (Gloyna, 1971). This relationship, shown by Equation 4, emphasizes the influence of temperature on detention time.

$$V = (3.5 \times 10^{-5})\ Nq\ L_a \theta^{(35-Tm)} \qquad \text{(Equation 4)}$$

where: V = Pond volume (m^3)

N = Number of people contributing waste

q = Per capita waste contribution (liters/day)

θ = Temperature reaction coefficient = 0.085

Tm = Average water temperature of coldest month

L_a = Influent ultimate BOD (mg/1)

McGarry and Pescod (1970) developed an equation describing the relationship between possible areal BOD loading and ambient monthly mean temperature. The applicable temperature range is 20 - 90°F, and the equation is as follows:

$$L_o = 10\ (1.054)^T \qquad \text{(Equation 5)}$$

where: L_o = Areal BOD loading (pounds/acre/day)

T = Ambient mean monthly temperature, °F

McGarry and Pescod (1970) also developed a design relationship for primary facultative ponds in tropical areas. Equation 6 was formulated after a study of ponds operating under 143 different conditions:

$$L_r = 9.23 + 0.725\ L_o \qquad \text{(Equation 6)}$$

where: L_r = Areal BOD removal (pounds/acre/day)

L_o = Influent BOD_5 (mg/l)

Siddiqi and Handa (1971) proposed a design equation after studying ponds in seven different cities in India. The relationship is as follows:

$$E = \frac{100}{1 + 0.188\, L_f^{0.48}} \qquad \text{(Equation 7)}$$

where: E = BOD performance efficiency (%)

L_f = Loading factor (ratio of BOD load to oxygen production by algae. The range of L_f must be between 0.44 and 8.0)

Oswald (1968-2) proposed the following design equation for aerobic ponds:

$$\frac{d}{D} = \frac{0.66\, FS}{L_a} \qquad \text{(Equation 8)}$$

where: F = Oxygenation factor or ratio of oxygen produced to the oxygen required (usually between 1.2 and 1.8)

S = Solar radiation(calories/cm^2/day)

d = Depth (m)

D = Detention time (days)

L_a = Influent first-stage BOD (mg/l)

Zajic (1971) presented a design equation developed by Oswald and Gotaas. This relationship has also been applied to the design of aerobic ponds:

$$A = \frac{hW}{FES} \qquad \text{(Equation 9)}$$

where: A = Surface area of pond (cm^2)

h = Unit heat of combustion (cal/gm)

W = Net weight of oxygen produced (g/day)

E = Efficiency of solar energy conversion to usable photosynthetic energy, usually 2 to 4%

Aerated ponds, or lagoons, represent an intermediate treatment system between natural treatment (waste stabilization ponds) and mechanical treatment (activated sludge plants). Aerated lagoons are basically ponds with provisions for oxygenation through the use of surface aeration devices. Brazilian design criteria for facultative ponds and aerated lagoons are summarized in Table 12.

Pathogen Removals in Ponds

Pond removal efficiencies for coliform and pathogenic bacteria are usually high, and values of up to 99% are often observed. Many theories about the destruction of pathogens in ponds have been suggested. Parhad and Rao (1974) suggested that the rapid die-off of coliforms may be attributed to the high pH found in ponds. They found that E. coli could not grow in wastewater with a pH greater than 9.2. Gann, et al (1968), conducting a study with model ponds in Oklahoma, concluded that reduction of coliforms in ponds is closely related to BOD removals, thus indicating that coliforms are removed because of their inability to compete successfully for nutrients. McKinney (1962) also proposed competition for food as a principle reason for coliform removal in ponds. He suggested that predatory protozoan populations can also be responsible. Caldwell (1956), Davidson (1961), and Merz, et al. (1962) suggested that toxic substances produced by algae reduce the number of bacteria and coliform bacteria. Chlorellin, a substance liberated by Chlorella, was reported to have a marked antibacterial activity. Oswald and Gotaas (1955) stated that in a study they conducted in laboratory and pilot

TABLE 12

Design Criteria for Ponds and Aerated Lagoons*

	Facultative Pond	Aerated Lagoon
Efficiency(%)	90	90
Depth (m)	2	3
Detention Time (days)	--	6
BOD_5 (gm/capita-day)	54	54
Flow (l/cap-day)	170	170
Temperature (°C)	17°C → 21°C	20°C
BOD_u/BOD_5	1.46	1.46
Maximum Area per Pond (ha)	8	8
Constant K_1 (day^{-1})	--	0.35
KgO_2/Kg BOD Removed	--	0.7
KgO_2/Hp-hr	--	1.2
Hp/1000 m^3	--	2.68

* Personal Communications with E. Jordao, Rio de Janeiro, Brazil

plants, no anticoliform activity can be credited to algae. They proposed that besides the normal dieaway of coliforms, the bactericidal effect of solar radiation should be taken into consideration. Smallhorst, et al. (1953) suggested that detention time and settling are also important factors in the removal of bacteria from stabilization lagoons. Other environmental factors responsible for a decrease in bacterial concentrations include: (a) dilution and mixing, (b) aggregation, (c) presence of toxic substances, and (d) temperature (Gloyna, 1971).

Several equations have been developed to describe bacterial removals in ponds. A modification of Chick's Law that describes the rate of bacterial disappearance is as follows (Gloyna, 1971):

$$\frac{(N'_o - N'_R)}{N'_o} = \frac{N'_t}{N'_o} = (1 + ck'_1R) - \frac{1}{c} \qquad \text{(Equation 10)}$$

where: N'_t = Bacterial population at detention time R (days)

N'_o = Initial bacterial population

$N'_R = N'_o - N'_t$

c = Non-uniformity coefficient

k'_1 = Rate constant, $\log_e$ (bacterial disappearance/day)

R = Detention time (days)

When removal occurs at a uniform rate, c = 0.

Marais (1966) proposed equations to relate the reduction of faecal bacteria in a single pond and in a series of ponds. These equations are:

For a single pond:

$$\frac{N'}{N'_o}\ \% = \frac{100}{(2R + 1)} \qquad \text{(Equation 11)}$$

For a series of ponds:

$$\left(\frac{N'}{N'_o}\right)\% = \frac{100}{(2R_1 + 1)} \cdot \frac{100}{(2R_2 + 1)} \qquad \text{(Equation 12)}$$

where: N' = Faecal bacteria in pond effluent (per ml)

N'_o = Faecal bacteria in pond influent (per ml)

R, R_1, R_2 = Retention time for completely mixed separate pond system (days)

Canter (1969) presented an equation for predicting pathogen removals developed by Mauldin.

$$P.R. = \frac{(100)\ (K)\ R^{0.04}}{L^{0.306}\ D^{0.0033}} \qquad \text{(Equation 13)}$$

$$K = 0.0089\ (L) + 2.55$$

where: P.R. = Percentage removal

K = Proportionality constant

L = Organic loading rate (lb. BOD_5/acre/day)

D = Depth (feet)

R = Detention time (days)

Considering the removal of viruses, stabilization ponds seem to have higher percentage removals than conventional wastewater treatment plants if the pond is loaded to its design capacity (Stander, et al. 1973). Shuval (1973), in studying the effectiveness of an Imhoff tank, biological filtration plant, and stabilization ponds for removal of enteroviruses, concluded that ponds, although not very efficient in virus removal (67% removal), were still more effective than the two other wastewater treatment units. Slanetz, et al. (1970), suggested that virus removal depends on exposure to solar radiation, adsorption due to static forces, or detention beyond the normal survival time of the virus. Virus removal seems to be independent of the biological processes occurring in ponds.

Pond System Performance

Table 13 contains a summary of BOD and bacterial removals observed for ponds in developing countries. The data reveals that the majority of the pond systems have BOD removals of 80% or more. Values obtained for coliform removal are much higher than for BOD removal. The data also suggests that higher removals of coliform bacteria are obtained in ponds working in series.

