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APPROPRIATE TECHNOLOGY FOR SEWAGE POLLUTION CONTROL IN THE WIDER CARIBBEAN REGION

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CARIBBEAN ENVIRONMENT PROGRAMME

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Appropriate Technology for Sewage Pollution Control in the Wider Caribbean Region

TABLE OF CONTENTS

Title *Page No.*

LIST OF TABLES

LIST OF FIGURES

Appendices

A. Tables 9 to 12 of CEP Technical Report No. 33;
Distribution of Caribbean Pollution Sources

B. Water Quality Standards from the U.S. and Other Countries

C. Abstracts on Selected Works From Literature Review

D. Fact Sheets on Specific Sewage Pollution Control Technologies

Collection Systems
Fact Sheet C1—Conventional Sewers
Fact Sheet C2—Pressure Sewers
Fact Sheet C3—Vacuum Sewers
Fact Sheet C4—Small-Diameter Gravity Sewers

Domestic Wastewater Treatment
Fact Sheet D1—Septic Tank Systems
Fact Sheet D2—Holding Tank
Fact Sheet D3—Household Systems
Fact Sheet D4—Lagoons (Stabilisation Ponds)
Fact Sheet D5—Constructed Wetlands
Fact Sheet D6—Land Treatment
Fact Sheet D7—Sand Filtration
Fact Sheet D8—Preliminary Treatment
Fact Sheet D9—Primary Treatment
Fact Sheet D10—Secondary Treatment
Fact Sheet D11—Biological Nutrient Removal
Fact Sheet D12—Disinfection
Fact Sheet D13—Effluent Disposal

Industrial Wastewater Treatment
Fact Sheet I1—Oil-Water Separation
Fact Sheet I2—Coagulation/Precipitation
Fact Sheet I3—Air Stripping
Fact Sheet I4—Biological Treatment of Industrial Waste
Fact Sheet I5—Suspended Solids Removal
Fact Sheet I6—Activated Carbon Adsorption
Fact Sheet I7—Demineralisation
Fact Sheet I8—Chemical Oxidation

Solids Treatment and Disposal
Fact Sheet S1—Sludge Thickening
Fact Sheet S2—Sludge Stabilization
Fact Sheet S3—Sludge Dewatering
Fact Sheet S4—Cold Digestion / Drying Lagoons

E. Experts Meeting Invitees and Participants

CHAPTER 1.
INTRODUCTION

BACKGROUND

Under the Cartagena Convention the Governments of the Wider Caribbean Region (WCR) are developing a *Protocol on Marine Pollution from Land-based Sources and Activities* (the LBSMP Protocol.) The LBSMP Protocol will have source-specific annexes, through which measures will be taken to address priority pollutants. A regional inventory from the 1994 "Regional Overview of Land-based Sources of Pollution in the Wider Caribbean Region," CEP Technical Report No. 33 (UNEP, 1994) identifies domestic and industrial sewage as the priority source of marine pollution in the Caribbean Region. The Governments in the region have decided that the first two annexes will address domestic wastewater and agricultural non-point sources of pollution.

This report is part of an effort to assist the Governments in developing the annex on domestic wastewater. The purpose of the annex is to identify the most appropriate wastewater treatment technologies and water quality standards for the Wider Caribbean Region (WCR).

The United Nations Environment Programme (UNEP) has developed a draft protocol (*Protocol to the Cartagena Convention*) to reduce marine pollution in the Caribbean Sea from land-based activities. All contracting parties to the Draft Protocol commit to take steps to help reduce marine pollution. The *Regional Overview of Land-Based Sources of Pollution in the Wider Caribbean Region*, *CEP Technical Report No. 33*, identifies domestic and industrial sewage as priority sources of pollution (UNEP, 1994). This report is part of an effort by the UNEP Caribbean Regional Co-ordinating Unit (CAR/RCU) to address or identify the most appropriate wastewater treatment technologies and water quality standards for the Wider Caribbean Region (WCR).

The following excerpts from Article III of the Draft Protocol explain some of the general obligations defined:

> Each Contracting Party shall develop and implement appropriate national plans, programmes, and measures. In such plans, programmes, and measures, Contracting Parties shall adopt the most effective means of preventing, reducing or controlling pollution from land-based sources and activities on their territory, including the use of best available technology.
>
> In its national plans, programmes and measures, each Contracting Party shall specifically include effluent and water quality standards taking into account available national, regional, or global standards and recommended practices and procedures adapted to national circumstances.

Article I of the Draft Protocol defines "best available technology" as follows:

> The best of currently available techniques, practices, or methods of operation, including cleaner production, appropriate to the social, economic, technological, institutional, financial, cultural and environmental conditions of the Contracting Party or Parties ensuring the effective prevention, reduction and control of pollution.

In this report the term "appropriate technology" is considered to be synonymous with this definition of "best available technology" from the Draft Protocol.

SCOPE OF CONTRACT

KCM, Inc. was contracted to prepare a report for the UNEP Caribbean Regional Co-ordinating Unit (CAR/RCU) outlining appropriate pollution control technologies for domestic and industrial sewage, both rural and urban, in the WCR. Preparation of the report included the following tasks:

- A list was prepared of experts in wastewater treatment for the WCR who could help KCM identify relevant literature, assist with site visits, and give critical comment on the draft report.
- A review was conducted of literature addressing control of urban and rural sources of domestic and industrial sewage pollution. Based on the literature reviewed, technologies appropriate for all sub-regions of the WCR were evaluated, with an emphasis on low-technology solutions.
- Site visits to the WCR were made to inspect innovative, low-cost, low-technology controls for domestic sewage pollution.
- A draft report was prepared describing the most appropriate technologies to control marine pollution caused by domestic and industrial sewage from both urban and rural sources. Technologies described in the report target pollutants such as biochemical oxygen demand (BOD), total suspended solids (TSS), oil and grease, nutrients (nitrogen and phosphorus) and toxics. Appropriate treatment alternatives have been evaluated and described in terms of practicality, capacity, ease and cost of construction, ease and cost of ongoing maintenance, environmental effectiveness, relationship to existing technologies and practices, potential for cultural and community acceptance, and other factors relevant to application in the WCR. The report includes recommendations for appropriate effluent limitations and technologies to meet those limitations.
- The draft report was submitted for review to a panel of experts selected by UNEP from the list of contacts and discussed at a workshop. This final report has been prepared based on comments from the workshop meeting.

REPORT PLAN

The goals for this document are as follows:

- To identify the most appropriate technologies for domestic and industrial sewage pollution control in the WCR. Domestic sewage or wastewater is considered in this report to be the liquid waste produced by households, schools, hotels, and small commercial establishments commonly combined in town or city sanitary drainage systems. Industrial sewage is considered to be liquid waste from manufacturing plants for a variety of industrial products.

- To describe expected treatment limits for these technologies, which can help government officials develop water quality guidelines.
- To develop a reference list of relevant information that is not covered in the report or is beyond its scope.

This document is not intended to stand alone as a design manual, textbook, or reference book. It has been prepared for use by government agencies, government regulatory officials and consultants in the WCR, to help them make preliminary decisions about appropriate wastewater treatment technologies based on community size, location, hydrogeologic conditions, and other factors. Key elements include the following:

- "Decision trees" to be used in identifying appropriate pollution control technologies—Decision trees present a sequence of questions about the scenario for which pollution control is being evaluated. Each new question to be answered is determined by the answer to the preceding question. The result of the decision-tree process is identification of the treatment or disposal technologies that merit further evaluation for the scenario under review. The decision tree is a general guideline taking into account the most important criteria. Other important issues, such as social acceptance, planning, and management, are not included in the decision tree, although they are discussed separately in the report.
- Fact sheets summarising key features of each technology—The fact sheets include design criteria, expected efficiency, references for more information, a list of facilities using the technology in the WCR, and, in some cases, diagrams showing how the technology works. The references provide the information needed for a thorough evaluation of each technology and selection of the most appropriate technology. The appropriate technologies are the "recommended practices and procedures adapted to national circumstances" called for in the Draft Protocol.
- Expected treatment efficiencies for each control technology—The efficiencies are shown to give an indication of effluent discharge standards that should be achievable by the given technology when adequately designed and operated. This document has not investigated receiving water quality requirements. It is intended to support the process of standard setting by identifying the potential for sewage pollution control by different technologies, but it was not prepared to recommend specific water quality standards for the WCR.
- A review of papers, textbooks, and manuals that can be used to obtain more detailed information—The organisation of the literature review parallels that of the report, so that the reader can look up the references used in this report by topic, as well as by author.

ACKNOWLEDGEMENTS

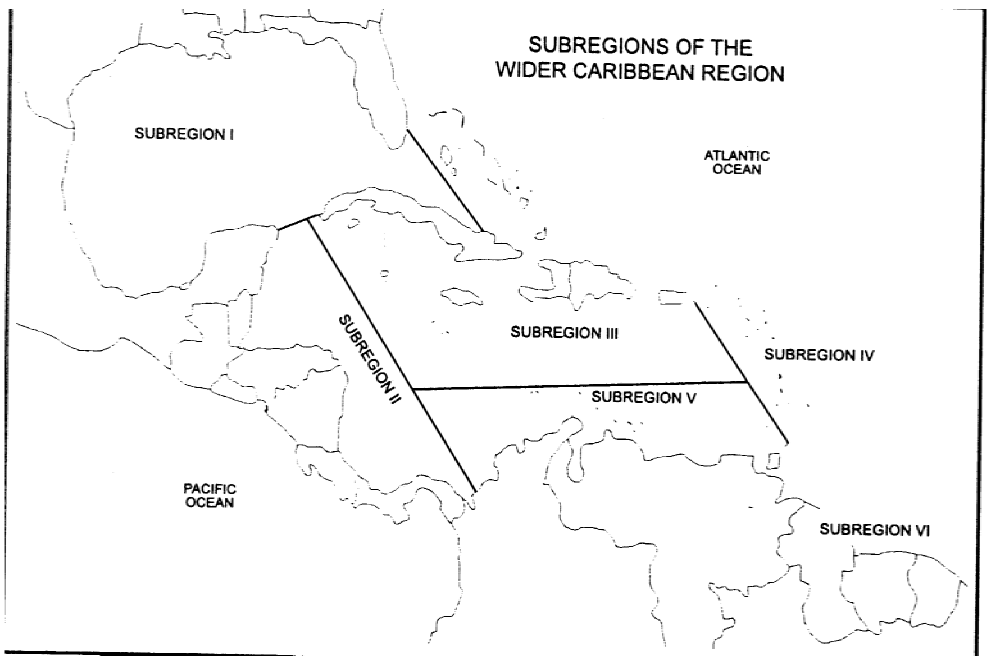
The principal authors of this report were Andre Gharagozian and Randal Samstag of KCM, Inc. Technical editing and graphics for the report were provided by Dan Portman of KCM, Inc. The authors express their appreciation for management advice and thoughtful review comments from the manager for the UNEP-CAR/RCU for the project, Kjell Grip. Tim Kasten of the United States Environmental Protection Agency also reviewed draft versions of the report and gave insightful comments. Mary Beth Corrigan of Tetra Tech, Inc. in Fairfax, Virginia provided management assistance above and beyond the responsibilities of her role as project manager and principal contractor to the UNEP-CAR/RCU for the work. Members of the experts panel that reviewed the report and whose names are listed in Appendix E provided important comment and review. Their assistance and advice has been sincerely appreciated. Special appreciation is due to the Caribbean Environmental Health Institute (CEHI) and its director, Vincent Sweeney, for graciously hosting the Experts Meeting held as part of the work.

CHAPTER 2.
BACKGROUND

GEOGRAPHIC DEFINITION OF WIDER CARIBBEAN REGION

For the purpose of this report, the Wider Caribbean Region includes states and territories within the Caribbean region as defined by the Cartagena Convention.

The WCR is divided into six sub-regions for further reference, as described in the map and list below (UNEP 1994):



- **I. Gulf of Mexico**—Cuba, Mexico, and United States (Texas, Louisiana, Mississippi, Alabama, and Florida)
- **II. Western Caribbean**—Belize, Costa Rica, Guatemala, Honduras, Mexico, Nicaragua, and Panama
- **III. North-eastern and Central Caribbean**—Bahamas, Cayman Islands, Cuba, Dominican Republic, Haiti, Jamaica, Puerto Rico, and Turks and Caicos Islands
- **IV. Eastern Caribbean**—Anguilla, Antigua and Barbuda, Barbados, British Virgin Islands, Dominica, Grenada, Guadaloupe, Martinique, Montserrat, St. Maarten, St. Lucia, St. Kitts and Nevis, St. Vincent and the Grenadines, and the U.S. Virgin Islands
- **V. Southern Caribbean**—Colombia, Netherlands Antilles, Trinidad and Tobago, and Venezuela
- **VI. Equatorial Atlantic North West**—French Guyana, Guyana, and Surinam.

WASTEWATER COMPOSITION

Domestic sewage is a significant contributor to marine pollution in the WCR. Domestic sewage originates mostly from households, public facilities, and businesses. For wastes from communities where most homes and businesses have piped water, typical pollutant composition of domestic sewage is as follows:

Total Suspended Solids (TSS)	200-300 mg/L
5-day Biochemical Oxidation Demand (BOD)	200-250 mg/L
Chemical Oxidation Demand (COD)	350-450 mg/L
Total Nitrogen as N	25-60 mg/L
Total Phosphorus as P	5-10 mg/L
Oil and Grease	80-120 mg/L

In unsewered areas, septic tanks are common. Septic tanks accumulate solids known as septage, which must be removed every few years to ensure effective operation of the system. Typical pollutant composition of septage taken to wastewater treatment facilities is as follows:

TSS	10,000-25,000 mg/L
5-day BOD	3,000-5,000 mg/L
COD	25,000-40,000 mg/L
Total Nitrogen as N	200-700 mg/L
Total Phosphorus as P	100-300 mg/L
Oil and Grease	2500-7500 mg/L

Industrial wastewater has a wide range of pollutant concentrations. Oil refinery wastewater produces 70 percent of the entire BOD load in the Caribbean. These wastes are high in BOD, dissolved salts, odour, phenol, and sulphur compounds. Food processing industries, distilleries, and soft drink industries produce about 5 percent of the BOD load in the Caribbean. They are characterised by very high BOD concentration, suspended solids, dissolved solids, variable pH, and a high level of organic matter. Chemical industries produce about 1 percent of the entire BOD load in the WCR. Even though they have low BOD strength, wastewater from chemical industries is important because it is frequently toxic to aquatic organisms at very low concentrations. This toxicity may actually mask assessment of BOD for these wastes by killing the BOD test organisms. Pesticides and insecticides used for agriculture are the primary chemical wastes in the Caribbean. These wastes are high in organic matter and are toxic to bacteria and fish.

Table 2-1 shows typical pollutant characteristics from common industries in the WCR.

TABLE 2-1.
TYPICAL INDUSTRIAL WASTEWATER POLLUTANT CHARACTERISTICS

Industry	BOD Concentration (mg/L)	TSS Concentration (mg/L)	Oil & Grease Concentration (mg/L)	Metals Present	Volatile Compounds Present	Refractory Organics Concentration (mg/L)
Oil Refinery	100 to 300	100 to 250	200 to 3,000	Arsenic, Iron	Sulphides	Phenols 0 to 270
Tanneries	1000-3000	4000-6000	50-850	Chromium 300-1000	Sulphides Ammonia 100-200	
Bottling Plant	200 to 6,000	0 to 3,500				
Distillery, Molasses, or Sugar Factory	600 to 32,000	200 to 30,000			Ammonia 5 to 400	
Food Processing	100 to 7,000	30 to 7,000				
Paper Factory	250 to 15,000	500 to 100,000		Selenium, Zinc		Phenols 0 to 800
Chemical Plant	500 to 20,000	1,000 to 170,000	0 to 2,000	Arsenic, Barium, Cadmium		Phenols 0 to 5,000

DISTRIBUTION OF POLLUTION SOURCES

The Caribbean Environmental Programme's (CEP) Technical Report No. 33 is the best resource for a detailed distribution of pollutant loads in the WCR (UNEP 1994). The highest estimated pollutant loads into coastal waters are from Sub-regions I and V, which contribute, respectively, about 2 million and 1 million tonnes of BOD per year. BOD loads from Sub-regions II, III, and IV range from 100,000 to 400,000 tonnes per year for each region. Industrial loading of BOD is 3 to 200 times that of domestic sources in all sub-regions. More detailed information is provided in Tables 9 to 12 of CEP Technical Report No. 33, which are included in Appendix A.

Table 2-2 presents a regional summary of pollutant loads. It can be seen from Table 2-2 that industrial sources account for as much as 80 percent of the pollution load to the Wider Caribbean Basin. Even though domestic sources are a relatively small part of the total current pollution load, control of pollution from domestic sources receives considerable attention in the current report. This is because domestic sources are important in all countries of the WCR (they are ubiquitous), because pollution control from domestic sources is an important element of public education about environmental and public health issues, and because human health risk arises primarily from domestic sewage.

TABLE 2-2.
SUMMARY OF POLLUTANT LOADINGS IN THE WIDER CARIBBEAN BASIN
TONNES PER YEAR

Parameter	Subregion I	Subregion II	Subregion III	Subregion IV	Subregion V	TOTAL
BOD						
Domestic	115,656	16,785	71,079	4,790	260,171	506,482
Industrial	2,245,762	126,858	357,441	94,707	603,370	3,428,138
TSS						
Domestic	116,327	16,427	90,214	4,617	228,744	456,329
Industrial	27,821,848	149,887	993,964	270,270	2,684,948	31,920,953
TN						
Domestic	34,070	2,419	5,239	710	86,338	128,786
Industrial	17,234	40,526	43,265	37,306	211,107	349,435
TP						
Domestic	19,141	1,467	5,503	531	33,475	60,117
Industrial	17,717	4,519	12,690	15,171	32,537	82,634
Oil & Grease						
Domestic	41,370	2,001	6,089	504	18,975	68,939
Industrial	640,181	8,611	128,024	41,227	162,608	908,701

Reference: CEP Technical Report No. 33

SEWAGE TREATMENT GOALS

The primary purpose of sewage treatment is to remove pollutants from wastewater streams before disposal into receiving waters including:

- Pathogens—These organisms are harmful to humans and cause many illnesses and deaths each year in developing countries. Pathogens commonly found in raw sewage include hepatitis and pathogenic enteric viruses, Klebsiella pneumonia, Shigella, Salmonella, Leptospira, Vibrio cholerae, and typhoid bacillus bacteria, pathogenic protozoa such as Entamoeba histolitica and Giardia lambda, and parasitic organisms such as Schistosoma, Ascaris lumbricoides, and hookworm.
- Organic and other oxygen demanding materials— Organic materials are a major pollutant in sewage. The common measure of the organic content of sewage is the Biochemical Oxygen Demand (BOD) test. BOD is a measure of the oxygen needed to degrade organic and inorganic compounds in the waste stream. It is called "Biochemical Oxygen Demand" because bacteria in the sample are the primary catalysts for conversion of organic materials and consumption of oxygen in the sample. High BOD levels in natural waters cause a drop in dissolved oxygen (DO) concentration, often killing aquatic life. The chemical oxygen demand (COD) test is a simple laboratory analysis in which all of the oxidisable material in the sample is

oxidised by potassium dichromate. The COD test measures the combined oxygen demand of biochemically reducible contaminants and non-biochemically degradable reduced contaminants. Fats, greases, and lignins are biochemically degradable, however, the rate of oxidation is very slow and they have little effect on the 5 day BOD test. These are measured by the COD test.

- Total suspended solids (TSS)—High levels of suspended solids can be damaging to benthic habitats and cause anaerobic conditions on the bottoms of lakes, rivers, and seas due to breakdown of volatile materials in the solids.
- Nutrients—An excess of the nutrients nitrogen and phosphorus may cause eutrophication in natural waters (a state of excessive nutrient concentration). Eutrophication begins with algal blooms, followed by high BOD levels (when the algae die) and low DO concentrations.
- Fats, oil, and grease (FOG) - Fats, oil, and grease float on the surface of receiving waters. FOG interfere with natural reaeration, can be toxic to certain species of fish and aquatic life, can create a fire hazard when on the water in sufficient quantity, destroy vegetation along the shoreline which can lead to increased erosion, and create an unsightly film on the surface of the water which can reduce recreational uses.

A secondary purpose of sewage treatment is to treat and dispose of the solids, or sludge, generated by the treatment processes. For sewage from industrial sources, special attention must be given to removal of toxic substances.

CURRENT PRACTICES AND EFFECTS

Resources cited in the literature review provide detailed information about current practices and the condition of sewage treatment in the WCR. UNEP-CAR/RCU, the Caribbean Environmental Health Institute (CEHI), and other organisations and governments in the WCR have funded numerous reports addressing the state of sewage collection and treatment in the region. One study concluded that less than 10 percent of the population in the Caribbean basin is served by sewage treatment.

The effectiveness of existing sewage collection and treatment facilities in the region is usually constrained by limited capacity, poor maintenance, process malfunction, poor maintenance practices, and lack of experienced or properly trained staff. Most collection and treatment facilities dispose of their effluent and wastes directly into the marine environment, resulting in high coliform concentrations and low dissolved oxygen levels in coastal waters.

In rural areas of the WCR, collection systems are rarely used, and pit privies, latrines, or septic tanks are the most common waste disposal systems. These processes can be effective, provided they are designed, installed, maintained, and used properly. The biggest problem with them is lack of maintenance. Septic tanks, pit latrines, and pit privies need to be cleaned (“desludged”) periodically. Failure to desludge results in poor effluent quality. Also, septic tanks with soil absorption for effluent disposal work poorly if the soil is not very permeable, or if ground water levels are high.

In areas of higher population density, it is feasible to develop a local collection system and use a single facility to treat the community’s wastes. Lagoons, stabilisation ponds, and aerobic package plants are common treatment options for mid-size communities in the WCR. Lagoons are often appropriate, but they require a large area to provide adequate treatment. Package plants are used mostly for resort communities, hotels, and other public buildings. Many package plants in the WCR are operating improperly because of improper design and inadequate maintenance. In centralised, urban centres, lagoons, package plants, and conventional activated sludge systems are used. Many of these treatment facilities do not provide adequate treatment because of improper maintenance, and lack of skilled operators. A report by CEHI and the Pan American Health Organisation (PAHO) described the following disposal practices for systems in the WCR that collect and treat sewage (Bartone, 1984) :

- 21 percent reuse effluent.
- 14 percent practice subsurface discharge.
- 28 percent use marine disposal, mainly on shoreline.
- 22 percent discharge to surface waters such as lagoons or streams.
- 14 percent practice on-site disposal.

The percentages do not sum to 100 in the original.

Poor sewage treatment and disposal affects the health of the local population and the environment. In St. Lucia, children have been affected by helminths. In Barbados, extremely high coliform counts have been measured. In Colombia and the United States bordering the Gulf of Mexico, sewage pollution has been identified as the cause of fish kills. And in Cuba, impacts of sewage pollution have been measured as far as 1 kilometre from sewage effluent discharge points. According to PAHO data, as of 1979, enteric and diarrhoeal diseases are the most common cause of infant mortality in many Latin America and Caribbean countries.

Problems with less severe consequences include pollution of tourist and bathing beaches and pollution impacts on the marine environment. Problems associated with poor disposal practices are high coliform counts in coastal waters, eutrophication in bays and harbours, damage to coral reefs, and fish kills or abiotic waters in the most extreme instances. Fish kills occur from oxygen depletion due to the high BOD. Table 2-2 summarises sewage collection and treatment practices in the WCR and their effects on the environment. Data in Table 2-2 were derived from a report on a seminar entitled "Monitoring and Control of Sanitary Quality of Bathing and Shellfish-Growing Waters in the Wider Caribbean," held in Kingston, Jamaica in 1991. (CEPPOL. 1991) The CEPPOL report includes the disclaimer that "the information was extracted from a variety of reports, some of which were prepared in the early 1980's and for which no more up-to-date information was available. For some countries, information was not available at all and therefore, these have not been included in the report. As a result, the report may not accurately reflect the actual status of sewage pollution in the region, nor the existing monitoring programmes and implemented control measures." Where KCM had specific knowledge of new data, this new data was used to update the table.

TABLE 2-3.
SEWAGE COLLECTION AND TREATMENT PRACTICES AND EFFECTS IN THE WCR

Country	Degree of Collection	Degree of Treatment/ Type of Treatment Prevalent	Problems	Monitoring Programs and Standards
Bahamas	15.6% of population	Deep well injection of raw sewage; 44% of sewage treatment works (STW) are in poor condition or non-operational	High incidence of gastro-enteritis	Department of Environmental Health conducts random sampling of coastal waters; Twice monthly sampling to begin; WHO and U.S. EPA standards currently used
British Virgin Islands	1 collection system	Pumping of raw sewage to marine outfall; some septic tanks	Some wastes return to shoreline, ground water pollution problems	Permanent program being established; monthly sampling of total (TC) and faecal (FC) coliforms in bays. U.S. EPA standard of 200 FC/100 mL and 1000 TC/100 mL
Dominica	13.5% of population	Raw sewage, septage, and effluent disposal into rivers and ocean; virtually non-existent treatment	High incidence of water borne diseases—65 cases typhoid in 1982	
St. Lucia	13.2% of population. Treatment facility in Rodney Bay	Usually untreated raw sewage discharged into ocean & inner harbours; 54% STW are in poor condition or non-operational	High bacterial levels in some coastal areas	Random sampling of coastal waters conducted by the Ministry of Health in co-operation with CEHI
Trinidad & Tobago	Most of population serviced	Lagoons, trickling filters, activated sludge; oxidation ditches; package plants; discharge into estuaries and rivers; 46% in poor condition or non-operational	Poor maintenance practices; high coastal bacterial counts. Rivers of poor water quality.	Institute of Marine Affairs conducts surveys to assess quality of bathing. No legally declared standards yet, but EMA, CEHI, and Trinidad & Tobago Bureau of Standards developing them now.
Montserrat	Virtually none, only 1 STW	Septic tanks with soil absorption fields (volcanic sandy loam provides good treatment)	Inadequate for large developments; otherwise few problems	
Barbados	10% - only for Bridgetown, South Coast system under construction	STW for Bridgetown, outfall for South Coast, remainder of island - septic tanks and soakaway pits or suck wells. Few package plants at hotels.	Nutrients in coastal zone impacting coral reefs. High coliform counts in some coastal areas.	Coastal Zone Management Unit & Environmental Engineering Unit monitor swimming areas for faecal coliform.
Grenada	1 for city of St. George	Virtually no treatment in some areas; about 60% STW in okay condition	Pollution at Grand Anse Bay	
Guadeloupe (France)		Oxidation ponds		Sanitary quality of bathing waters assessed on a regular basis and before each tourist season. Maps issued to describe water quality. EEC guidelines of 1976 used
St. Vincent	6% - only for City of Kingstown	Kingstown has preliminary treatment and outfall. Most of island uses septic tanks and poor quality absorption pits or fields. Few package plants at hotels.	Impervious soils and high water table in coastal zone causes overflowing of absorption fields.	None

TABLE 2-3 (continued).
SEWAGE COLLECTION AND TREATMENT PRACTICES AND EFFECTS IN THE WCR

Country	Degree of Collection	Degree of Treatment/ Type of Treatment Prevalent	Problems	Monitoring Programs and Standards
Antigua & Barbuda	Mostly for hotels	Numerous hotel package plants; 48% in poor condition or non-operational; septic tank effluent directly to sea		Random sampling by Ministry of Health with CEHI; Emphasis on potable water quality; WHO standards used mainly
St. Kitts - Nevis	Mostly for hotels and hospitals	A few package plants, most in decent condition; the remainder use septic tanks	No serious problems, but some septic tank effluent saturation	Random sampling of coastal waters conducted by the Ministry of Health in co-operation with CEHI
Belize	Very little; new system being built for Belize City	Aerated lagoons before ocean outfall; high water table encourages draining septic tank effluent directly to canals and ocean for fear of contaminating drinking water supplies	High coliform counts in coastal waters	
Colombia	25% of coastal population	Very little treatment	Enteritis, hepatitis, and typhoid fevers; eutrophication in harbours	Regular sampling and analysis in a few area, such as Cartagena Bay. Very developed environmental legislation, set standards for faecal coliforms, and waste water effluents for new & existing plants.
Cayman Islands	System built in 1988	Stabilisation ponds outfall		Government agencies jointly monitor coastal water quality (total, faecal coliforms & Enteroc...). EEC & WHO standards currently used. Comprehensive surveys carried out in identified pollutant areas.
Costa Rica		Limon discharges raw sewage into harbour	No major problems except coliform count near Limon discharge	No regular program is known to exist. Studies of coastal waters have found total coliforms (TC) to be twice that of faecal coliforms (FC). In U.S., more common values of TC:FC are 5:1
Cuba			Problems concentrated in Havana with faecal coliforms	Ministry of Public Health is in charge of ensuring compliance with standards. Regular monitoring program in place. Standards and guidelines adopted from international organisations & European countries.
Dominican Republic	25% of urban population (in 1979)	Sewage discharge into sea		
Guatemala		At least 27 treatment facilities - Imhoff tanks, lagoons, trickling filters, and activated sludge.	Many treatment facilities impaired due to poor design, lack of spares, and shortage of qualified operators.	

TABLE 2-3 (continued).
SEWAGE COLLECTION AND TREATMENT PRACTICES AND EFFECTS IN THE WCR

Country	Degree of Collection	Degree of Treatment/ Type of Treatment Prevalent	Problems	Monitoring Programs and Standards
Haiti	None	40% population (mostly urban) uses latrines and septic tanks; 41% urban + 12% rural have acceptable disposal means 80-90% septage and latrine solids dumped into rivers and sea illegally	Human waste disposal is most pressing problem	
Honduras	No data.			
Jamaica		109 STW; 21 serve Kingston area; however not enough capacity; 8-10 mgd of inadequately treated sewage is discharged into Kingston harbour; 25% STW are in poor condition or are non-operational	Coastal waters are abiotic	There is monitoring of sewage and discharge limits for sewage treatment plants. However, no documentation if regular monitoring of coastal waters is conducted.
Mexico		Commonly discharge into rivers; in Cancun, sewage collected and discharged into lagoon	Abiotic conditions near urban centres	Monitoring program or practices not known. Minimum water quality levels are required for various water uses, such as bathing or shellfish growing.
Panama	6 sewer systems serve 95% of coastal population	4 have primary treatment (10% of coastal population); 2 systems discharge raw sewage (85% of coastal population)		No information available on monitoring programs. Water quality criteria recently adopted based on WHO/PAHO standards.
Gulf of Mexico, U.S.	460 municipalities discharge	Majority receive secondary treatment or better; 10% have only primary treatment; more than 1 billion gallons per day Some malfunctioning septic systems, particularly in Louisiana and Florida	Oxygen depletion in areas has caused fish kills due to marine growths	National monitoring, assessment, and control system in place for all coastal states. US/NOAA program determines national inventory on pollutants discharged into coastal waters. EPA, FDA, etc.
Puerto Rico				
U.S. Virgin Islands				
Venezuela	65% served	3% of population served by sewage treatment - mainly on Margarita Island. Projects under construction for Valencia and Maracaibo. No municipal treatment for Caracas and other major cities. Significant industrial load.	Oxygen depletion and coliform contamination of rivers.	Monitoring and compliance programs are implemented. National standards for coastal water quality criteria developed in 1983 based on EEC, WHO, and U.S. EPA guidelines.

CURRENT WATER QUALITY STANDARDS

Sources upon which water quality standards can be based include extensive studies on the effects of pollution in receiving waters as well as existing standards from other countries or states. Most countries in the WCR use microbiological water quality standards taken from U.S. EPA guidelines written prior to 1986. However, these standards often are too stringent and expensive for a developing nation. Planners need to account for the economic realities and development priorities of developing nations when setting water quality standards.

Three general categories of microbiological water quality standards are based on intended water uses: protection of indigenous organisms, primary contact recreation, and shellfish harvesting. For developing countries, the pollutants of greatest concern are pathogens because they pose an immediate health danger. The most stringent requirements are those for shellfish harvesting, since some shellfish tend to concentrate contaminants. The UNEP/World Health Organisation (WHO) standard for shellfish harvesting waters is a maximum of 10 faecal coliforms per 100 mL for 80 percent of samples taken. Shellfish contamination is associated with typhoid fever, cholera, viral hepatitis, and many other gastro-enteric conditions.

Currently, the UNEP-CAR/RCU, CEHI, Trinidad's Environmental Management Authority (EMA), and other Caribbean agencies are working to develop water quality standards for other pollutants from domestic and industrial sewage. Water quality criteria have been proposed for BOD, TSS, nitrogen, phosphorus, pH, temperature, oil and grease, and bacteria. Standards from the United States and other countries are provided in Appendix B.

CHAPTER 3.
PLANNING ISSUES

This section provides an overview of environmental planning fundamentals required to develop appropriate wastewater treatment facilities for developing countries like many in the WCR.

DOMESTIC WASTEWATER MANAGEMENT PLANNING PROCESS

A typical process for domestic wastewater management planning consists of the following steps (EPA, 1994):

- Create a community profile
- Define problems
- Develop and evaluate alternatives; select a preferred alternative
- Assess environmental impact
- Encourage public participation
- Finalise planning.

Additional considerations in the overall wastewater management process are :

- Building institutional infrastructure
- Land use zoning

Community Profile

The first step in a wastewater management plan is characterising, or defining, the community or communities involved. The objective criteria that must be characterised are the number of people, the population distribution and density, whether piped water or a collection system is available, location of natural drainage basins, and economic status. Subjective criteria address questions such as the following:

- Does the local population understand the need for wastewater disposal?
- How much money is a community willing to spend, if any?
- Is skilled labour available?
- Would any cultural habits or beliefs prevent proper use of the disposal system? (Some cultures do not allow contact with wastes—this would prevent traditional treatment options.)

Problem Definition

With a community profile established, the next step is to define what specific problems the wastewater management plan must address. Problem definition may be as simple as recognising the potential for unlined pit latrines to leach contaminants into groundwater; it is possible that building a new lined latrine could solve a problem of local residents becoming ill from drinking well water. On the other hand, problem definition may be quite complicated, involving such efforts as soil borings to determine soil permeability, aerial surveys to identify septic tank failures, or water quality monitoring. Questionnaires can help identify the local population's perception of the problem.

Alternative Evaluation and Selection

After the community is adequately characterised and the wastewater problem is defined, a group of feasible solutions can be considered. One approach is to eliminate technologies or groups of technologies that clearly are not feasible for the community. It is not necessary or wise to select a single technology without evaluating others. "Appropriate technology" can be defined as technology that is affordable and operable by the user and that reliably provides the needed degree of purification (Kreissl, 1996). Other criteria are that the technology be financially sustainable by the local community and use a holistic approach (Bhamidimarri, 1996). Appropriate technology for a rural, low-density development may be septic tanks or a facultative lagoon. It would not be appropriate to use an activated-sludge process because such processes are energy-intensive and require much operational skill. The focus of this document is to provide a methodology for determining which technologies are appropriate.