Eckley, et al. (1974) presented performance equations for a pond system that had been working in the Canal Zone, Panama for five years. The data collected during that period of time was subject to multiple regression analyses. The following selected performance equations were observed for a three-pond system (anaerobic - facultative - polishing):

$$\%\ \text{BOD Removal} = 14.469 + 27.244\ \frac{(P-E)}{P} + 73.942\ \frac{(I-E)}{I} + 0.071\ BOD_L - 0.160\ N_L - 0.149\ P_L + 0.027\ COD_L$$

$$\%\ \underline{E.}\ \underline{coli}\ \text{Removal} = -85.264 + 122.170\ \frac{(P-E)}{P} + 194.613\ \frac{(I-E)}{I} + 0.969\ N_L - 0.586\ P_L - 0.069\ COD_L$$

$$\%\ \text{N Removal} = 11.466 + 87.464\ \frac{(I-E)}{I} + 0.272\ P_L - 26.979\ \frac{(P-E)}{P} + 0.036\ COD_L$$

$$\%\ \text{P Removal} = -293.396 + 4.921\ P_L + 326.894\ \frac{(I-E)}{I} - 2.962\ N_L + 0.229\ COD_L$$

Table 13: BOD and Bacterial Removals
for Ponds in Developing Countries

Location	Loading (lb. BOD_5/acre/day)	BOD Removal %	Coliform Removal %	Number of Lagoons	Remarks	Source
Latin America						
Cauas, Costa Rica	213	93	97	2	Facultative, Parallel	1
Lima Peru	254	70	N.D.	1	Facultative	2
(Same lagoon)	490-540	68	N.D.	1	Odor Problems	2
Durango, Mexico	N.D.	69-80	N.D.	2	Facultative, Parallel	2
(Same lagoon)	N.D.	73-82	95.3->99	2	Facultative, Series	2
Brasilia, Brazil	536[a]-80[b]	86[c]	90[c]	2	Anaerobic-Facultative Series	2
Canal Zone, Panama	143	75	>99	3	Anaerobic-Facultative Series	3
Palmira, Colombia	128[a]	93	>99	3	Facultative, Series & Parallel	4
Asia						
Madras, India	170	67-87	93-99	5	Anaerobic-Facultative Series	5
Ahmedabad, India	246	80	N.D.	2	Facultative, Series	6
Ahmedabad, India	325	73	N.D.	1	Facultative	7
Nagpur, India	185	88	N.D.	2	Facultative, Series	7
Nagpur, India	417[a]-394[b]	74-79	N.D.	2	Facultative, Parallel	7
Bhilai, India	N.D.	86	N.D.	1	Facultative	7

Continued on next page

Table 13 (Continued): BOD and Bacterial Removals for Ponds in Develcping Countries

Location	Loading (lb. BOD_5/acre/day)	BOD Removal%	Coliform Removal %	Number of Lagoons	Remarks	Source
Bangkok, Thailand	200-400	83-95	N.D.	24	High rate, Parallel	8
Bien Hoa, Viet Nam	600	62	N.D.	N.D.	Facultative - Shallow	9
<u>Africa</u>						
Mandarellas, Southern Rhodesia	282 [a]	74-88	N.D.	6	Facultative, Series	10

Sources:
1. Saenz (1969)
2. Talboys (1971)
3. Eckley et al (1974)
4. Canter (1969)
5. Purushotaman (1970)
6. Jayangoudar et al (1970)
7. Dave and Jain (1966)
8. McGarry (1970)
9. Duttweiler and Burgh (1969)
10. Hodgson (1964)

[a] Primary Ponds

[b] Secondary Ponds

[c] Entire System

N.D.- No Data

where: BOD_L = Biochemical Oxygen Demand Loading (lb./acre/day)

COD_L = Chemical Oxygen Demand Loading (lb./acre/day)

N_L = Organic Nitrogen and Ammonia Loading (lb./acre/day)

P_L = Orthophosphates Loading (lb./acre/day)

$\frac{I-E}{I}$ = (Influent Flow - Effluent Flow)/ Influent Flow

$\frac{P-E}{P}$ = (Precipitation - Evaporation)/ Precipitation

N = Organic Nitrogen and Ammonia

P = Orthophosphates

Sludge Accumulation in Ponds

During the first years of operation of a facultative pond, deposition of sludge occurs at a faster rate than it is removed by fermentation. With time (two to twenty years), an equilibrium is reached where the rate of deposition equals the rate of fermentation (Marais, 1970). After equilibrium is reached, sludge accumulation in ponds treating primary and secondary effluents of domestic wastes is practically negligible (Stander, et al., 1973). However, in tropical areas where high BOD surface loadings are utilized and water consumption per capita is low, sludge accumulation may become significant if lagoons are not properly designed (Gloyna, 1971).

Eckley, et al. (1974) reported four inches of sludge accumulation in a pond loaded with 200 lb. BOD/acre/day after two years of operation in the Canal Zone, Panama. In the same location, another study was made with a small experimental pond with loadings between 5,000 and 11,000 lb. BOD/acre/day. After six months of operation, sludge buildup was only twelve inches. The relatively small accumulation of sludge was probably the result of high temperatures in the area, and consequently, high rates of fermentation and methane production. Cubillos (1970) reported 6.6 inches of sludge accumulation after two years of operation in a pond with loadings ranging from 70 to 407 lb. BOD/acre/day in Palmira, Colombia. Hodgson (1964) reported 4.4 inches of sludge accumulation in a pond at Mandarellas, Southern Rhodesia, after fourteen months of operation with loadings ranging between 127 and 182 lb. BOD/acre/day. According to Callaway and Wagner (1966), in properly designed lagoons the high rates of fermentation and methane production in tropical areas make de-sludging of lagoons unnecessary until after eight to sixteen years of operation.

Costs of Wastewater Treatment in Developing Countries

The cost of construction and operation of waste stabilization ponds is lower than for any mechanical wastewater treatment plants, provided that land costs are not prohibitive (Gloyna, 1971). Stabilization ponds are especially economical for small communities in rural areas (Callaway and Wagner, 1966). Pond treatment, in most cases, is less expensive in developing countries than in developed ones. Table 14 summarizes a comparison of captial costs and operation and maintenance costs for stabilization ponds in the United States, India, and Brazil (Reid, 1974). India's costs can be considered applicable to other Asian and African developing countries, and Brazilian costs can be extrapolated to other Latin American countries.

The costs of facultative waste stabilization ponds in Brazil compare relatively well with the data presented for ponds serving

Table 14: Waste Stabilization Pond Costs
for the United States, India, and Brazil

	U. S. A.[1]		India[1]		Brazil[2]
Population	Capital[3] $/capita	Operation & Maintenance $/yr./capita	Capital[3] $/capita	Operation & Maintenance $/yr./capita	Capital[4] $/capita
5,000	16.56	0.50	2.09	0.32	14.50 (7.40)[5]
10,000	10.89	0.39	1.84	0.25	12.50 (6.60)
25,000	-	-	-	-	10.50 (6.40)
50,000	4.11	0.20	1.29	0.17	9.00 (6.00)
100,000	2.70	0.14	1.25	0.14	-
200,000	1.78	0.11	1.17	0.12	-

[1]Reid (1974).

[2]Personal correspondence between J. Malina and E. Jordao, Rio de Janero.

[3]Excludes land costs.

[4]Cost includes excavation, parshall flume, inlet and outlet structures but does not include cost of land.

[5]Numbers in parentheses represent aerated lagoon capital costs.

populations between five and ten thousand people in the U.S. and India. However, the Brazilian information indicates that the cost of a stabilization pond serving a population of 50,000 people is approximately $9 per capita, which is more than 2 1/2 times the cost of construction in the U.S. and more than eight times the construction costs in India. The Brazilian costs do not include any cost of land but do include ground clearing, excavation, clay lining, fences, landscaping, parshall flume, piping, dikes, etc. It should also be pointed out that the maximum size of a single pond is limited to approximately 20 acres (eight hectares).