Environmental Impact Assessment

An environmental impact assessment should address cost, potential growth impacts, energy consumption, water quality. These criteria should be examined by the community or planners. They are applicable to small rural areas as well as large urban centres.

Public Participation

Public participation offers important benefits for wastewater management planning. It increases a community's awareness of waste-related problems, the value of waste management, and the likely cost. Surveys of rural residents in developing countries find that in healthy communities most people attribute their health to good air, good climate, easy accessibility to help in case of emergencies, and privacy (World Bank, 1982). They do not usually associate clean water with a healthy environment, but they do associate unsanitary conditions with an unhealthy environment. It is important for communities to make the connection between good health and clean drinking water. Residents are more supportive of wastewater management plans when they understand the importance. Ways to increase public participation include community meetings to discuss plans and to allow input to final decisions.

Finalising the Plan

The final stage of planning is to re-examine all issues addressed in the initial stages, evaluating information that becomes available later in the planning process and using it to update earlier findings and decisions. It is a fine-tuning of the decision-making process. If a new facility is to be built, design details are prepared at this stage.

Building Institutional Infrastructure

Even after a project has been successfully implemented, it will not be effective in reducing pollution and improving public health without a management structure to ensure effective operation of facilities. The management structure must have adequate economic resources obtained through user fees or other means to fund maintenance and effective operation of the systems. The major problem, as perceived by many in the WCR, is development of an appropriate organisation, forceful and with an adequate mandate to successfully administer and carry out the planning process from beginning to end.

Land Use Planning

As a part of the process of building effective wastewater management programs in developing countries there is a need for land use planning on a national scale to protect existing ground and surface water sources from pollution related to unregulated development. Zonal Planning policies should also define specific areas where sewage treatment systems are required to protect the resource, whether a river for potable water or a nearshore marine swimming area. Barbados has practised zonal planning to good effect since the 1960s to protect ground water resources.

CONSIDERATIONS FOR INDUSTRIAL WASTEWATER MANAGEMENT

Industrial wastewater makes up about 80 percent of the entire pollutant load in WCR coastal waters. However, the economies of developing nations are very dependent on industry, which presents a dilemma: Can the environmental benefits of wastewater treatment outweigh negative economic impacts?

Developing countries often view environmental regulation of industry as a costly luxury. A common justification for failing to adopt such regulations is that the regulations would diminish the competitiveness of the nation's industries, and that the jobs those industries provide are more important than pollution control (Miller, 1981). Experience has shown, however, that effective pollution control facilities cost 1 to 5 percent of the installed capital cost of a new industry, whereas future programs to clean up industrially polluted areas can cost as much as 1,000 times the original cost of industrial development (Miller, 1981).

Key steps in developing an industrial wastewater management plan are as follows:

- Government involvement
- Define problems
- Assess economic conditions
- Determine the availability of needed personnel
- Establish priorities.

Government Involvement

Government involvement is essential for effective industrial wastewater management. Industry is unlikely to propose and implement pollution controls on its own because of the significant financial impact. Also, without standard, industry-wide requirements, any company that takes on the financial responsibility for pollution control can be placed at a competitive disadvantage to companies that do not. For this reason, government must assume responsibility for industrial pollution control and impose uniform effluent regulations and standards. It is important that the government involve the industry leaders when deciding on appropriate effluent regulations and standards. Local governments also can provide subsidies to encourage the use of pollution control technology and alleviate some of the associated economic burden.

One strategy for industrial wastewater management is to establish organised industrial districts (OIDs). The Turkish government has successfully applied this program since 1961 (Filibeli, 1996). The strategy creates industrial zones with suitable infrastructure at a low cost to attract industrial investors. Roads, power, water supply, wastewater collection and disposal, technical consulting, and other incentives are included in the OIDs. Most OIDs have a central treatment facility to pre-treat waste streams before discharge to municipal sewers. Waste minimisation programs are also encouraged.

Problem Definition

Goals and methods for defining problems to be addressed are the same for industrial wastewater management as for other wastewater management plans. The volume of waste, seasonal variation, and waste characteristics need to be quantified.

Economic Assessment

Understanding of a country's economic conditions is important for deciding the amount of local and foreign currency that can be spent for industrial pollution control. Countries with strong economies can afford to spend more on pollution control. However, countries with weaker economies that are inclined to spend little on pollution control must bear in mind that pollution cleanup is far more costly than pollution prevention.

Personnel Availability

Few developing countries have an abundance of personnel skilled in wastewater management and planning or treatment plant design and operation. Some international funding agencies can help set up a wastewater management program to train workers in facility operation and maintenance. The Caribbean Water & Wastewater Association (CWWA) has among it's aims and objectives :

- To advance the science, practice, and management of water supply and wastewater disposal for the benefit of Caribbean people.
- To promote education and training in water supply and wastewater disposal to ensure an adequacy of trained manpower and well informed members of the public.

The CWWA is currently in the process of establishing an indigenous Certification Programme for operatives in the water and wastewater industry across the Caribbean. This programme was conceived to address the needs for trained work force in facility operations

Priorities

Ultimately, government officials need to decide their nation's priorities. Are planning decisions based on short-term or long-term goals? It is difficult to spend money on the environment in developing countries facing other very pressing problems, such as housing shortages and poverty. However, planners need to consider all factors, including the cost, health risk, and environmental degradation, resulting from delaying pollution control programs.

CHAPTER 4.
LITERATURE REVIEW

Papers, textbooks, manuals, and handbooks that contributed to sections of this report are summarised below. Some of the texts and articles cited address issues in parts of the world other than the WCR, but they are included for their usefulness in explaining technologies or procedures. The structure of this literature review follows the section outline of the report. Abstracts on some of the works discussed in this section are provided in Appendix C.

BACKGROUND ON SEWAGE POLLUTION IN THE WCR

A key source of current information on sewage pollution issues for the Caribbean region is the series of conference proceedings published since 1992 by the Caribbean Water and Wastewater Association (CWWA). The proceedings provide a convenient handbook of papers of current topical interest. Included in the 1994 proceedings, for example, were a number of papers of interest to the reader of this report. "Near Zero Discharge Systems : As Low Cost, Advance Technology For Caribbean Water And Wastewater" by Donald Bullock (Bullock 1994) presents a concept for on-site systems including "underwater reversing sand filters" for sink and washing drainage followed by aeration and reverse osmosis. The intended use of this system is to treat household grey water for return to potable use. A separate, smaller system would be used for toilet water to prepare it for soil absorption or discharge to a receiving water. "Coral Reefs, Sewage and Water Quality Standards " by Thomas J. Goreau (Goreau 1994) presents summary data on the damage done to coral reefs by eutrophication of the coastal zone, soil erosion, high temperatures, sport divers, and overfishing. The author reports from a perspective of 35 years of study of the ecology of coral reefs in Jamaica. The author finds that eutrophication (excess nutrient fertilisation) of coastal waters has caused a dramatic withdrawal of coral reefs. Reefs which formally had more than 95 percent live coral are now more than 95 percent covered by algae. The author reports that rising nitrate and phosphate concentrations in the coastal waters have had a direct effect in this conversion to a less desirable ecology. "Impacts of Wastewater on Caribbean Coastal and Marine Areas" by Arthur B. Archer (Archer, A. B. 1994) presents an overview of sewage pollution problems faced by the Caribbean region including algae deposition on sea-grass beds, coral reef damage, and reduction in fisheries. The potential for amelioration of these problems by nutrient removal from sewage effluent and installation of long marine outfalls is discussed. "Sandfiltration Treatment of Domestic Wastewater A Viable Option in Complex Areas" by Desmond Munroe (Monroe 1994) presents a discussion of potential solutions to the pressing problem of nitrate contamination of ground water supplies by septic tank effluent. A series of alternatives are considered including:

- Evapotranspiration beds
- Intermittent sand filters
- Aerobic systems
- Total retention, and
- Overland flow system

The author presents background examples from Jamaica where pollution of groundwater by latrines and septic tanks connected to leach fields or percolation/absorption pits has led to serious public. Three articles discussed numerical modelling, environmental condition, and water quality modelling for Kingston Harbour in Jamaica (Gay and Burgess 1994, Hamman 1994, Tarbotton 1994.) Several articles (Chaulk, et al. 1994, Suite 1994, Pemberton 1994, and Hunter 1994) discuss management issues directly pertinent to building wastewater utility infrastructure in the region. Several others present strategies for design of wastewater treatment lagoons (McTaggart and Barnard 1994, Marococchio 1994, and Pearson 1994.)

"Wastewater Disposal in the Caribbean: Status and Strategies" (Archer, A. 1989) and "Developing Alternative Approaches to Urban Wastewater Disposal in Latin America and the Caribbean" (Bartone 1984) are good overviews to wastewater disposal in the Caribbean. The authors mention such possible waste treatment technologies in the WCR as submarine outfalls with minimal pre-treatment, treated effluent reuse for irrigation and other "unconventional" technologies for urban slum sanitation. They also mention current problems in setting water quality standards. Too often, the regulatory agencies in Latin America and the Caribbean attempt to define a set standard based on water usage or classification. This approach has not worked well because of its inflexibility, its failure to correlate water quality with discharges, and its disregard of economic issues.

Regional Overview of Land-Based Sources of Pollution in the Wider Caribbean Region (UNEP 1994) provides an overview of the volume and types of pollution generated in various regions of the Caribbean. The report identifies sewage as one of the major pollution sources. Waste loads from each region in the WCR are provided, along with a breakdown of existing sewage plants and the industries that are predominant in the different regions.

The *Report on a Rapid Assessment of Liquid Effluents from Land Based Sources in Trinidad and Tobago* (Institute of Marine Affairs 1992) is a detailed survey of pollutant loads and sources in Trinidad and Tobago's coastal waters. The report identifies oil refineries, livestock farms, food and chemical processing industries, and domestic sewage as the main BOD sources in coastal waters.

"History and Application of Microbiological Water Quality Standards in the Marine Environment" (UNEP 1994) provides a history of the development of water quality standards in the United States and the effect of this development on water quality standards in other countries. Water quality guidelines for the United States and a few Central American countries are listed. The author points out that most WCR countries with national water quality standards adopted them from U.S. standards, with minimal consideration given to the economic situation and priorities of the adopting country. The author feels that planners must "conduct a thorough review of the prevailing local water quality guidelines/standards (if any exist) to ensure that local economic development priorities are reasonably accounted for." Also, "the decision to design the system for other than minimum water quality standards should be supported by demonstrated need, or a state local/national policy decision." The author also introduces the controversy of whether swimming in water that is moderately contaminated with coliforms is a public health issue or one of aesthetics. Studies correlating sickness upon contact with water to quality of the water (in terms of coliform count) are reviewed.

"Review on the Present State of Marine Pollution by Sewage and Present Monitoring and Control Practices in the Wider Caribbean" (CEPPOL 1991) is a draft report written for an April 1991 CEPPOL Seminar in Kingston, Jamaica. The report was meant to be amended after the meeting, and may have some incorrect information. However, it is an excellent review on existing wastewater treatment practices used in different countries in the region. The overwhelming trend is that most of the Caribbean is not served by wastewater collection systems with centralised treatment. For example, in the Eastern Caribbean and the Bahamas, approximately 40 percent of the population is using pit privies, 40 percent is using septic tanks, 11 percent use connected disposal systems with centralised treatment, and 9 percent have no waste disposal facilities at all. In the WCR, many of the existing collection systems and treatment facilities are in poor repair. This review includes current monitoring programs for different countries.

ENVIRONMENTAL PLANNING AND MANAGEMENT

The, *Appropriate Sanitation Alternatives* (Kalbermatten, J.M. 1982; World Bank Studies in Water Supply and Sanitation No. 1) is a comprehensive paper on the steps and questions a planner in a developing country needs to address to improve sanitation associated with excreta disposal. It includes information on technology options. The authors argue that developing countries are better served by being provided with lists of inappropriate technology they should avoid than by being told that a single, particular technology is most suitable. Site-specific conditions, social and economic considerations, and local preference are difficult to account for in selecting "appropriate" or "correct" technology for developing nations.

Management of Industrial Wastewater (High Institute of Public Health 1981) is a compilation of the Proceedings of the 1981 International Symposium in Alexandria, Egypt. It includes case studies and papers on planning, management and control of industrial pollution, as well as on specific treatment technologies. The case studies are not very current, but the book serves as a good reference for some of the treatment technologies available to the industrial wastewater industry.

"Industrial Pollution Control in Developing Nations" (Miller, J.P 1981) discusses the conflict of encouraging economic growth in a developing country, while at the same time imposing environmental restrictions that discourage industrial development. However, "experience shows that reasonably effective pollution control facilities cost from one to five percent of the installed capital cost of a new industry. Clean up programs needed in the future to clean up industrially polluted areas, however, can cost a hundred or even a thousand times as much as the original industrial development." Other topics such as funding, governmental involvement, and subsidies for pollution prevention are also discussed.

Planning for Small Community Wastewater Treatment Systems (U.S. State Department et al. 1994), sponsored by the U.S. EPA, is taken from "The Middle East Peace Process Multilateral Working Groups on Environment and Water Resources" which was held in Cairo, Egypt in June 1994. This document touches on planning, management, water reuse, collection and treatment technologies, and information resources available in the Middle East and United States.

The manual *Wastewater Treatment/Disposal for Small Communities* (U.S. EPA 1992) includes a chapter on planning, and management, yet is not an appropriate source for planning in the

Wider Caribbean Region. This manual assumes that the user will be planning in the well-defined regulatory framework of the United States.

Guidelines for Improving Wastewater and Solid Waste Management (Andrews, R.N. 1993) was written with developing countries in mind. Many industrialised countries manage waste through advanced technology and stringent regulatory requirements. However, some developing countries do not have institutions or regulatory agencies strong enough to enforce stringent requirements or the resources to pay for advanced technology. This manual offers guidance in determining the best technologies, policy instruments, and institutions for a particular country or community.

The following EPA manuals also discuss planning of treatment facilities or processes:

- Alternative Wastewater Collection Systems (U.S. EPA 1991)
- Municipal Wastewater Stabilisation Ponds (U.S. EPA 1983)
- Onsite Wastewater Treatment and Disposal Systems (U.S. EPA 1980)
- Rapid Infiltration and Overland Flow (U.S. EPA 1984)
- Sludge Treatment and Disposal (U.S. EPA 1979)

"Planning Replicable Small Flow Wastewater Treatment Facilities in Developing Nations", (Gaber, A. 1993) describes the steps required to plan for a small community treatment plant in a developing nation. The author indicates that two responses have historically been given to the question, "How can wastewater development best occur in the complex environment of a developing country?" One response has been that innovative external technology and components can always solve wastewater problems. The other is that technology is useless unless the local system can adequately sustain the required infrastructure. This paper focuses on the latter response.

"Evaluation of Innovative Wastewater Treatment Technology" (Qasim, S.R. 1993), "How Appropriate are 'Appropriate Waste Management Technologies'" (Bhamidimarri, R. 1996), and "Appropriate Wastewater Treatment Technology for Small Communities" (Kreissl, J.F. 1996) all attempt to define the terms "innovative" and "appropriate." Most seem to agree that appropriate technology must be:

- Affordable in capital cost and operation and maintenance
- Operable at a reasonable cost and with locally available labour
- Reliable enough to consistently meet effluent quality requirements.

"Control of Pollution in Organised Industrial Districts: A Case Study from Turkey" (Filibeli, A. 1996) discusses planning strategies in Turkey for controlling industrial wastewater pollution. In 1993 there were 100 "Organised Industrial Districts" (OIDs) in Turkey, and much growth is anticipated. The idea of the OID is to provide to industrial investors parcels with suitable infrastructure (roads, power, water supply, wastewater collection and disposal, technical consulting, communication, etc.) at a low enough cost to encourage development. Each OID has a central wastewater treatment plant. Some of the industries must pre-treat their wastewater before discharging to the central collection system. The authors emphasise waste minimisation and strategic zoning of the industrial sectors so that similar industries can be near each other and share pre-treatment facilities and costs.

"Wastewater Treatment Meets Third World Needs," (Nichols, A.B. 1987) addresses some of the sanitary and health-related needs of developing nations, as well as the World Bank's financial assistance in various projects. The impact of coliform-polluted waters is discussed. According to the World Bank, "acute water shortages combined with pollution now cause 25,000 deaths a day." The Bank notes that "the appropriate reuse wastewater treatment system must be able to remove helminths, reduce bacterial and viral pathogens, and be free from odour and appearance nuisances." Also, "Latin America should not adopt *a priori* official policies which advocate secondary treatment, unless there appears to be clear justification." For developing countries, it is very important to determine the cost of wastewater treatment, and what degree of treatment is necessary. Bacterial and pathogen removal in wastewater has been directly correlated with health, but questions remain about the health impacts of BOD and TSS.

COLLECTION SYSTEM ALTERNATIVES

The EPA manual, *Alternative Wastewater Collection Systems* (U.S. EPA 1991) discusses pressure sewers, vacuum sewers, conventional gravity sewers and small diameter sewers. Potential applications are discussed for all kinds of geographical and hydrogeologic conditions, quantities of flow, economic constraints and distribution of wastewater sources. This is a comprehensive manual on collection systems.

Guidelines for Improving Wastewater and Solid Waste Management (Andrews, R.N. 1993) provides a brief list of wastewater collection systems. It also lists factors that must be considered in determining whether a collection system is needed or an on-site treatment system will be adequate. The choice is influenced by lot size, population density, topography, groundwater elevation, and soil characteristics. "On-site disposal is appropriate for low-density areas with nearly flat topography, good percolating soils, and a water table at least one meter below the surface. For households, the on-site choices are latrines or septic tanks that combine collection with treatment. Off-site treatment is appropriate in high-density areas with gently sloping topography, high water tables, clay soils or rock with poor percolation, and where space for off-site treatment and disposal is available."

Planning for Small Community Wastewater Treatment Systems (U.S. State Department et al. 1994) provides examples of "simplified sewers." The basic principles behind simplified sewers are: determining the tractive force necessary for movement of particles versus minimum velocity; reduced sewer depth; and consideration of improved materials, construction and cleaning equipment. Example layouts and plans are included

A presentation by Charles Vanderlyn on "Small Diameter Sewers" (Inter-American Development Bank 1992) at The Seminar on Appropriate and Innovative Wastewater Technologies for Latin American Countries discusses traditional collection system technologies with an emphasis on small diameter sewers. For small communities, the cost of installing a conventional gravity sewer is prohibitively large. These systems need costly, large-diameter pipes to ensure that sewage flows freely, with manholes every 100 meters or at any change of direction. By pre-treating sewage from households or small clusters with septic tanks, most of the solids can be retained, thus allowing smaller diameter pipes to be used for sewer construction. Since most of the solids are removed, there is no need to maintain minimum velocity to prevent solids build-up. Another option is to use a grinder pump instead of a septic tank, to break down any solids that could cause clogging. The author stresses that even though these systems are cost-effective in the United States, more evaluation or pilot studies need to be performed in other countries to determine their cost-effectiveness there, due to the difference in the relative cost of power and materials.

"The Feasibility Studies and Design of a Public Sewage Collection, Treatment and Outfall Scheme for the South Coast of Barbados" (Fries, H. 1992) discusses the methodology and process of designing a wastewater collection system for the southern part of the island of Barbados. Forty kilometres of sanitary sewer and 80 kilometres of service connections are to be installed, pending funding from the Inter-American Development Bank. Trenchless construction methods are being investigated due to utility line congestion. Direct and indirect social costs are expected to be high. These include:

- Compensating businesses for construction disturbances
- Property damage claims
- Reduction of pavement life through installations
- Cost in traffic diversions and delays.

"Alteration in Sewage Characteristics Upon Aging" (Kaijun, W. 1995) discusses how the performance and efficiency of a treatment system depends on the characteristics of the wastewater when it arrives at a treatment facility. The main points are that most odorous components from sewage in transport lines are from the formation of sulphate reduction products. The author maintains that the odour can be controlled by imposing aerobic conditions on the sewage. He also states that the sewer systems could contribute a lot more to pre-treatment from anaerobic microbial reactions than is presently the case in many systems. One possibility recommended for further investigation is "seeding" sewage lines with an active microbial population to increase COD reduction during transport. Another possibility is recycling the sludge build-up in the lower part of the sewer line back to the upper region, to increase the bacterial concentration. The author's proposed "seeding" or aeration is very expensive and does not seem feasible or cost-effective.

"The Option of Appropriate System for Wastewater Treatment in Low-Density Areas" (Ukita, M. 1993) is a statistical review of when collection systems in lieu of on-site treatment become economical in Japan. The authors determined that collection systems are advantageous when housing density exceeds 9.5 houses/hectare. Curves are given for collection system costs per household versus house density in Japan. Emphasis is also given to choosing the appropriate treatment system by considering economic factors, receiving-water quality, and the overall environmental impact of the discharged effluent.

DOMESTIC SEWAGE TREATMENT OPTIONS FOR HOUSEHOLD SYSTEMS

Appropriate Sanitation Alternatives (Kalbermatten, J.M. 1982) has information on household sanitation systems that can be employed by developing countries when collection systems are not available. Pit latrines are essentially a hole in the ground where excreta fall. The excreta decompose anaerobically, yet the pit eventually fills up. When it is three-quarters full, it must be decommissioned (sealed up) or pumped out. There are many variations on the pit latrine, such as a pour-flush toilet, where the excreta falls down a curved chute into a separate compartment. Water or sullage is used to flush the waste. An advantage to a pour-flush toilet is that it can be inside since it does not smell. Composting toilets are another alternative, yet require more maintenance and operational skill. In addition to the mixing and occasional heating requirements, grass, ash, sawdust or other organic material must be added to maintain the necessary balance of organic material and nutrient. There are some complications in wet climates as well.

The *Innovative and Alternative Technology Assessment Manual* (U.S. EPA 1980) has a fact sheet on three different types of non-water carriage toilets: incinerating toilets; composting toilets; and oil recirculating toilets. These options may be viable where water is scarce or other wastewater treatment options are not available. Incinerating and composting toilets have potential as an economical option, but the oil-recirculating toilet is not recommended as it generates oily residuals and requires solid-oil separation.

"Wastewater Treatment Technologies: Pit Latrines." (Kaltwasser, B.J. 1995) is a comprehensive discussion of the theory of pit latrines, design considerations, variations on pit latrine design, maintenance requirements, and applications. Some important considerations are: size needed; groundwater contamination (lining or no?); ventilation; proper measures to prevent problems with pests (flies, rodents); and not using the latrine when it is at capacity. Another consideration is that wet latrines can decompose solids faster than dry latrines because the microbiology can migrate faster to more food sources in water. Designing a wet latrine can minimise the required maintenance of solids removal or decommissioning.

DOMESTIC SEWAGE TREATMENT OPTIONS FOR ON-SITE SYSTEMS

The *Innovative and Alternative Technology Assessment Manual* (U.S. EPA 1980) includes a few fact sheets on septic tanks with different effluent disposal options. Septic tanks can be used with soil absorption fields for effluent disposal if the soil permeability is at least 25 mm/hour. Sandy soils are the most permeable. At least 660 mm is needed between the infiltrative surface and the highest potential groundwater level to minimise groundwater contamination. If effluent application rates are not excessive, the soil effectively removes BOD, TSS, bacteria, viruses, and metals. If groundwater levels are typically high, mound or at-grade systems can be used to dispose of septic tank effluent. Mound systems are elevated absorption beds which provide treatment for the effluent before ultimate disposal into the groundwater. *The Municipal Wastewater Technology Facts Sheets* (U.S. Department of Commerce 1991) includes the same facts sheets on septic tanks with absorption beds and mound systems.

The EPA manual, *Onsite Wastewater Treatment and Disposal* (U.S. EPA 1980) discusses the same information in greater detail. Information is provided on determining whether the soils are appropriate for absorption fields, on what size and shape the septic tank needs to be for proper treatment, on how to ensure proper hydraulics in the tank, on proper maintenance procedures and time intervals, and on the options for effluent disposal. In addition to absorption field or mound disposal, disposal possibilities include sand filters, surface water discharge, and evaporation ponds. This is a comprehensive reference book on soil treatment systems.

The manual, *Wastewater Treatment/Disposal for Small Communities* (U.S. EPA 1992) does not discuss septic tanks in great detail, but mentions that holding or containment tanks can be used to store wastewater until it can be collected for off-site treatment or disposal. Although this option eliminates the need for treatment, it has many drawbacks. Pumping may have to be frequent (depending on tank size) and it can be prohibitively expensive if the community is in a remote area. The holding tank must be of very high construction quality to prevent liquid, solid, or odour leakage.

"Wastewater Treatment Technologies—Septic Tanks" (Kaltwasser, B.J. 1995) provides an academic explanation of how septic tanks work, as well as some important design considerations. If properly sized, septic tanks need to be emptied only once every five to seven years, although an emptying period of two to three years is more typical. One option for effluent disposal is using small-diameter gravity sewers to carry the effluent to another treatment facility or process. This may not be appropriate in very rural areas, but it may be economical if the population density is high enough.

DOMESTIC SEWAGE TREATMENT OPTIONS FOR LOW-TECHNOLOGY, LAND-INTENSIVE TREATMENT

Each of the following manuals provides important design, operation, maintenance, and other applicable information about lagoons/ponds, fixed film processes, infiltration/percolation, wetlands, overland flow, and sand filtration:

- *Innovative and Alternative Technology Assessment Manual* (U.S. EPA 1980)
- *Municipal Wastewater Treatment Technology Fact Sheets* (U.S. Department of Commerce 1991)
- *Design Manual: Constructed Wetlands for Municipal Wastewater Treatment* (U.S. EPA 1975)
- *Onsite Wastewater Treatment and Disposal Systems* (U.S. EPA 1980)
- *Wastewater Treatment and Disposal for Small Communities* (U.S. EPA 1992)
- *Manual of Appropriate Wastewater Treatment Technologies for the Caribbean Including Relevant Technologies in Operation Worldwide* (Millette, E. 1992)

The Process Design Manual of Land Treatment of Municipal Wastewater (U.S. EPA 1984) is a useful resource for infiltration/percolation and overland flow treatment processes.

The following manuals provide design information on lagoons or stabilisation ponds; each contains excellent resource data for a design engineer in the planning or design stages of a project.:

- *Manual of Appropriate Wastewater Treatment Technologies for the Caribbean Including Relevant Technologies in Operation Worldwide* (Millette, E.M. 1992),
- *Municipal Wastewater Stabilization Ponds* (U.S. EPA 1983), and
- *Notes on the Design and Operation of Waste Stabilisation Ponds in Warm Climates of Developing Countries* (Arthur, J.P. 1983)

"BOD 5 Removal in Facultative Ponds: Experience in Tanzania" (Mayo, A.W. 1996) provides data from nine facultative ponds in operation under tropical conditions. The authors feel that improper operation is due to incorrect design. For example, designs must take into account the appropriate reaction rate for microbiology in tropical climates. The BOD removal versus detention time and the BOD removal rate constant versus BOD loading rate are some topics explored here. An optimal loading rate of 450 kilograms/hectare/day is given.

"Comparison of the Purifying Efficiency of High Rate Algal Pond with Stabilisation Pond" (Picot, B. 1992) discusses the pros and cons of two types of pond system for use in coastal areas with "Mediterranean" climates. In high rate algal ponds (HRAPs), algal growth is encouraged (thus increasing nutrient removal), depths are shallower, mechanical mixing is introduced, and detention times are shorter (4 to 10 days). This reduces the surface area needed. This study found that HRAP lagoons could provide the same level of treatment as stabilisation ponds in one fifth the area. Although stabilisation ponds require more area, their long detention times promote sedimentation and bacterial and pathogen die-off or removal.

The trend of low pathogen concentration in HRAPs and stabilisation ponds suggests that temperature elevation or sunlight on the pond can remove pathogens. "The Effect of Sunlight on Faecal Coliforms in Ponds: Implications for Research and Design" (Curtis, T.P. 1992) tackles the complex problem of modelling faecal coliform removal in stabilisation ponds. Sunlight intensity, dissolved oxygen of the water, and pH of the lagoon affect coliform removal rates. The authors found in their research that "1) light can only have an impact on faecal coliforms if complemented by a high dissolved oxygen (DO) concentrations (sic) and a high pH; 2) the tendency of algae to impede light penetration is offset by their ability to raise the pH and DO; and 3) that visible light is more important than UV." A history of previous work on the topic is provided in this report.

"Efficiency of Faecal Bacterial Removal in Waste Stabilisation Ponds in Kenya" (Mills, S.W. 1992) presents faecal coliform die-off rates for seven waste stabilisation ponds in Africa. The results were lower than predicted by traditional design equations based on temperature. Good correlation was found between faecal coliform first-order removal rate constants and temperature and influent faecal coliform concentration. The authors note that higher removal rates have been recorded before, but may reflect removals by sedimentation also. The pH values rarely exceeded 9, and the authors speculated that much better removal could be achieved if the pH could be maintained near 10.

In "Influence of Climate on Stabilisation Ponds" (Mendes, B.S. 1995), a correlation was developed for BOD removal and BOD loading rate for five different climates in Portugal.

"Sustainabililty and Wastewater Treatment" (Panetta, 1992) looks at wastewater treatment with a focus on environmental and cost appropriateness. The paper describes an alternative to conventional wastewater treatment technology in the form of the Advanced Integrated Pond System (AIPS). AIPS is a lagoon treatment system developed by William J. Oswald of the University of California that attempts to optimise features of anaerobic, facultative, high rate algae, and settling ponds for integrated wastewater management. The raw wastewater flows through the ponds in series. The first cell in the treatment train is the anaerobic or primary pond. This pond is designed for 5-10 days of hydraulic residence time and is relatively deep (4-5 meters.) Wastewater is directed to the centre of the anaerobic cell at the bottom of the pond to trap most solids, including helminth ova and parasite cysts. The second cell in the series is a more shallow (2-3 meters) facultative pond in which algae growth and sedimentation both take place. The third cell in the series is the high rate algae pond which is shallow (1-2 meters) to encourage full penetration of sunlight throughout the water column to maximise photosynthetic growth, and which may contain paddle wheel or axial flow mixers to prevent sedimentation. A portion of the oxygen-rich effluent from this cell may be recirculated by pumping to the anaerobic cell to provide an aerobic cap for odour control. The fourth cell in the pond series is relatively deep (2-3 meters) and unmixed to encourage sedimentation of algae. More cells in the pond series may be provided for further sedimentation and exposure of effluent to ultraviolet light and elevated pH for disinfection. The author provides brief descriptions of AIPS facilities in St. Helens, Ridgemark, Santee, and Arcata, California.

"Experimental Plants for Very Small Communities" (Boutin, C. 1993) evaluates five existing small-community wastewater treatment processes in France with wastewater flow equivalents from 50 to 400 people. The author states that one of the two most used treatment processes for this flow range in France—the lagoon or stabilisation pond process—is not satisfactory for communities so small. If the pond is oversized or if the connection rate remains low in the first few years, the pond fills to a very low level. This causes an increasing concentration of pollutant in the pond due to lack of effluent. Also, when a strong storm occurs, due to the small capacity of the pond, hydraulic overload can flush the pond, causing a discharge with high organic content.

"Rotavirus Removal in Experimental Waste Stabilisation Pond Systems" (Oragui, J. 1995) reviews rotavirus removal in different pond configurations. The authors found that rotavirus removal is a very slow process, requiring a lot of detention time in several ponds in series. In one configuration, the rotavirus removal was not related to pH, chlorophyll, ammonia or sulphide levels. In the "innovative" configuration, the combination of shallow depth and long retention times permitted development of a high pH in the pond, which encouraged rotavirus die-off.

"Treatment of Wastewater by Stabilisation Ponds—Application to Tunisian Conditions" (Ghrabi, A. 1993) concludes from studies of stabilisation ponds in France that warm climates greatly improve the efficiency of ponds due to increased microbial reaction rate. This can allow for a higher loading rate or decreased area. Also, sediment accumulation occurred mainly in the first in a series of ponds. The deposition rate was high (5 cm/year in the first pond and 1.3 to 1.6 cm/year in the maturation pond). In contrast to Boutin, (Boutin, C. 1993), the author feels that stabilisation ponds offer many advantages for small communities (with wastewater flows less than 0.25 million gallons per day (mgd)). These advantages include "easy plant operation and minimum maintenance, low construction and operation costs, high degree of pathogen removal, no requirement for external energy other than solar, and ponds are also useful for storing water for agriculture."

"Land Treatment of Wastewater" (Goldstein, N. 1981) describes operation of a few towns in the United States performing land application of wastewater to forests and crops. Land application serves three purposes:

- Tertiary treatment of wastewater
- Fertilisation of vegetation or crops
- Groundwater recharge.

Capital costs for spray irrigation can be large, but operation and maintenance costs are usually much lower than for mechanical tertiary treatment processes. One drawback is that irrigated crops can assimilate toxic metals, or pathogens.

“Natural Treatment Systems” (Kruzic, A. 1994) includes a literature review of ponds. It cites a few papers dealing with sedimentation of suspended solids and scour mechanisms of soil surface in overland flow.

“Biomass Nutrient Recycling” (Braangart, M. 1997) describes a wastewater treatment project in Rio de Janeiro, Brazil. The wastewater is very successfully treated by settlement and oxidation ponds, fish ponds, and aquaculture ponds. The idea behind the treatment facility’s design is to recycle nutrients back into the soil. The effluent is used for irrigating fruit and vegetable crops. The fish grown in the ponds were fit for human consumption, however the fruits and vegetables were only fit for livestock production because of the presence of pathogens in the effluent.

“The Advantages of a Compact Filter for Individual or Semi-Collective Waste Water Treatment” (Fazio, A. 1993) discusses a compact sand filter used for treatment and disposal of septic tank effluent. The filter relies on supply regulation and improvement of the waste’s surface distribution over the filter media. The purification achieved in the study using a dosing rate of 150 litres/square meter/day was over 90 percent for BOD, COD, NH_4, and total nitrogen. The author attempted to optimise the efficiency by compartmentalising the filtration media, adjusting the distribution nozzle, and using a biotextile over the filtration media so as to distribute the influent evenly. Unfortunately, one of the drawbacks of biotextiles is their tendency to clog with biological growth.

“Alternative Approaches for Upgrading Effluent Quality for Lagoon Based Systems” (Evans, B. 1993), evaluates two processes for polishing lagoon effluent: intermittent sand filtration and polishing lagoons. Benefits cited by the author for intermittent sand filters following lagoons are that they nitrify very well and are effective in removing algae, which is a chronic problem in lagoons. A cost analysis was performed for the Toronto area, which found that lagoon/sand filtration processes are cheaper than conventional extended aeration plants until the flow reaches about 1 mgd.