A wastewater treatment system including an aerated lagoon with a six-day detention time followed by a second lagoon with a two-day detention time to remove excess suspended solids also was considered. The per capita costs of construction are shown in Table 14. These costs range from $6 per capita for a system serving 50,000 people up to $7.40 per capita in a system serving 5,000 people. These costs are based on construction costs similar to those for waste stabilization ponds including the excavation, landscape, parshall flume, inlet and outlet structure, etc. as well as a cost of approximately $400 per installed horsepower of aeration equipment. Fixed mounted surface aerators are included in the aerated lagoon design. The per capita capital costs of the aerated lagoon systems are approximately half those for stabilization ponds to serve populations of 5,000 to 10,000, and approximately 2/3 the cost per capita for ponds serving a population between 25,000 and 50,000 people, however the operating costs would be considerably higher. This increased cost results from the electrical requirements to operate the surface aerators. If a relatively low cost of electricity, for example, hydroelectric power is available, these operating costs could be minimal.

In fact, in Brazil where most of the electrical energy is generated by hydroelectric power plants, aerated lagoons do offer a reasonable alternative to waste stabilization ponds. The mechanical surface aerators can also be replaced by static aeration devices which require compressed air. This type of aeration system would minimize maintenance. A direct-drive blower could be used to provide the compressed air and the need for electricity would be minimized.

The cost of land as well as the availability of land would also affect the type of waste treatment facility that should be installed in developing countries. The data presented in Table 15 indicate that the land requirements for waste stabilization ponds, aerated lagoons, and activated sludge systems are not markedly different for a plant with a capacity of one million gallons/day (MGD) which is equivalent to a plant serving 10,000 people. The land requirements range from 10-18 acres for a 1 MGD facility. However, as the capacity of the treatment facility approaches 10 MGD (serving approximately 100,000 people) the land requirements for waste stabilization ponds are approximately 4 times the requirements for an aerated lagoon system, and 9 times the land requirements for an activated sludge plant.

The land requirements for treating wastewater in stabilization ponds increase rapidly as the capacity of the plant increases, so that the requirements to treat 100 MGD of wastewater (serving approximately 1,000,000 people) is 1800 acres for waste stabilization ponds compared to only 70 acres for an activated sludge system. In some of the large urban-industrial metropolitan areas in developing countries, land may not be available at a reasonable cost to rely on waste stabilization ponds as a means of providing adequate treatment of municipal

Table 15: Land Requirements of Wastewater Treatment Facilities

Capacity MGD	Population	Ponds* Acres	Aerated Lagoons** Acres	Activated Sludge*** Acres
1	10,000	18	15	10
10	100,000	180	50	20
25	250,000	450	90	35
50	500,000	900	125	45
100	1,000,000	1,800	250	70

*Based on $V = (3.5 \times 10^{-5}) NqL_a \theta^{(35 - Tm)}$ and depth = 2 meters

**Based on 6-day detention time

***EPA estimates

wastewaters. Therefore, it may be necessary to install a waste treatment facility which includes screening, grit removal, primary sedimentation, activated sludge system, and anaerobic digestion of the sludge. In such a system, the sludges can be handled by the anaerobic digestion and the methane gas produced can be recovered and used to provide some of the energy required to operate the plant.

The capital and operating costs for wastewater treatment using activated sludge for biological treatment and anaerobic digestion and energy recovery is presented in Table 16. It should be noted that for a plant with a capacity of 1 MGD (serving 10,000 people), the capital costs are three or four times the cost of waste stabilization ponds. By adding energy recovery by anaerobic digestion the cost is approximately doubled, therefore, the capital cost of the total system is eight to ten times that of stabilization ponds to provide the same quality effluent. However, as the size of the plant increases, the overall capital costs of the activated sludge system becomes quite competitive with waste stabilization ponds, especially in areas where the cost of land is high. For example, the capital cost of a 100 mgd activated sludge system with anaerobic digestion and energy recovery would be approximately the same as that for waste stabilization ponds if the cost of land was approximately $10,000 per acre. Approximately 1,800 acres of land would be devoted to wastewater treatment in the case of the waste stabilization ponds, whereas only 70 acres would be required for the activated sludge system. Therefore, the various alternatives should be evaluated in terms of land availability, costs of land, and ease of expansion of the system to meet future population requirements.

Energy requirements for wastewater treatment represent another

Table 16: Capital and Operating Cost for
Wastewater Treatment Plant Using Activated Sludge for
Biological Treatment and Anaerobic Digestion and Energy Recovery (1975 dollars)

		Capital Cost		Operating Cost	
Capacity MGD	Population Served	Wastewater $/Capita	Sludge Digestion and Energy Recovery $/Capita	Chemicals, Labor, etc. $/Cap-yr.	Sludge Handling and Electrical $/Cap-yr.
1	10,000	$53.70	$48.93	$3.35	$1.52
10	100,000	21.43	10.79	0.96	0.32
25	250,000	17.58	7.30	0.70	0.27
50	500,000	15.78	6.58	0.56	0.24
100	1,000,000	14.22	6.18	0.46	0.22

decision factor for treatment process selection. Some energy can be obtained from digester gas in an activated sludge plant. For example, a schematic diagram of anaerobic digestion system with power and heat recovery using dual fuel engines is shown in Figure 2. The gas produced during anaerobic digestion contains approximately 600-700 BTU per cubic foot. However, to use the gas in a dual fuel engine, the hydrogen sulfide must be removed. Hydrogen sulfide is generally removed using iron oxide mixed with wood shavings. The dual fuel engine uses the methane gas with some auxiliary diesel oil, and the mechanical energy generated can be used to drive the blowers required to aerate the activated sludge system. The cooling water from the engine is used in a heat exchanger to heat the sludge entering the digestion system. Any excess gas beyond that required to drive the blowers is converted to electrical energy by means of a dual fuel engine and an electrical generating set. This electrical energy is used throughout the treatment plant to operate pumps and meet other electrical needs.

The energy requirements to treat municipal wastewater at activated sludge plants with capacities ranging from 1 MGD up to 100 MGD are shown in Table 17. Energy balances for municipal waste treatment plants with energy recovery and utilization are shown in Table 18 for plant capacities of 1, 10, 25, 50, and 100 MGD. The total energy requirements are separated into energy required by the diffused air system and other energy requirements in the plant. The energy available from the digested gas also is tabulated along with the requirements for pilot oil which is essential to the operation of the dual fuel engine. The conversion factors for reducing all the energy requirements to BTU's per day are also included in Table 18. The energy balance indicates that the amount of