“Lateral Flow Sand-Filter for Septic-Tank Effluent” (Check, G.G. 1994) is a laboratory study of lateral-flow sand filtration units, each filled with different permeability sand. The dosing rate used was 3.3 cm/day. After the filter matured, removal rates for BOD, total organic carbon (TOC), suspended solids, and coliform bacteria were excellent. The maturation time was about six weeks for BOD removal, but up to three months for bacteria removal and nitrification. The distribution system of the sand filter was laid with gravel and separated from the sand with a biotextile to improve flow distribution. Sand with three different values for permeability was tested. The least permeable developed a thick biomat most quickly, and the coarsest fill developed a thinner biomat. The model with the coarsest fill had the best removal rates for coliforms and the worst for viruses (viruses are much smaller than coliforms). The authors recommend the coarser sand fill due to good treatment, system longevity and free-flowing hydraulics.

"Low-Tech Systems for High Levels of BOD and Ammonia Removal" (Rich, L. G. 1996) gives case studies of lagoons and intermittent sand filters in combination that perform with high efficiency in South Carolina. Sand filters are effective in removing BOD, TSS, and pathogens as well as nitrifying. The author notes that intermittent sand filters used for septic tank effluent lost popularity in the United States after World War II due to large land requirements and odour problems. When used as a polishing step after lagoons however, twice the dosing rate can be applied or half the land is required. The dosing rate for a filter in South Carolina was observed to be 23 cm/day. However, the author cites recent studies indicating that loading rates as high as 60 cm/day can be used if the proper sand is selected.

"Upflow Filters—Appropriate Technology for the West Indies?" (Sammy, G.K. 1978) provides some general information, design data, and a few case studies of upflow filters used as a final, polishing treatment process. At the time, no upflow filters were in operation in the West Indies.

"Actual Experiences with the Use of Reed Bed Systems for Wastewater Treatment in Single Households" (Perfler, R. 1993) is a study of reed-bed systems designed for single households (8 to 10 person equivalents) in Austria requiring improved nutrient removal. Three configurations were examined. All received pre-treatment in settling pits and a buffering tank before application to the subsurface flow reed bed. Elimination rates for nitrogen and phosphorus varied from 60 to 70 percent. The controllable water level in the bed affects nitrogen removal. In one instance, the water level was raised to the maximum level in the bed without any outflow. This caused a noticeable increase in ammonia in the effluent.

"Constructed Reed Beds: Appropriate Technology for Small Communities" (Green, M.B. 1995) considered subsurface flow reed beds as secondary treatment for small communities (up to 50 people) and tertiary treatment for larger communities (up to 2,000 people). Area requirements for reed beds as secondary treatment were stated to be 5 square meters per person to achieve a 20 mg/L BOD effluent concentration. As tertiary treatment, 1 square meter per capita is recommended to achieve 10 to 15 mg/L BOD. Constructed Reed Beds are excellent solids removal systems, but they do not nitrify well because of anaerobic conditions. Maintenance requirements include periodic cleaning of the distribution system and keeping a weedless reed bed. The authors found that some attention to weeding is necessary in the beginning stages of the reed bed. As the bed matures, less weeding is needed.

"Development of a Land Limited Wastewater Treatment Plant for Small and Rural Communities in the Tropics" (Yang, P.Y. 1994) finds that the combination of subsurface flow wetland coupled with an aerobic fixed film treatment process provides very good BOD removal while maintaining a small footprint. BOD conversion with this coupled system occurs twice as fast as in a wetland, pond, or oxidation ditch alone. The author claimed that mosquito and fly breeding are suppressed by the biological mat of vegetation that forms on the wetland surface.

"Integrated Constructed Wetland for Small Communities" (Urbanc-Bercic, O.) considers nitrification and denitrification efficiency in subsurface flow reed-bed wetlands. Aerobic and anaerobic regions can be produced by varying flow direction and volume. The authors referenced a paper which found that intermittent dosing does not always introduce enough oxygen for nitrification. The authors also found that dense reed stands increase the efficiency of decomposition of nitrogen compounds by denitrification.

"Natural Treatment Systems" (Kruzic, A. 1994) provides a summary of 1992 and 1993 papers written on constructed wetlands treatment systems. Wetlands provide a low-maintenance system that can remove BOD, nitrogen, phosphorus, and some toxic metals often found in industrial wastewater. They can serve as primary, secondary, or tertiary treatment processes.

R. Netter's (1993) "Planted Soil Filter—A Wastewater Treatment System for Rural Areas" explores design parameters for subsurface-flow planted-soil filters. The hydraulic loading rate used was 0.4 to 6.0 cm/day and BOD loading rates were from 0.9 to 9.7 grams/m^2/day.

The author of "The Use of Wetlands for Water Pollution Control in Australia" (Mitchell, D.S. 1995) contends that there is no overall consensus in design equations or understanding of the mechanisms involved in wetland treatment processes. Problems associated with wetland design or usage include variability in phosphorus removal efficiencies from wetland to wetland, hydraulic short-circuiting in small wetlands, lower than expected performance from scale-up laboratory experiments, and the inability of some vegetation to tolerate shock loads. Wetlands are predictable and effective as a tertiary process. When too much strain or loading is applied or if the wetland is used as a secondary process, efficiency can be unreliable.

"Long-Term Impacts of Sewage Effluent Disposal on a Tropical Wetland" (Osborne, P.L. 1994) warns readers that a wetland's life span as an efficient "sieve" is finite. The author gives a case history of a wetland in New Guinea that received stabilisation pond effluent. Pictures are presented to demonstrate decline in vegetation over 25 years and a corresponding decrease in treatment efficiency. The author is not sure whether the vegetation decline was due to the wastewater pollutants or to fluctuation in flow volume. The author feels more research is needed on wetland capacity for wastewater treatment.

The author of "Experimental Plants for Very Small Communities: Choice and Design Criteria for Five Different Processes" (Boutin, C. 1993) found that efficiency improved when infiltration beds were allowed to rest between doses to facilitate oxygen transfer into the soil matrix. This can be done by alternating between two or more beds. The author feels that the greatest problem for proper operation is even distribution of effluent on the surface. This is difficult to achieve with gravity flow (the usual kind of flow in rural or medium density areas), but not if a small pump supplies the flow.

"Natural Treatment Systems" (Kruzic, A. 1994) provides a review of studies performed on rapid infiltration and soil treatment techniques. One paper in the review found an optimal infiltration rate of 2.13 m/day and an optimal wet-to-dry ratio of 1:1. Coliform removal was in the range of two to three orders of magnitude. Other attempts were made to use treated effluent as reclaimed water for non-potable and potable uses. One study found that significant nitrification occurred during the drying cycle in a system with an intermittent dosing regime. Nitrate concentrations in the groundwater increased sharply at this time.

"Wastewater Treatment of Greater Agadir (Morocco): an Original Solution for Protecting the Bay of Agadir by Using the Dune Sands" (Bennani, A.C. 1992) describes the infiltration/percolation treatment processes following anaerobic stabilisation ponds for a town of 350,000 people. At a loading rate of about 1 meter/day, nearly 100 percent of the suspended solids and 95 percent of the COD is removed while 85 percent of the nitrogen is oxidised. Also, a four to five log removal of coliforms is achieved.

"Development of a Biofilter Using an Organic Medium for On-Site Wastewater Treatment" (Talbot 1996) describes the development and commercialisation of a peat-based biofilter suitable for on-site use in areas where percolation and infiltration techniques are not viable due to poor soil permeability or a high water table. This process is meant to be used for septic tank effluent treatment and consists of a thick peat layer over a thin gravel bottom. Initial removal efficiencies of 97 percent BOD , 99 percent faecal coliform, 60 percent ammonia, 22 percent total nitrogen, and 12 percent total phosphorus were obtained treating septic tank effluent. An upper limit for the daily hydraulic loading rate (where treatment efficiency begins to drop off considerably) is 300 litres/square meter. During this period, a yellow colour is generally imparted on the effluent, and the pH may reach 4.0 or less.

"Experimental Plants for Very Small Communities: Choice and Design Criteria for Five Different Processes" (Boutin, C. 1993) evaluates five different treatment options for communities from 50 to 400 person equivalents. A trickling filter was used as one of the treatment options and was the most expensive per capita.

"The Cyclic Activated Sludge System for Resort Area Wastewater Treatment" (Goronszy, M. 1995) describes a proprietary sequencing batch reactor (SBR) treatment process. What is special about this process is the use of a contact or selector zone in the batch reactor. The influent first comes into an anoxic region that is separated from the rest of the aeration basin. The idea is to maintain a high food-to-mass ratio for the organisms in the contact or selector zone, which "selects" micro-organisms that settle well. Well-settling organisms thrive in high food and high dissolved-oxygen environments while filamentous (poor settling) organisms thrive in low dissolved-oxygen and low food conditions. The contact or selector zone will give the well-settling micro-organisms a head start in becoming the dominant seed to the mixed liquor. Timing in the basins can be adjusted to accommodate low, average, and peak flow conditions, while ensuring adequate treatment. Another advantage with sequencing batch reactor technology is the small footprint compared to continuous activated sludge systems with separate sedimentation tanks. SBRs are primary clarifiers, aeration basins, and secondary clarifiers all in one reactor. Also, there is no need for sludge recirculation pumping unless a selector tank is used. The primary drawback to the SBR process is that effluent disinfection facilities must be oversized to accommodate the intermittent flow.

DOMESTIC SEWAGE TREATMENT OPTIONS FOR CONVENTIONAL MECHANISED TREATMENT

The following are well-written textbooks or manuals on conventional, mechanised treatment technologies:

- *Recommended Standards for Sewage Works (Ten State Standards), 1978.*
- *Design of Municipal Wastewater Treatment Plants Vol. I & II* (ASCE 1992, WEF Manual of Practice No. 8);
- *Appropriate Wastewater Treatment Technologies for the Caribbean* (Millette, E. 1992);
- *Innovative and Alternative Technology Assessment Manual* (U.S. EPA 1980)
- *Municipal Wastewater Treatment Technology Fact Sheets* (U.S. Department of Commerce 1991).

"15 Years of Practical Sewage Treatment in Venezuela" (Lansdell, M. 1996) describes a few municipal treatment plants in Venezuela that use activated sludge processes to treat flows from a population of up to 5 million. It emphasises simplicity of operation and avoiding technological dependence on other countries for imported spare parts ("unskilled manpower is plentiful and foreign currency is in short supply"). Technologies included are simple activated sludge systems, modified sequencing batch reactors (MSBRs), oxidation ditches, and lagoons.

"An Evaluation of the Efficiency and Impact of Raw Wastewater Disinfection with Peracetic Acid Prior to Ocean Discharge" (Ruiz, C.S. 1995) explores an alternative disinfection strategy for wastewater. Peracetic acid (PAA) disinfection was observed in 5 to 10 minutes using doses of 2 to 80 mg/L. One advantage of PAA is that it quickly degrades into benign compounds, acetic acid and active oxygen. PAA is most suitable for disinfecting wastewater to be discharged to the sea. The author suggests that the optimal dose is 20 mg/L with a contact time of 10 minutes. Higher concentrations of PAA did not significantly improve disinfection efficiency. Neutral or slightly acidic wastewater improved PAA disinfection efficiency, while in alkaline wastewater (pH>8.l; pKa PAA=8.2) disinfection efficiency was lower. One wastewater sample with a pH of 7.9 was given a 20 mg/L PAA dose with 15 minutes of contact time and achieved a coliform inactivation rate of 6.45 logarithmic units. The main drawbacks of peracetic acid disinfection is that it is almost as hazardous to handle as chlorine and it may lower the pH of the receiving water.

"Feasibility of Anaerobic Sewage Treatment in Sanitation Strategies in Developing Countries" (Alaerts, G.J. 1993) discusses the feasibility of anaerobic treatment of sewage for on-site systems, mid-size communities or townships, and centralised off-site systems in developing countries. The author feels that anaerobic treatment is most economical in off-site centralised treatment schemes. Although BOD removals are not as good as most aerobic treatment units, there are many advantages to anaerobic treatment. Methane production can be significant at large-flow plants, biomass (sludge) production is about half of that produced in aerobic processes, the sludge produced can be well stabilised and thickened (5 to 8 times thicker), helminth ova removal is excellent, and effluent is high in nutrients, which makes it suitable for irrigation. Some disadvantages are that BOD removal is in the 25 to 80 percent range, and virtually no nutrients are removed. Consequently, some sort of aerobic treatment unit is usually needed to meet effluent requirements. If nitrification is a requirement, anaerobic systems are much less attractive as an alternative, according to the author.

"Mexican Project Combines Industrial and Municipal Wastewater Treatment" (Unknown 1994) provides a discussion of a wastewater treatment plant that treats both domestic and industrial sewage. The treatment plant, at Salamanca, Mexico, receives domestic wastewater from a population of 500,000 and wastewater from an oil refinery. The combined flow first goes through dissolved air flotation (DAF), where much of the oil is skimmed and sent to a centrifuge for further separation. The effluent from DAF then goes to aerobic digesters. After aerobic treatment, calcium carbonate is added for clarification, and then the effluent is chlorinated. Part of the effluent is routed back to the oil refinery for reuse, and the rest goes into a river.

"Submarine Outfalls—General Overview, Basic Design Concepts and Data Requirements for Latin America and the Caribbean" (UNEP 1994) provides an alternative view of wastewater disposal in coastal communities. Submarine disposal of wastewater can be just as effective as wastewater treatment, provided that dilution of discharged sewage is sufficient to reduce contaminant concentrations below water quality standards. A minimum initial dilution of 100:1 is common, and is adequate for achieving most water quality standards, if not all. Three mechanisms are considered in dilution calculations for an outfall: initial dilution; horizontal transport and dispersion; and kinetic reaction. The contaminant of concern for wastewater outfalls to open oceans is pathogen content. In bays or estuaries (or anywhere with limited exchange with the open ocean), nutrients and BOD become important concerns. Total dilution is the product of initial dilution, horizontal dilution, and coliform reaction/disappearance. Initial dilution and bacterial die-off are usually much more significant than horizontal dilution. For non-degradable substances, initial dilution is the most important factor in determining total dilution. This can be an economical alternative to conventional wastewater treatment. Receiving-water quality and currents must be characterised before submarine outfalls can be considered, however.

An extension of this article is "Submarine Outfalls—A Viable Alternative for Sewage Discharge of Coastal Cities in Latin America and the Caribbean" (UNEP 1993). The author gives an overview of the population distribution of this region and the cities or regions that use submarine outfalls for sewage disposal. At the time of writing, 84 outfalls were listed in Latin America and the Caribbean; almost half (39) are in Venezuela, and only one exists in Martinique in the Caribbean Sea.

"Wastewater Treatment and Reuse Aspects of Lake Valencia, Venezuela" (Lansdell, M. 1991) describes environmental problems of the Lake Valencia Basin and the treatment plan that has been funded by the Inter-American Development Bank. The author argues that reuse plans for developing countries must avoid excessive technological dependence. Availability of land and warm climate allows for the efficient operation of lagoons and wetlands. Primary objectives of the Valencia plan include: treatment of domestic and industrial wastes; effluent reuse in irrigation; recharging groundwater aquifers; desalination of groundwater aquifers; and reduction of artificial fertiliser usage by farmers.

INDUSTRIAL WASTEWATER

A few comprehensive and reference books on industrial wastewater treatment are:

- *Industrial and Hazardous Wastewater Treatment* (Nemerow, N. 1991)
- *Industrial Wastewater Treatment Technology* (Patterson, J.W. 1985)
- *Handbook of Industrial Waste Disposal* (Conwya, R.A. 1980)

All of these reference books provide valuable information on types of pollutants from different industries, appropriate treatment technologies for specific pollutants, and management issues.

Management of Industrial Wastewater in Developing Nations (High Institute of Public Health 1981) is a collection of articles from the "Proceedings of the International Symposium" held in Alexandria, Egypt in March of 1981. There are 41 articles in this collection, many of which are relevant to this project. Specific treatment processes for certain industries are included, along with effluent quality issues, water reclamation and reuse, and policy development and other related planning issues.

“Industrial Wastewater Management in the Caribbean Region” (Sammy, G.K. 1995) reviews the types and volumes of wastewater produced from 13 industries in the Caribbean. Effluent limits are discussed, and the concept of “reduce, reuse and recycle” is emphasised. The author states that more progress needs to be made in this area, since little has been done in the past.

The petroleum industry is the largest BOD contributor to coastal waters in the Caribbean. The following three books provide useful information about pollutants in typical petroleum industry wastes, and treatment processes that can reduce these pollutants before they are discharged:

- *Pollution Control in the Petroleum Industry* (Jones, H.R. 1973)
- *Pollution Control for the Petrochemicals Industry* (Borup, M.B. 1987)
- *Aqueous Wastes from Petroleum and Petrochemical Plants* (Beychok, M.R. 1967)

“Biodegradation of Petroleum Refinery Wastewater in a Modified Rotating Biological Contactor with Polyurethane Foam Attached to the Disks” (Tyagi, R.D. 1993) explores aerobic rotating biological contactor (RBC) technology for significant BOD removals from oil refinery wastewater. The foamy material acts as a porous support for more biomass than a conventional RBC, thus increasing contact opportunity for the biomass with the soluble organic materials. Up to 87 percent removal was observed with this technique.

Management of Water Discharge: Design and Operation of Oil-Water Separators (American Petroleum Institute 1990) provides design guidance for gravity-type oil-water separators for use in petroleum refineries. The manual also provides practical advice for solving operational problems and improving the performance of oil and water separation facilities.

“Innovative Technologies for Treatment of Oily Wastewater” (Benedek, A. 1992) discusses the energy-intensive technology of membrane filtration techniques to remove emulsified oil from wastewater.

The author of “Petrochemical Wastewater Treatment with Aerated Submerged Fixed-Film Reactor (ASFFR) Under High Organic Loading” (Park, T.J. 1996) found that 92 to 97 percent COD removal is possible at a volumetric organic loading rate of 0.9 to 6.3 kg COD/cm/day. COD removal increased with the packing ratio. Clogging and channelling typical of stationary filters were avoided since this filter has a separate settling zone.

“Skimming Oily Wastewater” (Hobson, T. 1996) emphasises the benefits of oil skimming. It is useful not only as a pre-treatment step, but can stand alone as a treatment process in light of recent advances in skimming technology. The author discusses design conditions and criteria such as reservoir design, turbulence, reservoir depth, and skimmer media.

“Treatment of Wastewater From Oil Manufacturing Plant by Yeasts” (Chigusa, K. 1996) explores the process of using yeasts to degrade wastewater from soybean oil manufacturing plants. The yeast strains were isolated out of the waste stream and found to perform well enough that dissolved air flotation was unnecessary as a pre-treatment step. Nine different yeast strains were studied.

Several other useful journal articles on oil and petrochemical refinery waste treatment were obtained through the Purdue Industrial Waste Conference Proceedings. These annual proceedings are an excellent resource for current developments on industrial waste treatment and management, and should be the starting point for any literature review related to industrial wastes. The journal articles obtained from the proceedings are:

- "Wastewater Reclamation and Reuse in a Petrochemical Plant" (Wong, J.M. 1995)
- "Evaluation of Physical, Chemical, and Biological Treatment to Remove Fats, Oils, and Grease from Petroleum Refinery Waste Effluent Prior to Recycling to Cooling Towers" (Mitchell, D.B. 1994)
- "Land Treatment of Petroleum Waste in Regina Area, Saskatchewan" (Viraraghavan, T. 1994)
- "Hazardous Sludge Reprocessing and Reduction in Petroleum Refining" (Engelder, C.L. 1993)
- "Environmental Solutions Based on Recycling of Water, Oil, and Sludge at an Integrated Oil Refinery" (Galil, N. 1992)
- "Disposal of Hazardous Wastes from Petroleum Refineries" (Bryant, J.S. 1991)
- "Pilot Testing and Design of an Activated Sludge System for Refinery Wastewater" (Copeland, E.C. 1991)
- "A Comparative Study of RBC and Activated Sludge in Biotreatment of Wastewater from an Integrated Oil Refinery" (Galil, N. 1990)
- "Removal of Oil and Grease in the Hydrocarbon Processing Industry" (Rhee, C.H. 1988).

"Anaerobic/Aerobic Combination Treats High-Strength Wastewater" (Ulrix, R.P. 1994) reviews a successful treatment process for wastewater from a beet sugar refinery. A single-stage upflow anaerobic reactor was used to treat the high strength waste. Following the anaerobic reactor was a polishing aerobic/anoxic phase to further lower BOD and nitrogen levels. The plant was able to treat a large seasonal fluctuation in organic loading over time, which is characteristic of many food-processing industries.

"Anaerobic Codigestion of Agricultural Industries' Wastewater" (Gavala, H.N. 1996) explores the idea of combining different food-processing industries' wastewater in a central facility, to minimise the seasonal flux of organic loads, which can shut down anaerobic treatment processes. A mathematical model is developed describing the codigestion process. The model is capable of predicting COD and fatty acid dependence on operating conditions, and should be useful for designing codigestion processes.

"Anaerobic Digestion of High Strength Molasses Wastewater Using Hybrid Anaerobic Baffled Reactor" (Boopathy, R. 1991) examines the process efficiency of the anaerobic baffled reactor, which essentially produces plug-flow-like conditions. The HABR successfully treated 20 kg COD/cm/day. The biomass in the reactor quickly adjusted to a change in feed volume, and high loading rates were observed without any biomass washout. Also, granulation was achieved more quickly than in other upflow anaerobic systems.

"Wastewater Treatment Technologies" (Farmer, J.K. 1991) provides an overview of treatment requirements for U.S. food processing industries and pre-treatment processes used to achieve them. Most U.S. food processing industries discharge to public sewerage systems that have pre-treatment requirements. The author notes that aerobic biological treatment units are the predominant technique, and that SBR technology is worth consideration.

"Brewery Wastewater Treatment in UASB Reactor at Ambient Temperature" (Yan, Y.G. 1996) is an academic study on granule development. BOD and hydraulic loading rates were determined for optimal sludge granule growth.

"Using an Anaerobic Filter to Treat Soft-Drink Bottling Wastewater" (Carter, J.L. 1992) describes the pre-treatment processes for the wastewater generated by for Shasta Beverage Company in Kansas. The effluent from the plant is discharged to the municipal wastewater district. The untreated wastewater, which ranges in BOD from 200 to 4,000 mg/L needs to be reduced to an EPA-required level of 200 mg/L as a weekly average. Detailed design information is provided. "Treatment of Soft Drink Syrup and Bottling Wastewater Using Anaerobic Upflow Packed Bed Reactors" (Capobianco, D.J. 1990) gives experimental results of 5 bench scale upflow anaerobic reactors. Impressive COD removals of over 85 percent were obtained with less than seven hours of hydraulic detention time. The influent COD values were close to 5,000 mg/L at times. The reactors also demonstrated an ability to withstand short term shock loads in COD.

"Application of Anaerobic Digestion to the Treatment of Agroindustrial Effluents in Latin America" (Borzacconi, L. 1995) surveys the use of anaerobic treatment processes in Latin America. The four most important industries in Latin America are breweries, distilleries, dairy production, and yeast plants. More and more industries are using anaerobic treatments to reduce BOD loads on municipal treatment facilities or receiving waters. The warm climate in many parts of Latin America, the generation of biogas as an energy source, and the ability to handle high-strength wastewater is making anaerobic reactors popular.

"A New Process to Treat Strong Biological Waste" (Henry, D.P. 1993) explores the idea of trickling brewery and piggery wastewater down a vertical curtain consisting of two layers of polyurethane foam. Attached biomass would provide treatment. The idea is to provide a large surface area for biomass to adhere, and thus provide more efficient treatment. Maintenance includes harvesting excess growth. A surface area of 1 square meter with a 4-meter fall will adequately treat 15 L/day of waste containing 60,000 mg/L total oxygen demand (TOD).

"Strategies in Agroindustrial Wastewater Treatment" (Sendic, M.V. 1995) describes the waste treatment processes of the three most important industries in Uruguay: slaughterhouses, wool scouring factories, and tanneries. The waste stream from wool scouring industries carries significant amounts of grease and COD, slaughterhouses produce a high COD and TSS load, and tanneries generate high COD loadings along with some metals (chromium and sulphides). Wool scouring factories and slaughterhouses require DAF with anaerobic reactors, while tanneries need chemical treatment to remove the metals from the waste stream.

"Anaerobic Pre-treatment of Dairy Liquid Effluents" (Filho, B.C. 1996) describes an upgrade project for a facility treating dairy liquid effluent in Brazil. The lagoons used to treat the waste streams were not capable of handling the increasing COD load accompanying the dairy factory's growth. To help treat the increasing COD load (with concentrations up to

37,000 mg/L, average value of 6,300 mg/L), an upflow anaerobic reactor was added after the screening process. With a hydraulic detention time ranging from 7 to 28 hours, the COD removal efficiency ranged from 40 to 70 percent, with an average efficiency of 53 percent. Suspended solids removal was a little less than 50 percent, and the total nitrogen removal was about 28 percent.

"Anaerobic Treatment of Swine Waste by the Anaerobic Sequencing Batch Reactor (ASBR)" (Zhang, R. 1996) evaluates the performance of an ASBR with a short hydraulic detention time (two to six days). The volatile solids reduction ranged from 39-61 percent and the BOD reduction ranged from 58 to 86 percent. Surprisingly, a better removal was achieved with a three-day detention time than with a six-day detention time.

"Application of Constructed Wetlands to Treat Some Toxic Wastewaters Under Tropical Conditions" (Polprasert, C. 1996) examines removal of phenolics and heavy metals by constructed wetlands with a free water surface. Influent chromium and nickel concentrations of 1 to 10 mg/L did not have significant effects on the wetland's performance. However, when the heavy metal concentration increased to 20 or 50 mg/L, COD removal efficiencies dropped to 70 to 35 percent.

"Closed-Loop System Recycles VOCs from Refinery Wastewater" (Pollution Engineering 1992) describes a system for removing volatile organic compounds (VOCs) at two major U.S. oil refineries with greater than 98 percent efficiency. The technology combines nitrogen stripping, relative humidity adjustments, and activated carbon technologies.

SOLIDS TREATMENT AND DISPOSAL

The design manual, *Sludge Treatment and Disposal* (U.S. EPA 1979) provides detailed design criteria for several treatment and disposal options.

The EPA handbook, *Septage Treatment and Disposal*, (U.S. EPA 1984) provides design criteria for appropriate treatment and disposal alternatives for septage.

"Treatment and Disposal of Domestic Sewage Sludge and Nightsoil Sludge for Bangkok" (Stoll, U. 1996) is a survey of solids or sludge treatment and disposal methods in Bangkok. Decision trees are provided for determining the "appropriate" treatment method to use. Some options identified are agricultural use, land reclamation, landfill disposal, mono-incineration, coincineration, and other recycling or reuse options. The authors point out that waste minimisation should be the first priority for management authorities, even though this is not always economically feasible. With that in mind, mono-incineration after dewatering is recommended as a preferred process for urban centres with large volumes of sludge, followed by direct agricultural use or composting. Landfill disposal has historically been cheapest in the past, yet this is changing in large urban centres.

"Treatment of Septage Using Single and Two Stage Activated Sludge Batch Reactor Systems" (Andreadakis, A.D. 1995) provides an option for septage treatment. Septage is characterised by high strength (2.5 times stronger than typical domestic sewage). Cyclic batch-operated systems (SBR) can treat this type of load, since flocs formed from septage generally settle well, and allow for a high mixed liquor suspended solids (MLSS) concentrations (up to 8,000 mg/L). A single-stage batch aerated system with a reactor volume of 1.6 times daily septage flow, a solids retention time (SRT) of 15 days, and COD loading of 0.15 mg/mg MLSS/day produced a well-stabilised sludge and good nitrification. Further improvements were made in the study by a second-stage system with anoxic and aerobic zones to encourage denitrification.

CHAPTER 5.
SITE VISITS

Site visits were arranged in November 1997 to sewage treatment facilities thought to be typical of facilities currently operating in the region. Facilities were chosen in three countries: Venezuela, Trinidad, and St. Lucia. Venezuela was taken as representative of several countries in the region—Spanish-speaking, continental, and urbanised with advancing industrialisation. Trinidad is a larger island republic with a continental geographic connection and a history of both Spanish and British political influence and well-established industrialisation. St. Lucia is a smaller island country with a political history of French and British influence whose economy is more agricultural and tourist-centred. Site visits will be discussed by country visited.

VENEZUELA

Venezuela is a relatively large Spanish-speaking country on the northern coast of the South American continent, the southern shore of the Caribbean Sea. It is largely urbanised. The City of Caracas is one of the largest cities in South America, with a population estimated at 5 million. The metropolitan areas of Maracaibo and Valencia both have populations in excess of 1 million. Sewage collection by gravity is relatively widespread. It has been estimated that approximately 85 percent of the population of the country is served by piped water, 60 percent by sewage collection facilities, but only 3 percent by sewage treatment (Lansdell, 1996). Currently none of the major cities of Caracas, Maracaibo, or Valencia treat domestic sewage. Isolated industrial discharges receive treatment, but residential areas are typically served by gravity sewers leading to outfalls in nearby rivers or streams.

During the site visit, KCM saw four sewage treatment facilities, two currently operating on the Island of Margarita and two under construction in the vicinity of Lake Valencia. Other facilities are currently under construction for Maracaibo. All of these facilities were designed by the firm of Mark Lansdell Associados in Caracas, and Mr. Lansdell served as an escort for the site visits. Upon completion, the new facilities will increase the population served by domestic sewage treatment in Venezuela from 3 to 25 percent.

Valencia Projects—General

The Valencia sewage treatment project is part of a comprehensive water management scheme for one of the largest fresh water bodies in the northern part of South America. The lake level has been extremely variable over the last 200 years of increasing human use of this broad drainage basin (30 km long by 20 km wide). Until 1978, the lake level fell by 260 mm per year, exposing rich agricultural land for human use. In 1978 it was discovered that the heavily polluted Cabriales River was influencing water quality in a major water supply reservoir. At that time the river was diverted into Lake Valencia, causing a rise in lake level and a decrease in lake water quality. The Valencia sewage treatment project will intercept discharges to the river and convey the sewage to the new Mariposa sewage treatment plant.

A raw sewage outfall into the Cabriales River. The Valencia sewage treatment project will intercept sewage from this discharge and many like it and convey it to the new Mariposa treatment plant.

The Valencia sewage treatment project was conceived to correct water quality and lake level problems. The project includes 90 km of interceptor sewers, 17 km of sewage pumping mains and associated pumping stations, and three major treatment facilities to serve a population of 3.4 million by 2015. The project will treat domestic and industrial wastes, control the level of Lake Valencia, and produce effluent for irrigation and indirect urban uses (Lansdell and Carbonnell, 1991). Project components have been under construction since 1988. To date, major portions of the interceptor and sewage pumping system have been constructed. Work is underway at all three treatment plants. A construction site for a siphon structure under the Cabriales River and two treatment plants, La Mariposa and Los Guayos, were included in the site visit.

The Lake Valencia projects have been funded by a major grant from the Inter American Development Bank. The total cost of the projects, including potable water supply aqueducts and treatment plants and the sanitary sewage facilities, has been reported as $125 million US (Republica de Venezuela, 1993.)

La Mariposa

The Mariposa plant was designed to receive wastewater from a population of 770,000. It will serve the city of Valencia on the western side of Lake Valencia. The plant will provide tertiary-treated effluent with partial nutrient removal for transfer out of the Lake Valencia basin for indirect potable water reuse. The plant includes a simple headworks structure with manual bar racks and grit removal. It features activated sludge treatment using a continuous-level cyclic feed aeration system called a modified sequencing batch reactor (MSBR). This process is further discussed below in the description of the Juangriego treatment plant. The plant has four MSBR treatment modules, each with a volume of 45,000 m^3 and a capacity to serve a population of 200,000, or 51,800 m^3/day of influent sewage flow. The design hydraulic residence time for each of the MSBR basins is approximately 21 hours.

MSBR tanks at the Mariposa treatment plant will use high-speed direct-drive propeller aerators suspended from concrete access bridges.

The MSBR tanks use high speed, direct-drive propeller aerators suspended from three concrete access bridges in each module. Each module will be equipped with twenty-two 75-hp aerators and twelve 3.3-kW mixers. Mixers in the first stages of the influent zones of each module will encourage denitrification. An open baffle between the middle, aerated zone and the anoxic influent zone will allow internal recycling; no internal recycle pumps are provided. Clarified effluent from the MSBR treatment units will be filtered in four declining-rate sand filters to remove residual suspended solids and phosphorus. Effluent from the filters will be discharged to a clearwell for filter backwash. Final effluent will be pumped by axial turbine pumps to areas of groundwater recharge and indirect water reuse. Sludge will be pumped from the MSBR basins to densification basins, with the supernatant returned to the plant headworks. Thickened sludge from the densification basins will be pumped to sludge drying basins for dewatering and stabilisation prior to eventual off-site land application as a soil amendment. When completed, the Mariposa plant will provide the most sophisticated treatment of any in the region, through use of simple, appropriate technology.

Los Guayos

Construction of concrete liner on the side slopes of the primary treatment cells at the Los Guayos treatment plant.

The Los Guayos treatment plant is a lagoon system designed for a population of 1.5 million. It will serve the community of Los Guayos and others adjacent to the city of Valencia on the western and northern shore of Lake Valencia. The plant includes two primary treatment cells with relatively deep hopper bottoms. Sludge from the cells will drain by gravity to a sludge drying basin. Effluent from the primary cells will discharge to a series of facultative lagoon cells with a total area of approximately 120 hectares. Based on the design influent flow of 2,000 litres per second, or 173,000 m^3/day, and an assumed influent concentration of 200 mg/L of BOD, the overall loading on the lagoon system will be approximately 288 kilograms of BOD per day per hectare. The plant features a recirculation canal and submersible pumps to mix treated effluent with influent to the anaerobic cells. Effluent from the plant will be made available for irrigation or discharged to the Los Guayos River, the receiving stream for the current raw sewage discharges of the upstream drainage area.

Dos Cerritos

The Dos Cerritos treatment plant for the city of Porlamar on the Island of Margarita was the first activated sludge plant of any substantial size to be constructed for treatment of domestic sewage in Venezuela. The Island of Margarita is the main coastal tourist attraction in Venezuela. In the early 1970s increases in sewage flows to raw sewage outfalls resulted in increases in faecal coliform concentrations at beaches. This caused significant concern and threat to the tourist economy and a desire for corrective action. The Dos Cerritos plant was first conceived in a master plan prepared for the city of Porlamar in 1975. It was designed in 1980. Project implementation suffered from delays in construction financing, and the plant did not come into service until 1989.