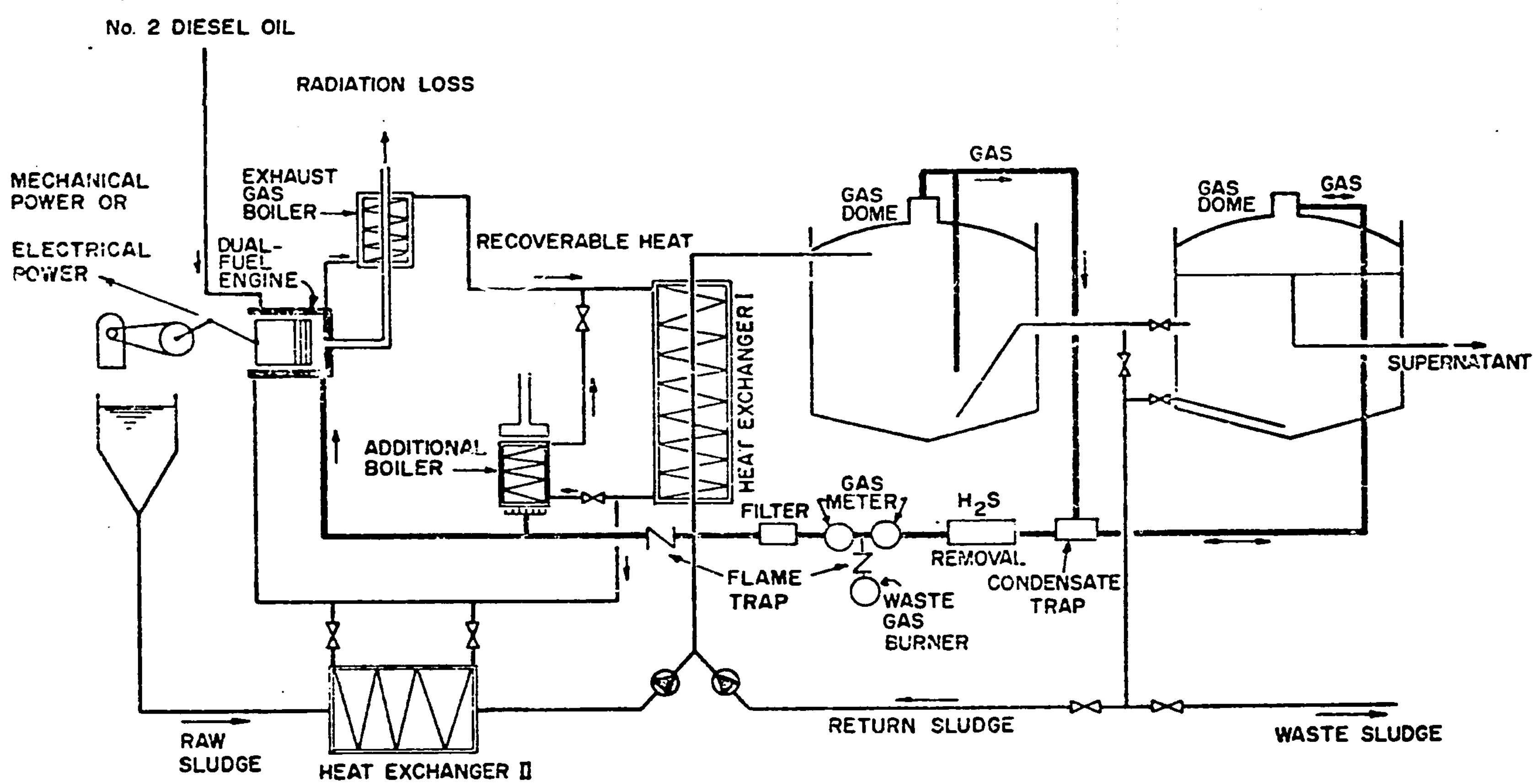

FIG. 2 . SCHEMATIC OF POWER AND HEAT GENERATION WITH DUAL-FUEL ENGINES.

Table 17: Electrical Energy Requirements for Various Wastewater Unit Processes and Operations

Type of Plant: Activated Sludge					
Plant Size (MGD)	1	10	25	50	100
Treatment Unit	Killowatt - hours/day				
Preliminary Treatment					
Bar Screens	2	2	3	6	11
Comminutors	16	61	92	142	204
Grit Removal	2	4	9	17	34
Influent Pumping (30 ft. total head)	153	1,451	3,233	6,467	12,933
Primary Sedimentation (800 gpd/sq. ft.)	31	122	224	347	734
Activated Sludge Process					
Diffused Air	553	5,324	13,310	26,620	53,240
Recirculation Pumping (50%, 17.5 ft.)	45	423	943	1,886	3,772
Final Sedimentation (800 gpd/sq. ft.)	31	122	224	347	734
Chlorination	1	1	67	134	267
Lights & Miscellaneous Power	57	210	450	950	2,400
Sludge Treatment					
Sludge Pumping	2	21	51	102	204
Gravity Thickeners	11	21	21	21	41
Anaerobic Digesters					
Mixing	84	212	334	448	673
Heating	23	68	119	180	324
Compressors (gas storage)	17	168	420	841	1,683
TOTAL (Kwh/day)	1,008	8,210	19,500	38,508	77,254

TABLE 18

Energy Balance for Municipal Wastewater Treatment Plant with Energy Recovery and Utilization

Plant Capacity	Population Served	BTU X 10^6/Day: Total Energy Required		Energy Available from Digester Gas	Deficit or Surplus	Pilot Oil*** Required (gal/day)
		Diffused Air*	Other**			
1	10,000	3.98	4.37	6.8	(-1.55)	7.1
10	100,000	39.78	26.55	68	(+1.67)	56.1
25	250,000	99.44	56.95	170	(+13.61)	132.1
50	500,000	198.88	109.37	340	(+31.75)	260.4
100	1,000,000	397.76	220.93	680	(+61.31)	523.0

* Diffused Air - Direct drive blowers
Conversion 6350 BTU/BHp Hr

** Electrical Generation - Conversion 9200 BTU/Kwhr

*** Pilot Oil No. 2 Diesel = 140,000 BTU/gal gas produced at a plant treating 1 MGD of wastewater (serving 10,000 people) is not sufficient to meet all the energy requirements for a wastewater treatment plant. However, even at this plant size, sufficient digester gas is generated to drive the blowers required for aeration of the activated sludge system and to generate a considerable portion of the electrical energy requirements. The amount of energy available in the digester gas produced at a treatment plant with a capacity of 10 MGD or greater is sufficient to meet all the energy requirements of the municipal wastewater treatment plant. In fact, the amount of gas produced contains more energy than is required to drive the diffused air blowers and meet other electrical requirements. The amount of excess energy increases as the plant capacity increases. However, it should be pointed out that the energy available in the gas produced by anaerobic digestion of municipal wastewaters would provide only a small fraction of the energy used by most major metropolitan areas. However, this energy may be made available to the population in the immediate vicinity of the plant either as heat for space heating or as electricity during peak hours.

Therefore, although waste stabilization ponds provide a relatively low cost treatment alternative for pollution abatement in developing countries, the availability of land and the cost of land may increase the capital cost of waste stabilization ponds to such a level that other wastewater treatment systems are in fact more economical. In large urban areas, the activated sludge system will provide high efficiency treatment of the wastewater, and the sludges generated during treatment can be stabilized by anaerobic digestion and the gases produced can be recovered and utilized to meet the energy demands of the treatment plant.

Summary

Wastewater treatment is needed in developing countries due to numerous examples where raw sewage is diverted into streams or oceans, thus contaminating waters that could be used for human consumption, industrial needs, land irrigation, fish production, or recreation. Only a small percentage of the population in most developing countries is served by wastewater treatment facilities. The basic reasons for this situation include the high costs of certain wastewater treatment processes, the lack of availability of qualified personnel to operate and maintain sophisticated treatment processes, and the low priority generally assigned to wastewater treatment relative to other national needs.

This study consisted of a survey of published literature found in libraries at the University of Oklahoma, the University of Panama, and several libraries in the Washington, D.C. area (Pan American Health Organization Library, Library of Congress Library, U. S. Army Library, State Department Library, World Bank Library, and U. S. National Academy of Science Library). A total of 783 potential references were identified, with 408 being associated with 10 basic treatment processes, 236 with general water pollution control, and 139 with treatment methods other than the ten basic processes (primary treatment, waste stabilization ponds, conventional sludge treatment, advanced sludge treatment, Imhoff tanks, standard filtration, high rate filtration, activated sludge, extended aeration, and disinfection). The most-often cited treatment process was the waste stabilization pond, with references identified from 31 countries, accordingly, the primary focus of this paper is on waste stabilization ponds. Wastewater treatment comparisons

for ponds, aerated lagoons, and activated sludge treatment systems are presented for various size plants in terms of capital costs, land requirements, and energy considerations.

There are two basic reasons for the popularity of waste stabilization pond systems in developing countries. One reason is associated with low costs, particularly for smaller communities. Another is related to required climatic conditions for ponds. Since many developing countries are located in tropical areas with optimum climatic conditions for waste stabilization ponds, the usage of this treatment process has been great.

Waste stabilization pond operation depends upon the symbiotic relationship between bacterial degradation of organic matter and algal photosynthetic production of oxygen. Pond design can be based on either the application of engineering factors associated with successful pond usage, or the utilization of empirical design relationships. Information is presented which summarizes both engineering design factors as well as empirical design equations. Empirical relationships are also included for predicting effluent concentrations of various wastewater constituents.

The analysis of wastewater treatment costs for developing countries is primarily based upon information from India and Brazil. The wastewater treatment system which has the lowest total treatment cost (capital cost, land cost, and operation and maintenance cost) is dependent upon the population served, land requirements and land availability. In general, ponds represent the most attractive wastewater treatment methodology for communities of 10,000 persons or less in developing countries. For populations in excess of 100,000 persons, activated sludge treatment would probably be the system choice. For populations centers of greater than 100,000 persons, the necessary qualified labor force should exist for operating more-sophisticated treatment systems.