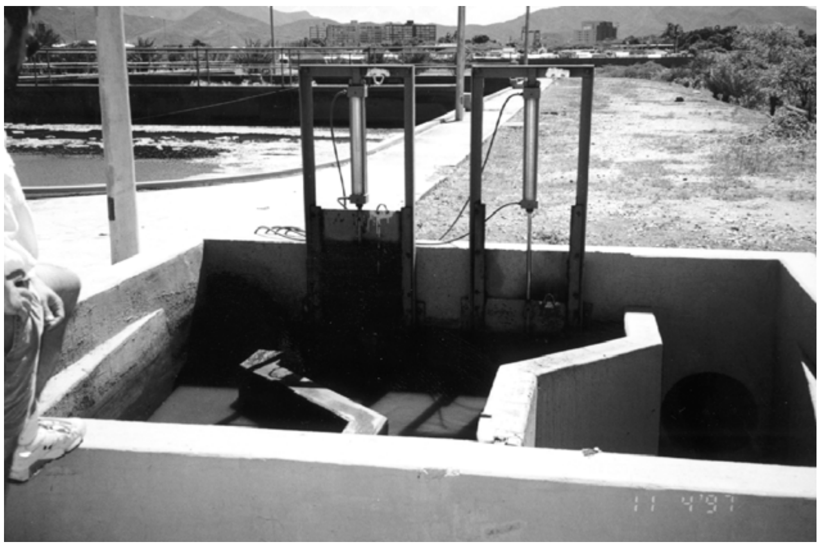
Aeration tanks at the Dos Cerritos treatment plant.

The plant provides secondary treatment by the activated sludge process. Effluent from the plant is used for irrigation or discharged to the Caribbean Sea. The plant was designed for a wastewater loading from a population of 200,000. The design influent flow was 600 L/sec or 51,840 m^3/day. At the time of the site visit, average plant flow was 31,146 m^3/day. Headworks facilities for the plant include manual bar racks and a grit removal channel. The plant has five aeration tanks with a total volume of 17,300 m^3 for a total hydraulic residence time of 8 hours under design flow.

Activated sludge is separated in six settling tanks, each 20 meters square for an average overflow rate at the design flow of 0.9 m/hr. The settling tanks have no rake mechanisms. Sludge is withdrawn continuously from four inverted pyramidal pockets through telescoping valves. The combined return activated sludge flow from all six settling tanks is pumped by Archimedes screw pumps into the plant headworks. Effluent from the activated sludge process is discharged to two maturation ponds for natural ultraviolet disinfection. The maturation ponds are 1.5 m deep and designed for an average detention time of five days. At the time of the site visit, the maturation ponds were reducing faecal coliform concentrations in the activated sludge effluent from 270,000 organisms per 100 mL to less than 200 per 100 mL prior to final discharge, through the effects of solar radiation and bacterial die-off in the shallow maturation ponds and without use of chemical disinfectants. The effluent concentration averaged approximately 15 mg/L BOD and 10 mg/L total suspended solids (TSS). The plant was fully nitrifying with effluent ammonia concentrations averaging 0.1 mg/L. Mixed liquor from the activated sludge process is wasted to sludge lagoons, which serve to concentrate and stabilise sludge prior to land application.

Juangriego

The site visit included the treatment plant for the community of Juangriego on the northern coast of the Island of Margarita. This plant currently protects the Bay of Juangriego from sewage contamination that had closed beaches to recreational use by the late 1970s. The plant came on line in 1990. It was designed for a population of 50,000 and an average flow of 10,000 m^3/day. Current flows are approximately one-fourth of the design flow. The plant contains the same basic elements as the Dos Cerritos plant—headworks, activated sludge treatment, and maturation ponds for final disinfection. The plant's activated sludge process is the first operating MSBR system and has served as a model for design of subsequent facilities by the Lansdell firm in Venezuela, including the Mariposa plant in Valencia, and similar facilities for Colonia Tovar, Cruz del Pastel, Cumana East, and Punta Gorda.



Simple pneumatically operated gates cyclically feed different zones of the MSBR at the Juangriego treatment plant.

The MSBR process is an activated sludge process in which different zones in a single activated sludge basin serve alternately for aeration and for sedimentation thus eliminating the need for separate settling tanks and return activated sludge pumping systems. Simple pneumatically operated gates cyclically feed different zones of the MSBR. Unlike conventional sequencing batch reactor (SBR) systems, the MSBR process has a constant water level in the basin and does not result in a significant loss of head. Neither does it produce elevated flow rates from batch discharge of effluent. SBR systems lose up to 3 meters of head across the process and produce a batch discharge up to eight times the average flow into the system. The batch discharge feature of a conventional SBR system requires downstream elements such as filtration, disinfection, and effluent outfalls to be sized for elevated flows. The MSBR process does not share these drawbacks. It has the added advantage that basins can be constructed as excavated earthen basins with a thin concrete or other liner to prevent leakage and erosion. This permits less expensive construction than the concrete-walled basins designed for hydrostatic loads that are typically used for activated sludge aeration.

Effluent zone of the Juangriego basin operating in a decant mode.

The Juangriego plant is divided into nine individual cells through which water flows in a serpentine path. The flow path is reversed on a regular cycle. The three outer cells on each side of the basin are alternately used for sewage feed and aeration and for sedimentation and decanting. The middle three cells in the basin are always used for aeration. The Juangriego plant uses nine floating surface aerators that are alternatively turned on and off in the inlet/sedimentation zones of the basin. The plant has consistently produced effluent in the range of 5 to 15 mg/L of TSS and BOD with less than 200 total coliform organisms per 100 mL. The Juangriego plant was constructed in 1989 for a total cost of $900,000 US. The Dos Cerritos and Juangriego plants are operated by a private contractor, Ejecuciones Terepaima, S.A.

Cost of Sewage Treatment Facilities in Venezuela

The construction cost of completed MSBR activated sludge systems in Venezuela has been in the vicinity of $80 US per m^3/day average flow capacity or $20 per population equivalent (Lansdell, M 1996). Comparable costs for construction of activated sludge treatment systems in the United States would be at least 15 times as great. This lower cost is due to many factors. A key factor is lower labour rates, which are a primary element in treatment plant construction costs. Higher temperatures and solar input in Venezuela result in higher growth rates for treatment organisms, allowing relatively small tank volumes for treatment reactors. Use of sludge lagoons for solids stabilisation and drying reduces the cost of the treatment facilities significantly in Venezuela compared to construction in Europe or the United States. In the United States, as much as 50 percent of the capital cost of sewage treatment construction can be for sludge treatment facilities. In Venezuela this ratio can be much less if solar sludge drying in open, unlined earthen basins is used. The experienced cost for construction of lagoon systems in Venezuela is only $4 US per population equivalent, one fifth the cost of activated sludge systems (Lansdell, M 1996). This cost does not include the cost of land.

Lansdell estimates the cost of operation and maintenance of MSBR systems in Venezuela at $2 per person per year, about half of which is for electrical power. This produces a total capital and operating cost for sewage treatment of approximately $5 per capita per annum, about 10 times the cost of lagoon systems in Venezuela, but only 10 percent of the cost of such systems in developed countries in northern climates. The ratio of the cost of sewage treatment to gross national product in Venezuela is estimated at approximately 0.25 percent for activated sludge systems and 0.025 percent for lagoons.

TRINIDAD

Trinidad and Tobago are the southernmost islands in the Caribbean region. Trinidad is the largest and most heavily populated island in the Eastern Caribbean. It was sighted in 1498 by Christopher Columbus who christened it La Isla de la Trinidad, for the Holy Trinity. The first Spanish settlement was in 1592 and it remained a part of the Spanish Empire until 1797 when it came under British control. It remained dominated by England until its independence as part of the Republic of Trinidad and Tobago in 1962. The island has a mix of urban development, rain-forested mountains and small farming communities. It is relatively heavily industrialised with major petrochemical complexes in the south of the island. Other industries include production of processed foods, fertilisers, cement, steel, and electronics.

The site visit included four sewage treatment facilities on Trinidad, three of them larger facilities serving major urban areas around Port of Spain and San Fernando, the island's largest urban centres. These plants were operated by the Water and Sewage Authority of the Republic of Trinidad and Tobago. The visit also included a smaller extended aeration treatment plant built for a housing development by the Housing Authority. This plant is typical of the more than 150 package plants treating wastewater from small residential developments on the island.

Beetham Lagoons

The Beetham Treatment Works was designed in 1959 as an oxidation pond or lagoon system to treat sewage from a population of 150,000 in the City of Port of Spain, Trinidad's largest city. The facility came on line in 1965. Influent sewage arrives at an influent screening works and pumping station just south of the Beetham Highway, from which it is lifted to an above-grade, 48-inch diameter pumping main designed to carry it to the oxidation pond system located in the Lavantile Swamp. The works was designed to discharge into the Caroni River basin, which is a prominent roosting area for the national bird of Trinidad and Tobago, the scarlet ibis. The oxidation ponds include four anaerobic ponds, each 540 feet (165 m) by 520 feet (158 m) in footprint area, and two aerobic ponds, each 1,880 feet (573 m) by 1,120 feet (341 m) in plan dimension. The total oxidation pond area is 122 acres, or 49.5 hectares.

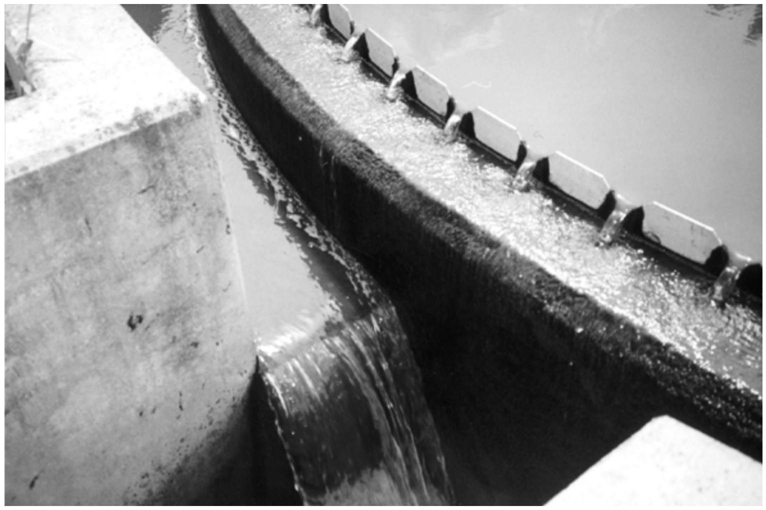
At the time of the site visit, it appeared that much of the lagoon system was filled with accumulations of grit and sludge. The entire surface of the first-stage cells and one of the second stage cells was covered with a dense accumulation of rooted vegetation, including good-sized shrubs. Ponded water was present on only a small part of one of the large second-stage cells, and that may be an accumulation of rain water. At the time of the site visit, little or no sewage appeared to be reaching the lagoon system; instead, it discharged through numerous openings in the 48-inch pumping main into the adjacent mangrove swamp.

Lagoons at the Beetham Treatment Works are largely covered over with vegetation.

Influent sewage is a combination of domestic wastewater and rum distillery waste. The sewage is distinctly red and hydrogen sulphide gas is released wherever it is exposed to the atmosphere, in the influent screen works and pump station wet well and at the discharge points in the swamp. Current influent flow rates are unknown because the influent flow meter is not functioning. Phelps and Griffith (1974) attempted to estimate the influent load. They reported that the distillery waste flow was 40,000 gallons per day (151 m^3/day) with a BOD strength averaging 25,000 mg/L. This is a BOD loading of 3,791 kg/day. The design BOD loading to the ponds is reported by Phelps and Griffith to have been 15 mgd (57,000 m^3/day) at 170 mg/L or 21,267 pounds per day (9,667 kg/day) of BOD. Thus the distillery waste load, which was not taken into account in the design, represents approximately 40 percent of the original design capacity.

Phelps and Griffith estimated the actual combined loading in 1972 to be 12 mgd (45,420 m^3/day) at a waste strength of 250 mg/L, or a combined loading of 25,020 pounds per day (11,373 kg/day). At this rate the unit organic loading on the overall lagoon system would be 205 pounds BOD/day/acre or 229 kg BOD/day/hectare. Considering that the current population of Port of Spain is reported at 300,000 and that most of the city is connected to the sewer system, actual loading could be greatly in excess of this, once the planned desludging project is completed to permit reuse of the lagoons for sewage treatment.

Arima



Effluent from the secondary sedimentation tanks at the Arima sewage treatment works.

The Arima sewage treatment works is a trickling filter plant serving an upland area that is an extension of the urbanised area of Port of Spain. The plant was constructed in the early 1960s. It includes a headworks structure with manual bar screens and conventional dry well/wet well influent pumps, an influent flow meter (non-functional), two primary sedimentation tanks, two trickling filter tanks, and two secondary sedimentation tanks. Effluent is discharged to an adjacent river, which appeared to have relatively good water quality at the time of the site visit. Sludge from the primary and secondary sedimentation tanks is pumped to two anaerobic digesters. No instrumentation at the works is in working order, but the main pumping and process equipment has been well maintained by a concerned and competent staff. This plant was the only one visited in Trinidad from which treated effluent was being discharged at the time of the visit. Design data for the plant were not available. With two primary sedimentation tanks estimated at 50 feet (15 m) in diameter at a design average day overflow rate of 1,200 gallons per day per square foot (2.0 m/hr) the equivalent plant capacity would be approximately 5 mgd or 18,000 m^3/day.

San Fernando

The San Fernando sewage treatment works serves industry and residential users of the city of San Fernando, Trinidad's second largest city, with a population estimated by the operator of the works at 75,000. The works is identical in configuration to the Arima works, including bar screens, influent pumps, primary sedimentation tanks, trickling filters, secondary sedimentation tanks, and anaerobic digesters. In addition, the San Fernando works has a septage receiving station and an aerated grit chamber. At the time of the site visit, the influent wet well and bar screen area were flooded and the influent pumps were off. According to an operator at the works, the pumps were operated 10 to 12 hours per day. The operator indicated that the capacity of the works was 12 mgd, or approximately 50,000 m^3/day. The influent flow meter was not functional. The San Fernando works dates from the same period of construction as the Arima and Beetham works, the late 1950s. The receiving water for discharge from the works is an estuarine river adjacent to the plant site. Water quality in the river was evidently quite bad. Its colour was nearly black and its visibility poor.

The San Fernando sewage treatment works.

Charlieville

The last plant visited in Trinidad was a small extended aeration plant designed for a residential development in a community called Charlieville, midway between Port of Spain and San Fernando on the west side of the island. Plant construction was completed recently. The plant includes self-priming influent pumps, two elevated concrete aeration tanks with coarse bubble aeration from positive displacement blowers, two rectangular sedimentation tanks, and a chlorine contact channel. Chlorine is delivered in solution from a 150-pound gas/liquid cylinder feed system. A sludge holding tank is included for partial stabilisation of waste sludge prior to discharge to sludge drying beds on-site. Effluent discharge is to a concrete channel leading to a small stream adjacent to the plant site. The plant appeared to be adequately designed, but operators had yet to be fully informed about the nature of its unit processes. The aeration blowers were on at the time of the site visit. The operators indicated that they turned them on and off using a timer. The plant was receiving no sewage at the time of the visit, on a Friday morning. The operators indicated that few houses had been connected to the collection system feeding the new plant. Design data for the plant were not provided. Based on the approximately 1-by-3-m footprint of each of the two rectangular sedimentation tanks at a design overflow rate of 1 m/hr, the capacity of the plant would be in the neighbourhood of 500 m^3/day.

Aeration tank at the small extended aeration plant in Charleyville.

ST. LUCIA

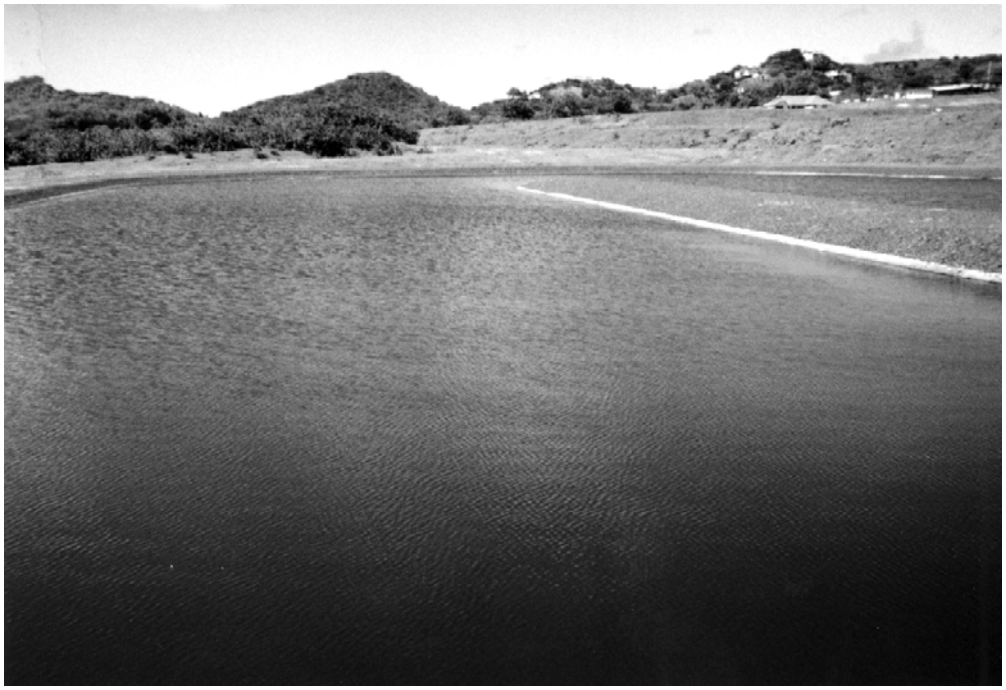
The island of St. Lucia is in the southern half of the Eastern Caribbean island chain. It is a teardrop-shaped island roughly 43 kilometres long and 23 kilometres wide. Its interior is very mountainous; the highest point is Mt. Gimie, with a peak elevation of 950 metres. The average temperature is 22 to 27° Celsius, and annual rainfall ranges from 150 to 345 centimetres.