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APPENDIX I

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APPENDIX II

ALTERNATIVE DISPOSAL METHODS

A. Algae Removal by Fish Production

B. Dutch Ditch

C. Advanced Sewerless Treatment

D. Wastewater Reuse

A. ALGAE REMOVAL BY FISH PRODUCTION

There are few carefully collected and analyzed data available on using fish to purify sewage. On the other hand, there is an increasing awareness of the potential of sewage treatment by using this technique.

Emphasis for the use of fish as collecting devices in the tertiary lagoon has recently developed in the United States primarily because of Federal (EPA) effluent requirements of 30 parts per million suspended solids. This is the requirement that makes obsolete a great number of single pass lagoons being used in small cities and towns. The possibility of aquaculture to achieve effluent standard certainly is one solution to this problem.

Dr. LeRoy Carpenter and Mark Coleman at the Oklahoma State Health Department, and Michael Spear, University of Oklahoma conducted specific work on fish production in sewage lagoons.[1,2,3] Work in this area has been undertaken in field laboratories in Norman as well as in the Philippines and in the Cameroons.

The primary impetus in the global sense in developing countries, of course, is that of food production.[4] These two goals are not consistant. Fish culture is a highly developed technology and the rules of fish culture, greatest production of fish being the goal, simply are not the same as the rules directed towards removing the greatest amount of contaminants.[4] Unfortunately, one cannot optimize against both fish production and nutrient removal.

The sanitary engineering profession today is well aware of the permissible contamination levels and the devices used to remove and convert contaminants. The other disciplinary group represents fish culturing. Unfortunately, in surveying the literature, there is a serious gap in technological matching.

The classic or basic work is that of Professor B. Hoser at the University of Munich who studied the use of fish ponds as a mechanism for waste water disposal. Another way to look at it would be the reclamation of the nutrient elements contained in sewage through the intermediate activity of bacteria, plankton and other small aquatic organisms in the form of fish flesh. The ability of such a process, of course, was logical from the observation of the secession of life in the sewage polluted streams. The difficulties encountered were:

1. maintaining a sufficiently high oxygen concentration by keeping the sewage fresh and avoiding sludge deposit and destroying surface growths which would prevent the adsorption of oxygen from water;

2. elimination of toxic substances, and

3. the maintainance of biological balance that would yield adequate quantities of fish food.

As practiced in central Europe, the dillutions of two to five volumes of clean water were employed for settled sewage and the ponds were from 1 to 2 1/2 feet deep with a loading of 800 to 1,000 people per surface acre of pond; Imhoff had suggested 2.5 acres/2,000 P.E. or 800. The ponds were drained and cleaned during the winter when ice conditions and retarded aquatic life interfered with fish raising and this necessitated the disposal by other means at this time. In some instances, special hibernating basins were provided for the animal and plant pond life and the ponds were filled again in the spring. Ducks kept the ponds clear of undesirable weeds. One acre of pond was said to produce from 400 to 500 pounds of fish and from 200 to 250 pounds of duck meat. Similarly, Peace Corps ponds of 400 square feet in developing countries, are being used for family food. From Japanese studies of aqua-culture and fish culture[5] and others, the contention was that one could grow as much protein from water surface areas as one could from land surface areas. The potential production of algae appears to be 40 to 50 times that of terrestial crops and if it could be economically harvested it would be a tremendous breakthrough.

Primary production estimates, according to Odum, in K Cal/M^2/day is as follows:[7]

Algal Cultures	72
Sugar Cane	74
Water Hyacintles	30
Marine Meadows	20 - 150
GalvestonBay, Texas	80 - 230
Silver Springs, Florida	70
Sub-tropical blue water	3

Fish can be produced from 13,000 to 20,000 #/acre when fed (grain, etc.) 3% of body weight/day; when fed on pea green algae 3,000-5,000 #/acre production appears to be reasonable; and on sewage effluent around 300 to 1,000 #/acre. Therefore, in contrasting waste treatment benefits to those of intensive fish production, there is a 4-5 fold difference. In fact, the fish culturist would prefer not to get involved with sewage.[6] The productivity also depends also on what is being grown. For example the 20,000 #/acre were for Tilapia, whereas a comparable figure for catfish and carp would be 13,000 #/acre and bass 900 #/acre. The studies in Oklahoma with Tilapia reported an increase from 1,500 to 4,300 #/acre in 191 days, or 2,800 #/acre. Similarly, catfish increased from 600 to 4,400 #/acre, shinners from 85 to 536 #/acre in a four month period.[2,3] These appear to be representative numbers of production when waste disposal is the primary objective, or about 12-18 #/day/acre for a 4-6 month period.

The trick is to select the most suitable vehicle, fish in this instance, but vascular Aquatic Plants including water hyacinth are also candidates for mineral nutrient removal.[8,9] Rush ponds in Holland are about 1/3 as expensive as activated sludge, 30 guilder/P.E., for example. The hyacinth production can be used for Ruminant feed, or for methane production. The fish can be used for animal feed, particularly domestic, fertilizer, etc. It is estimated in Oklahoma that the net income from fish is about 2 1/2¢/1,000 gallons of sewage treated.[2]

There are problems, not the least of which is health. The Europeans recommend that sewage grown fish be removed to fresh water for 2-3 weeks prior to sale.

Salmonella, Palivirouses, Coxsackie viruses, shigella, vikrio choleral, Enteropothogenic Viral hepatitits, have all been implicated in fish and shell fish.[10,11] In Southeast Asia, farmers growing fish on sewage sell them and buy other fish for home consumption. There is also the question of the possible undesirable spread to natural waters of Cichlids. Finally, if fish production is the goal, one still has an effluent to be dispersed.[12]

There are design and operational problems and to some extent legal problems. There will be toxic conditions, from ammonia, sulfides, pH, insufficient nocturnal D.O., water temperature (55°F. for Tilapia for example). But the results are impressive, using the data from Coleman et al,[2] Oklahoma City cultured successfully such species carp, gold fish, fathead minnow, golden shinner, black bull head, channel catfish, mosquito fish, bluegill, green sunfish, largemouth bass and Tilapia nilotrica. The Quail Creek (Oklahoma City) Sewage Plant consists of a six cell series lagoon, with a Hinde Air-Aqua in the first two cells, each cell six acres and five feet deep. The mean values, of weekly analyses, from June to October with catfish in the third and fourth cells, golden shinners in the fifth and sixth cells, and fathead minnow and Tilapia in the third cell were an overall BOD_5 removal of 97%. The individual cell removals were from influent to effluent - 75, 49, 49, 18, 36, 34 (percentages). Suspended solids similarly had an overall removal of 94% with an effluent concentration of 12 mg/l. The nitrogen to phosphorous ration started at 2/1 and was about 1/1 in the effluent lagoons. Today the input ration of N/P is well below the combining ratio, and as such Nitrogen is fixed from the atmosphere, indicate a potential biomass effluent in excess of the influent. Fecal Coli went from 3×10^6 to 2×10^1. The ammonia concentration went from 12 to 1 mg/l through cell one. Spear was not so successful using Buffalo fish under wintertime conditions.[3] Similarity Daphnia studies in Texas reduced BOD_5 from 57.5 to 11.8 or 79%, and VSS from 78.4 to 13 or 83%.[13]

So, there is a question about selection of fish and their food niche, what combination of fish are best, Bass/Tilapia, Salmon/Amphid, or Tilapia/Bass/Crayfish. Or what species of Tilapia - Nile, Java, etc. or whether to breed or fatten, use fish or fingerlings. There are questions of maintaining 3 ppm D.O., sprays such as the air-o-lator, upwelling, dilution, and the Hinde Air-Aqua all of which have been used. Narrow sluices seem to be best. The fish, so far, have been used on single pass lagoons. The question remains "Is this the best configuration or would new concepts involving " 'race ways' and higher density of fish be more suitable?"

Also it should be mentioned, there are legal restrictions on transporting fish from state to state and country to country as well as purely economic considerations of the various fish markets. So one must begin to look at both macro and micro models of fish pollution reduction technology: finding its detailed parameters and then its relative position in the larger ecosystem. It's effectiveness must be looked at separately and in conjunction with other processes, such as long term storage in Hungary,[15] a combination of lagoons and trickling filter [16] as in Ohio, or looking at such systems in relationship to other aquaculture and agricultural systems as in Israel.[17] Frankel and Phan at AIT, Thailand have attempted such a model.[18]

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B. DUTCH DITCH

The development of the device called the dutch ditch or the pasveer ditch is essentially a brush type aerator applied to extended aeration which has been covered under the general classification of aerated lagoons or oxidation ponds. This device was developed in Holland and used in the former colonies of Holland. There is very little published on its use but there is evidence of it having been used in Indonesia and in the Antilies; Dutch Antilies. The unit is well adaptable to small communities and particularly those in which it is desired not to provide too large a lagoon depth.

On the other hand the aerator unit which is manufactured in Europe or in the United States is a very expensive thing and costs from three to four times as much as the floating conventional pumping aerators. Thailand has been manufacturing aerator-rotors at approximatley a tenth of the cost of the European and American units. This is an excellent example of transferring appropriate technology to developing countries. One of the things that has been done to overcome this inordinate expense has been the revision of the device by Pasveer at the NTO in Delft of the new device called the carousel in which the ditch performance concept is used but at one end of the ditch is incorporated a deeper sump as it were and instead of the brush aerator there is a conventional mechanical floating aerator. In so far as is known, these are not being used in developing countries. There are other modifications of the dutch ditch, one called the Inka and there is some evidence that this has been used in India and in the Far East as indicated in the published works of Mr. Arsevela, METU University, Ankara, Turkey.

C. ADVANCED SEWERLESS TREATMENT

At the present time on-site sewage treatment technology primarily utilizes septic tank (or anerobic) treatment of household wastewater. Because of the availability of septic systems, their proven acceptance, and the public financing of such systems, this type of treatment is widespread. Introduction of septic tanks by public health educators and sanitarians is common whenever public water supplies are extended, especially in areas where central collection is impractical or infeasible.

Advanced methods of sewerless treatment have been classified into five categories: incinerating toilets, biological toilets, composting toilets, vacuum systems, and aerobic tanks. A sixth category, the oil flush toilets, also seems applicable with the increased application of them in remote areas. An ever expanding list of manufacturers are supplying and promoting units in these categories. The attached list details a number of the presently available systems.

A major concern which has been expressed about sewerless treatment is the energy requirement. Units within any of the six categories have varying energy requirements dependent on the climate, their capacity, and specific treatment process. The composting variety can be operated without electricity in some instances. No statistics are available which compare the energy requirements of conventional collection and advance treatment systems to an equal number of sewerless units.

The major advantage in sewerless systems, with the exception of the aerobic tanks, is the decrease in water consumption. By U.S. standards this would equal approximately 40% of domestic use. Some other advantages and characteristics are:

1. Composting toilets produce a humus product suitable for fertilizer.

2. Incinerating toilets destroy the waste material leaving only an inert ash residue.

3. Most of the systems can be installed in existing dwellings.

4. Two of the composting toilets require two story structures.

All sewerless toilets, again with the exception of the aerobic tanks, need a gray water disposal system. Gray water is the discharge water from the bath, kitchen, and laundry which usually contains soaps, fats, and virus from the skin and clothes. Attached is the start of a continuing bibliography maintained at the University of Oklahoma on sewerless toilets and related areas.

Category	Name	Country	USA $ Price: 0 - 100	USA $ Price: 100-500	USA $ Price: 500-1000	USA $ Price: Over 1000	Requirements: Water	Requirements: Power	Requirements: Chemicals
Incinerating	Destroilet	USA			*			*	
	Ecett	Sweden			*			*	
	Electro Standard	Sweden			*			*	
	Elonette	Sweden		*				*	
	Incinolet	USA						*	
	Toarett	Sweden		*				*	
	Xpurgator	USA				*		*	
Biological	Cycle-let	USA					*	*	*
	Bio-Flo	USA							*
	Jet Flush	UK		*				*	*
	Monomatic	USA		*				*	*
	Potpourri	Canada	*						*
	Craft Toilet	USA		*				*	*
Composting	Clivus Maltrum	Sweden				*			
	(Same Name)	(USA)				*			
	Mull-Toa	Norway		*				*	
	(Biu-Let)	(USA)						*	
	Saniterm	Sweden			*			*	
	Toathrone	USA			*				
	Farallones Privy	USA	*						
	Multrum	Denmark	*						
	Kern Compost Privy	USA		*					
	Mulbank	Sweden		*				*	
	(Ecolet)	(USA)			*			*	
	Humumat	Canada						*	
	Kombio	Norway			*				
	Mull-Toa Jumbo	Norway			*			*	
	KPS Miljoklosett	Norway		*				*	
	Tropic	Norway		*				*	
Vacuum	Vacu-Flush	USA			*			*	
	Electrolux Vacuum Sewage System	Sweden				*		*	
	Airvac	USA						*	
	Envirovac	USA			*			*	
	Vacu-Flush	USA						*	
	Lectra/San	USA						*	
Oil Base	Magic Flush	USA				*		*	
	Aqua Sans	USA				*		*	
	Sarmax	USA						*	

Category	Name	Country	USA $ Price				Requirements		
			0 - 100	100-500	500-1000	Over 1000	Water	Power	Chemicals
Aerobic	Digestomatic	USA					*	*	
	Aerobic Home System	USA					*	*	*
	Sewerless Toilet	USA				*	*	*	
	Waste Tamer	USA					*	*	
	Microx	USA					*	*	
	Cromaglass	USA			*		*	*	
	Flo-Thru	USA				*	*	*	
	Bio Disc	Canada				*	*	*	
	Aquarobic	Canada				*	*	*	

SEWERLESS TREATMENT

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D. WASTEWATER REUSE

Reuse of water that has already served some purpose and has been discharged to waste is one way to extend the utility of the available supply of fresh water for municipal, industrial, and agricultural use. Figure 1 illustrates an overview of water reuse. Figure 2 indicates specific reuse sectors for consideration in overall reuse planning. The wastewater may be reclaimed and made of suitable quality for reuse by several approaches (See Table 1). This potential as a means of conserving available water resources, has been recognized for some time. The Senate Select (Kerr) Committee on National Water Resources,*1/ summarized this potential based on a review of several thousand technical papers and abstracts, and reclamation methods then known. It stated that "the speed with which reuse comes into play will continue to be a result of market-place pricing, in which new developments will have their impact," and called for greater emphasis on research in water reuse.

Reuse of wastewater has been an accomplished fact in other countries such as Switzerland where the practice has been followed for many years, while the water economy of Israel relies heavily on water reclamation. Notable technical contributions have been made by investigators in these and other countries.

Regardless of its acceptance or non-acceptance for potable water supply, reused wastewater has enormous potential for increasing the water resources of individual localities and in developing countries as well as in developed countries. When it is realized that reuse of 80 percent of the wastewater discharged by a community would result in an effective increase in usable water resources by 400 percent, the magnitude of the potential

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FIGURE 1

WATER REUSE OVERVIEW

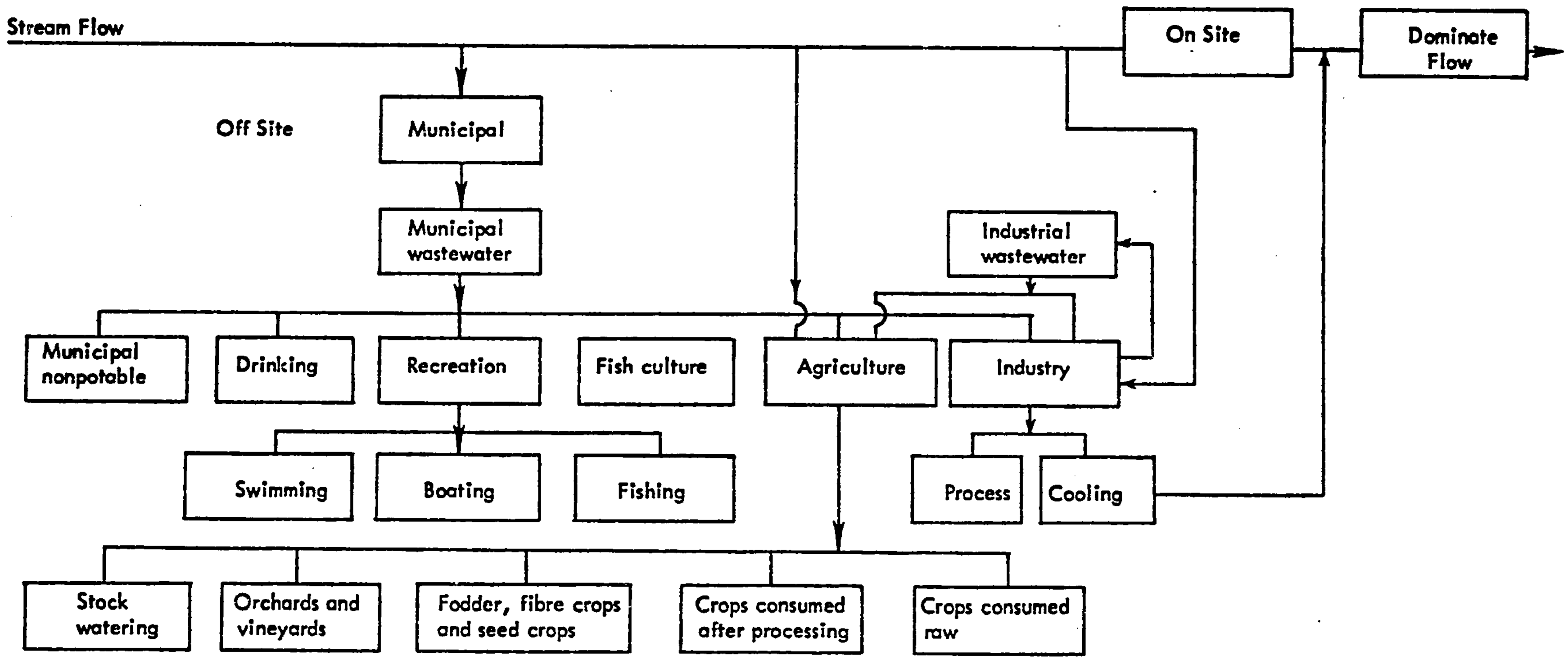
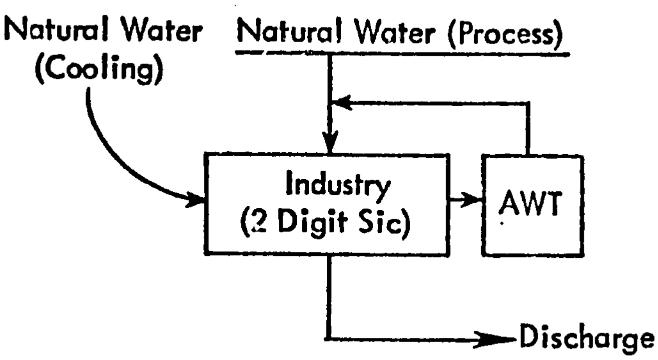


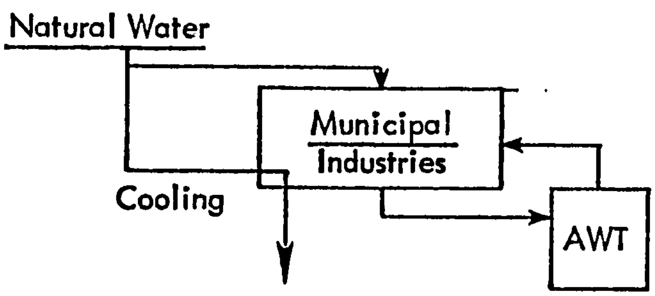
FIGURE 2

SPECIFIC REUSE SECTORS

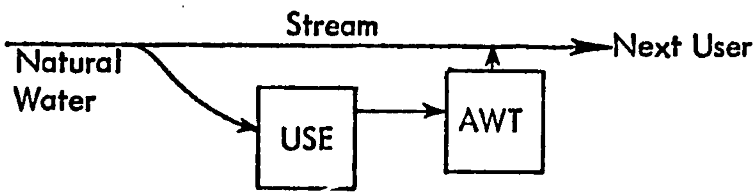
A. Localized Recycle (Industrial)



B. Local Aggregate Reuse



C. Integrated Stream



D. Sequential Use

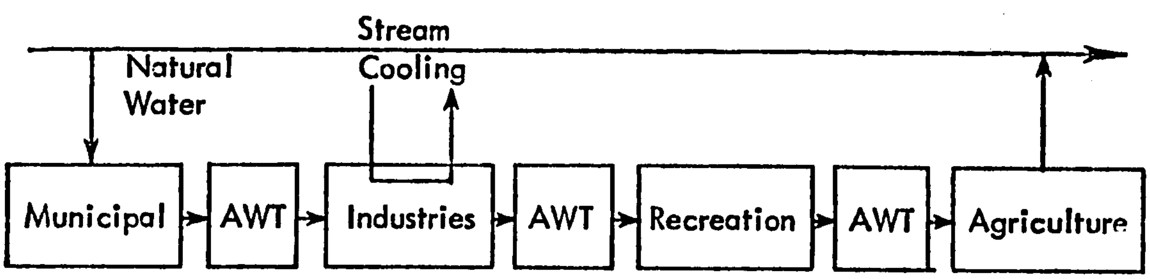


TABLE 1

REUSE PROCESS SELECTION

	Process	Goal (Pollutants Removal)	Effluent Reuse
Primary and Secondary Treatment	Facultative Pond	Solids, Nutrients, BOD	
	Aerated Lagoon	Solids, Nutrients BOD	
	Clarification	Solids, Biomass	
	Disinfection	Bacteria, Virus, COD/TOC	Industrial Irrigation
Tertiary Treatment	Filtration	Suspended and Colloidal Solids	Industrial Irrigation
	Soil Treatment	Virus, Nutrients, Specifications	Recreation
	Physio-chemical Process Activated Carbon Distillation, Foam, Freezing, Electrodialysis, Ion Exchange, Reverse Osmosis,	Virus and TOC, TDS	Potable
	Disinfection Chlorine, Bromine, Ozone, UV	COD/TOC, Virus Bacteria	Potable

becomes strikingly clear. Present technology is able to produce water of chemical quality equivalent to that of drinking water at a lower cost than from desalination of sea water. Its cost is still higher than the cost of natural water in most localities, but the cost differential will narrow and could reverse itself in coming years.

Further research leading to the establishment of attainable standards of chemical and virological safety will promote acceptance of reclaimed wastewater for potable supply in the future. Creation of recreational lakes and recharge of groundwater supplies are other uses for properly treated wastewater, but the largest available consumer for reclaimed wastewater is industry. Replacement of natural water by reclaimed water in industry will release large amounts of water for other uses. Thus, wastewater reuse can increase water resources greatly without concern for safety.

At the same time, application of advanced treatment processes to wastewater intended for discharge to receiving streams can, by reducing pollution, protect existing water supplies, and make current resources available for other use by not using the capacities of streams for self-purification.

However capable today's advanced treatment processes are, they are sure to improve in the future as the results of continued research and development are applied. This will lead to reduction in cost and to decreased complexity in advanced treatment plants. Advanced treatment will become more attractive as a means of augmenting water resources as a result. The remainder of this section discusses: (1) Wastewater Characteristics, Reclamation and Reuse; (2) Reclamation Processes and Efficiencies; (3) Quality Criteria; and (4) Grey Water. Also attached is a basic bibliography developed for this study.

Wastewater Characteristics, Reclamation, and Reuse

Wastewater characteristics may be divided into three major categories, physical, chemical, and biological. For example, color, odor, temperature, and turbidity are considered to be physical parameters. Inorganic and organic chemical compounds are chemical parameters. Microorganisms, including viruses, are the biological factors. Except for temperature, physical characteristics such as color, odor, and turbidity, are caused by certain inorganic or organic compounds. These wastewater characteristics are considered important when they are disposed of into the environment and/or reclaimed for reuse. They primarily affect public health, and secondarily affect public welfare, while influencing environmental quality.

Reuse of wastewaters for potable purposes faces many threats:

1. Fail-safe technology. A breakdown in water treatment may serve to carry hazardous chemicals, microorganisms and viruses to the consumers.

2. Hundreds of new chemical compounds are being introduced into our environment daily. The potential for ingestion increases significantly when wastewater is reused. Some of the chemicals, either alone or with others, have been shown to cause cancer, genetic damage, or birth malformations. The subacute effects of such chemicals ingested in low concentrations over long periods are difficult to estimate.

3. Virus threats, particularly those of infectious hepatitis, is uncertain. Only a few virus particles need be ingested for infection to result.

The design of the treatment system that provides time and travel distance without short-circuiting are important factors in fail-safe wastewater reclamation. It allows time and opportunity to monitor and selectively divert waters that have failed to respond to treatment. Provision of dynamic flexibility of the treatment processes is as important as the aforementioned factor when considering today's technology limitations. Available technology may not be able to handle newly introduced chemical compounds or "mutant" microorganisms and/or to meet higher water quality standards. The potential for phasing in new technology must be seriously considered. The particular blend or array of contaminants will differ with different base functions and sizes.

Reclamation Processes and Efficiencies

Viruses that have been isolated from wastewater are Adenovirus, Coxsackievirus, Echovirus, Poliovirus and Reovirus. Virus removal in water or wastewater treatment is dependent upon the type of treatment process utilized. Certain processes are more effective in virus removal than other processes, as will be discussed below. Very precise measurements of treatment efficiency in virus removal are not possible now because we are not able to efficiently concentrate small numbers of viruses from large volumes of water, nor are we able to identify the possible viruses that may exist. The development of efficient technology for detecting viruses and identifying those viruses has been, and continues to be, a central need in water pollution research. Organizations such as the U.S. Army and the Los Angeles County Sanitation Research Unit have developed methods for viral concentration.

Heavy metals and many synthetic chemical compounds are being classified as toxic chemicals to the water users or receiving environment. Generally, the largest single source of heavy metals and synthetic compounds is industrial waste flows. There are numerous treatment processes available to remove individual elements within these general categories. However, currently it appears that the single most effective treatment process for the removal of all wastewater pollutants, including toxic chemicals, is reverse osmosis. It has been suggested that reverse osmosis can effectively remove large organic molecules and poly-di- and mono-valent ions. Activated carbon adsorption, and ion exchange, chemical precipitation, electro-chemical plating are also considered to be effective methods for removing heavy metals and toxic chemicals. However, all of these listed methods require pretreatment to remove suspended solids and organic compounds that interfere with the process efficiency. Unit processes capable of removing heavy metals and synthetic compounds are significant to the wastewater reclamation and reuse system. It is important also to provide for identification of trace organics and heavy metals. At present the best methods are TOC and PIXE (Proton Activation Analyses) analyses.

A detailed symposia and publication (1973) by the American Institute of Chemical Engineers, on water reuse points up much of the treatment problems associated with reuse technology (21). A great deal of interest was at that time called "Water Reclamation by Tertiary Treatment Methods" and referred to as Advanced Waste

Treatment (AWT). A series of studies was made on the various treatment technologies by EPA (24). One of the more significant studies out of this was Print #17 authored by Louis Koenig and relating to the market projections for AWT and in a sense asking somewhat the same questions that are being asked of the current research (24). Piper looked at the deficiencies in terms of water quality requirements in stream water quality requirements (2). Other studies of that time (1969) included the University of Arizona's, "Water Reclamation by Tertiary Treatment Methods" series of reports (23). In 1973 the World Health Organization, technical report series #517 presented collective views on the reuse of water and methods of wastewater treatment and health safeguards (22). Reuse may be characterized as direct and indirect. Indirect reuse, occurs where water used for domestic or industrial purposes is discharging into the fresh water supply. Direct reuse would be the planned and deliberate use of treated wastes for some beneficial purposes e.g., in-plant recycling of sequential uses.

Data studied shows that from 3 1/2 to 18% of the water in low flow periods is indirectly reused or having to pass through domestic systems. If the volume of industrial affluents is also taken into account it would also be expected that some 20 to 40% of river water in some areas will be reused. Intentional reuse in agriculture, is an old and very common practice. In industry, most of the reuse has been by recycling, and municipal wastewater treatment effluents have been used as cooling water in industries (21). The reuse of water for recreation is common. The direct potable reuse is being practiced in a few places, such as Chanute, Kansas, and Windhoek. There are some very serious problems involved in this and those relate to a lack of adequate tests to assure safety of the water particularly from the standpoint of viruses, organic compounds and metallic ions. Therefore deliberate reuse on the municipal level, may have to wait for better technologies. Table 1 suggests treatment processes to meet the given health criteria for water reuse which illustrates some of the problems involved. Attachment A lists a special bibliography by the project team on this extensive literature.

The treatment of water for reuse depends upon a great many factors. It could be divided into conventional and advanced waste treatment technologies, the principal investigator has explored conventional processes such as sewage farming, primary and secondary treatment in Oklahoma and with others has looked at the growing of fish in ponds and vascular plants for purposes of reuse and pollution control. Advanced waste treatment processes involve the removal of phosphates and dissolved solids, nitrates and some clarification processes and such processes, particularly as ion exchange, electrolytes, distillation, reversed osmosis, to name a few. There is also a problem involving disinfection. Most of these processes are pretty well understood as applied in various industries.

Quality Criteria

It is necessary to know the cost-effectiveness of the various processes involved in reclamation technologies, but it is also necessary to know acceptable quality levels for different categorical uses. Work was done at the University of Oklahoma establishing water quality criteria for the State of Oklahoma which explicitly sets out the raw water quality requirements for every category of water application (24).

Many other studies have been developed since this, that provide information on quality and many of which have become legal documents. These include waste discharge standards, in-stream water quality standards, on drinking water quality standards developed by EPA now or to be developed, and recreation and irrigation waters standards. There is wide variation in the practice of setting toxic limits and some are guides rather than absolute limits. Most of the more exotic toxin substances are set up as guidelines taken from Water Quality Criteria, California State Water Resources Control Board, 1973, the NAS Blue Book and the EPA Criteria Red Book. It is also necessary to understand the water quality conditions of the streams and the availability of the quality of the flow; many studies of this type have been conducted by the University of Oklahoma as well as many others.

Grey Water

Environmentalists have questioned the wisdom of massive sewer projects-others question the viability of nationally supported sewering programs which many small communities cannot afford-and progressive architects and engineers begin to seek tools to manage wastewaters in smaller volumes. It is also of interest to reduce volumes of waters used to transport wastes, and to keep wastes separated in efforts to simplify their respective treatments.

As black waters and grey waters respond differently to treatment, it could be feasible to use the "waterless toilet" in relation to separate grey water treatment and thereby to achieve more efficient treatment and recycling of wastes.

Gray water, or wash water as it is commonly called, is discharged water from household sinks, baths, and washers. It contains grease or fats from cooking, soaps and detergents from cleaning, and viruses which have been washed from clothing and skin. Waste from food grinders of garbage disposals is not included in the classification due to their organic composition. Gray water and sewage are usually combined in the domestic effluent discharged to conventional water-carriage systems. In rural areas with septic systems gray water is sometimes discharged to the surface due to social customs and/or septic tank limitations.

Since most sewerless systems treat only sewage an alternate method of disposal is needed for gray water. Four or five ways of handling the water are potentially sound. Test results from gray water systems seems to be unavailable because the treatment of it separately from sewage is such a new concept. Gray water shows great potentiality for recycling, thus further reducing water demand. There is only one pertinent reference that discusses grey water in detail. This is the Manual of Grey Water Treatment Practice edited by John A. Wineberger in 1976.

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