St. Lucia is an independent state within the British Commonwealth with a population of 157,000. One-third of the population lives in Castries; the rest are distributed in small communities and fishing villages throughout the island. Almost all the settlements are within 8 km of the sea, and those that are not are located on streams that flow to the sea. The main industry in St. Lucia is agriculture. The primary exported products are bananas, coconuts, and cocoa. Tourism, another important industry, has been growing quickly in recent years. There has been a surge in new hotel and resort development, particularly on the western coast. Many of the hotels lie in the coastal areas, but others are being developed in the interior.

St. Lucia is served by a collection system only in Castries and parts of Gros Islet. Sewage from Gros Islet is treated in a series of lagoons before being discharged to the sea. Untreated sewage from Castries is discharged directly to the sea through a nearshore outfall. The rest of the population is served by package wastewater treatment plants, septic tanks, outhouses, and other local methods of wastewater disposal.

The site visit included the Rodney Bay Sewage Treatment Works in Gros Islet and four hotel package plants.

Rodney Bay



Excluding small package plants, the Rodney Bay Sewage Treatment Works is the only sewage treatment facility in St. Lucia. The treatment works is operated by the Water and Sewerage Authority (WASA) and serves a portion of the Gros Islet population in the north of the island. Gros Islet is one of the few areas on the island with large, open spaces. The Rodney Bay facility is an Advanced Integrated Pond System (AIPS) designed by the engineering firm founded by the man that invented the concept, William J. Oswald. It was constructed though a grant from the French govenment. The sewage flows through a screen before entering the first of a series of four lagoons. The first two lagoons are equipped with mechanical surface aerators. Lagoon effluent is discharged to a stream that flows to Rodney Bay. The effluent quality appeared to be good at the time of the site visit. Effluent quality measurements indicate that the colour and dissolved oxygen (DO) level of the effluent vary on daily cycles, suggesting the presence of algae. The lagoons are currently underloaded. WASA anticipates more sewer connections in the future. Design data are presented in Table 5-1. Effluent data are presented in Table 5-2.

TABLE 5-1.
DESIGN DATA. RODNEY BAY AIPS.

Parameter	Value	Units
Flow		m^3/day
Design	2,600	
Current	800	
Volume		m^3
Pond 1 and 3A	25,000	
Pond 2 and 3B	25,000	
Pond 4	5,000	
Pond 5	7,000	
Pond 6	8,000	
Depth		m
Pond 1 / 3A	4.5/2.7	
Pond 2 / 3B	4.5/2.7	
Pond 4	1.5	
Pond 5	1.9	
Pond 6	2.7	

TABLE 5-2.
EFFLUENT QUALITY DATA. RODNEY BAY AIPS. 1996-1997.

Parameter	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
BOD, mg/L	24	16	21	9	11	15	11	12
TSS, mg/L	18	26	46	41	38	38	39	52
Phosphate, mg/L	4.5	13.1	13.8	10.9	12.6	16.3	11.6	14
Nitrate, mg/L	3.4	1.6	7.5	2.4	2.2	2.5	21.2	1.6
Faecal Coliform, Colonies/100 mL	43	2	23	40	24	2	8	32
pH	7.9	8.3	9.2	8	8.5	9.0	9.5	9.5

Hotel Package Plants

Several large hotels on the island represent a population density too high for septic tanks to be efficient or economical. To avoid pollution of nearby bathing beaches, many of these hotels use small, extended-aeration package plants. The site visit included three extended aeration package plants and one wetland treatment system.

Of the hotel package plants visited, the highest quality effluent was noted at a wetland treatment system for a medium-sized hotel. The treatment process includes pre-treatment with screening and settling. The wastewater then flows into a three-tiered, free-water-surface wetland system dug into a hill. The wetland effluent passes through a filter and then is disinfected with an ultraviolet lamp. Monitoring data showed that the effluent BOD and suspended solids concentrations were typically less than 10 mg/L.

Constructed wetlands in a package treatment plant serving a hotel in St. Lucia.

The extended aeration package plants visited are equipped with most of the processes that an ordinary activated sludge treatment facility uses, but on a smaller scale. All used a process sequence of screening, followed by an aeration basin, followed by sedimentation tanks, followed by chlorine disinfection before discharge or reuse for landscaping. At one of the hotels, an equalisation basin was provided before the aeration basin. Sludge from the sedimentation tanks was recycled back into the aeration basins, with the excess typically wasted to a thickening tank. No design data were obtained for these plants, but it is estimated that most were designed with capacity to serve a population of 500 to 2,000. Overall effluent quality was adequate to excellent, except at one package plant that was not operating adequately due to broken down equipment awaiting replacement.

CHAPTER 6.
METHODOLOGY FOR SELECTING APPROPRIATE TECHNOLOGY

The current chapter presents methodologies for identifying appropriate technologies for sewage pollution control. The methodologies have been developed with the target audience in mind—government and funding agency planners, local officials, and engineers in the Caribbean region who must develop or evaluate plans for sewage pollution control for a given pollution source. Each methodology has been developed using a "decision tree"—a structured series of questions leading the reader to an appropriate technology or group of possible technologies that can abate or solve the problem at hand. The technologies identified in the decision trees are described in detail in Appendix D. Methodologies have been prepared for four broad areas of pollution control:

- Collection Systems
- Domestic Wastewater Treatment
- Industrial Wastewater Treatment
- Solids Treatment and Disposal

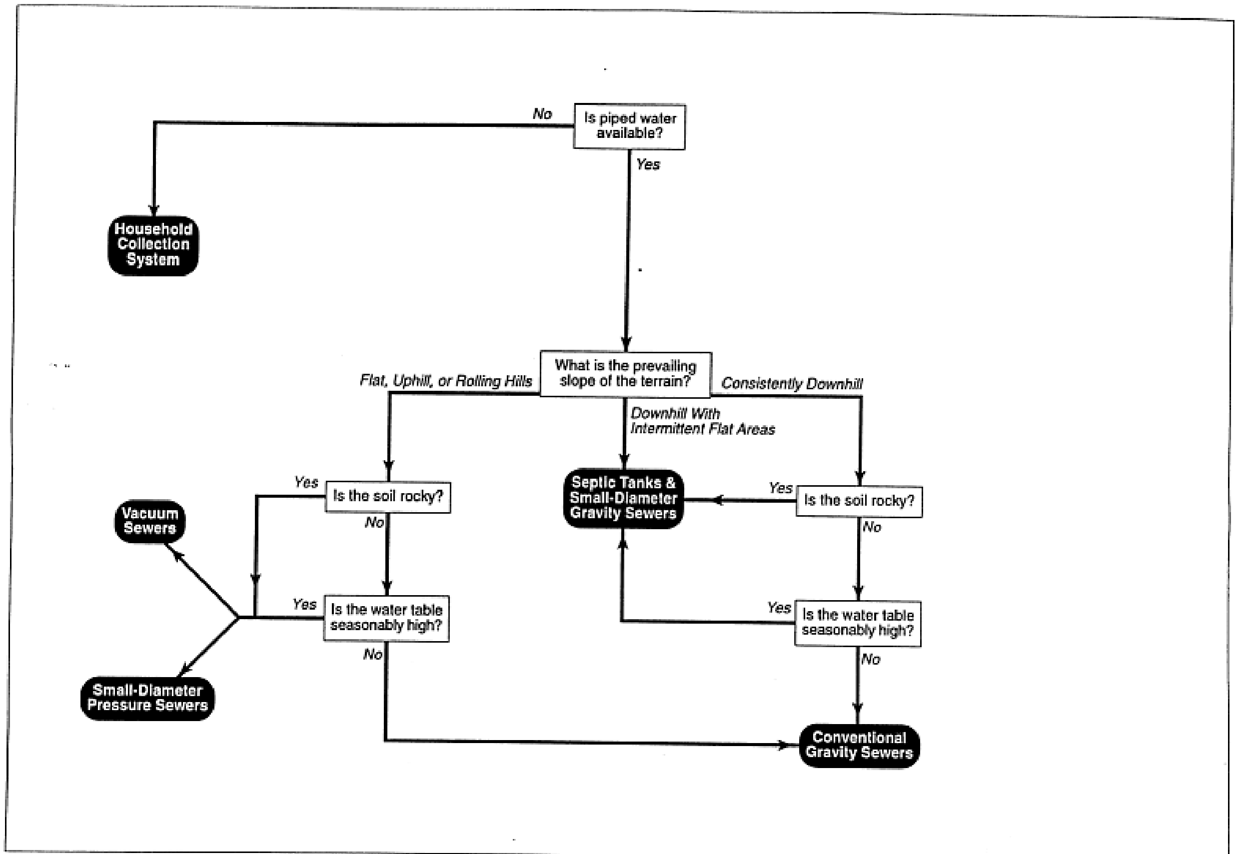
COLLECTION SYSTEMS

Until recently, an engineer designing a sewage collection system had few options from which to choose. The oldest sewage collection system, and most common system to this day, is the system that in this report is called "conventional gravity sewers." These are gravity driven pipelines or channels that carry raw sewage away from homes and businesses. The conduits are constructed with a constantly downward slope so that gravity drives the flow. The main advantage of conventional gravity sewers is that design criteria are well established. However, conventional gravity sewers have many disadvantages compared to alternative systems. They are expensive to build, especially when the water table is high or soils are rocky, and can be susceptible to infiltration and inflow (I&I) of groundwater and suspended solids into the waste stream. Wastewater treatment facilities must be sized to handle the wastewater flow plus the I&I. Other, newer collection system technologies include small-diameter gravity sewers, pressure sewers, and vacuum sewers. These newer systems address some of the disadvantages of conventional gravity sewers.

Figure 6-1 is a decision tree for selecting an appropriate sewage collection system. The main factors which must be considered in choosing a system for sewage collection are population density, surface topography, and subsurface conditions. Collection systems considered in the decision tree and presented in Appendix C include :

- Conventional Gravity Sewers
- Small-diameter Pressure Sewers
- Vacuum Sewers

- Small-diameter Gravity Sewers



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United Nations Environment Programme
APPROPRIATE TECHNOLOGY FOR SEWAGE POLLUTION CONTROL IN THE WIDER CARIBBEAN REGION

Figure 6-1.
DECISION TREE FOR APPROPRIATE SEWAGE COLLECTION

Decision-Tree Criteria

Below are the most important criteria for selecting appropriate technologies for sewage collection. The relevance of each criterion in the decision process and its implementation in the decision tree is discussed. The main factors in choosing a domestic wastewater conveyance technology are water availability, the prevailing slope of the terrain, hydrogeological considerations, and social considerations.

Water Availability

The first question in the decision tree is whether piped water is supplied to homes and businesses to be served. If little or no piped water is available, the volume of wastes generated will be minimal, and excreta and other household wastes can be disposed of in household systems, such as pit latrines or other non-water carriage toilets. Septic tanks should not be considered in such cases because they will operate the same as latrines or composting toilets, due to lack of fluid, but cost much more to install. Typically, not enough wastewater volume is generated to use a septic tank when residents do not have piped water supplies.

Surface Topography

If the surface topography allows sewers to be laid at a downward slope from homes and businesses to a sewage treatment facility, then gravity systems can be used. Gravity systems should always be preferred over pumping. Large pumping (lift) stations dramatically increase operation and maintenance costs, and may increase capital costs as well.

Subsurface Conditions

Unstable soils, rocky soils, and high groundwater levels make conventional gravity sewers more expensive to build and maintain. In these conditions, small-diameter or vacuum sewer systems may be cost-effective. Small diameter gravity sewer lines, made from PVC pipes, can bend to accommodate unstable soils, virtually eliminate I&I, and can be constructed around rock outcroppings relatively easily. Because small diameter gravity and septic tank effluent pressure (STEP) sewers do not carry a significant amount of suspended solids (they generally carry septic tank effluent), they can be installed at a lesser downward slope than conventional sewers (conventional sewers carry raw sewage, and must maintain a minimum flow velocity to prevent excessive deposit of solids in the sewer). This saves in construction costs since excavations for small diameter sewers are not as costly as for conventional sewers. Vacuum sewers can be used most effectively under conditions of flat terrain and high water table. Under these conditions vacuum sewer lines can be placed in shallow trenches to minimise construction cost. They are sealed systems from the house vacuum valve to the central vacuum station, so infiltration and inflows are eliminated. I&I can still enter the system through the house lateral line, however, since it is a conventional gravity pipe.

Social Considerations

Although not specifically mentioned in the decision tree, social considerations play an important part in selecting an appropriate sewage collection system for a community. The conventional gravity sewer system has been widely used with a variety of community types because it is the simplest system which requires no routine operational attention. It has been used in both high and low-income urban communities and for clusters of rural homes. Alternative systems, which may be of lower cost for initial construction, are either more complex or require more maintenance than a central gravity collection system. Small-diameter pressure sewers, for example, require a grinder pump in each house. This proliferation of powered equipment requiring routine maintenance is a significant disadvantage of this type of system in many communities. The experience with this system in developed world is that this type of system is very difficult to keep operating properly even in a fully developed economy. Vacuum sewers are less complex, but still require a valve to be maintained at each house and, generally, more vacuum/pump stations than would be required for a comparable gravity collection system. Small-diameter gravity sewers are used with septic tanks at each house which must be desludged at regular intervals.

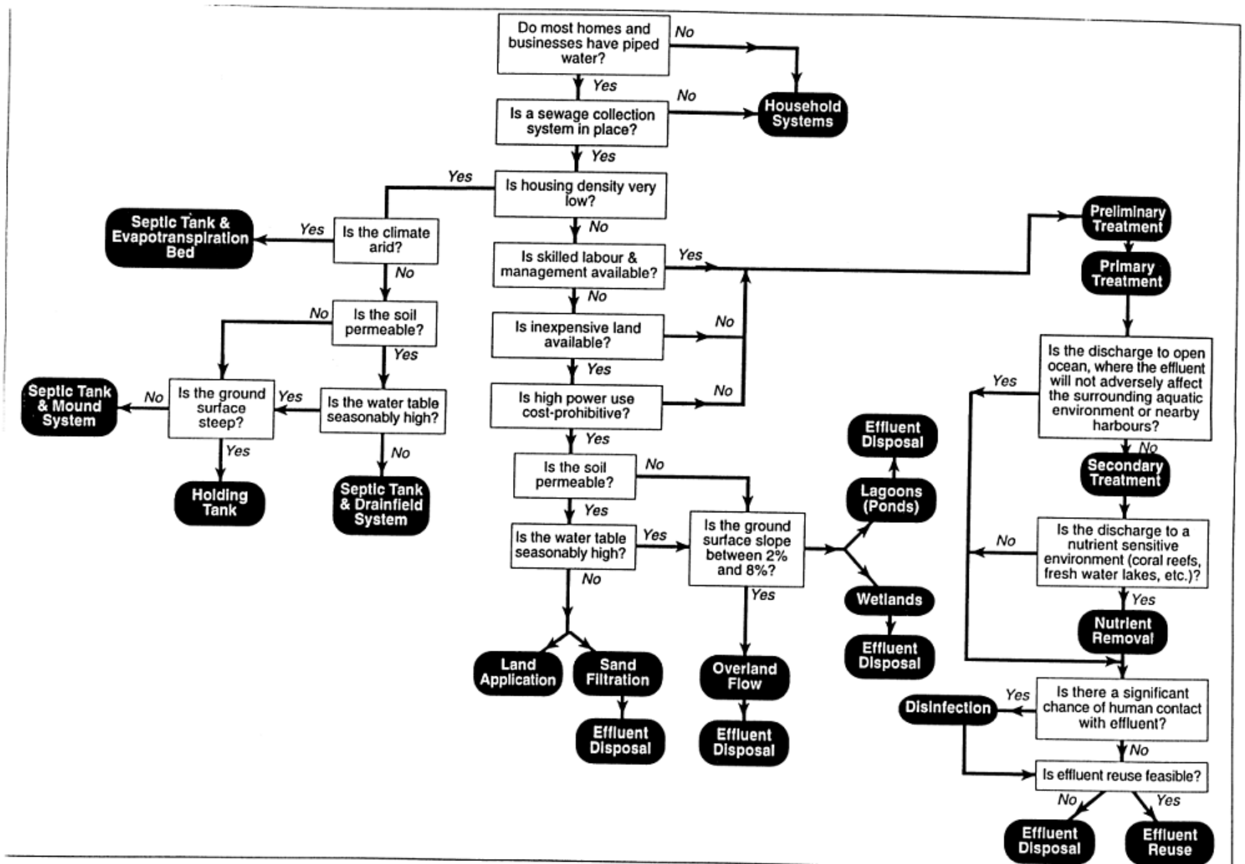
Planners of collection systems should ask the question "Will the community accept maintenance of equipment in the house or permit access of utility personnel onto private property for such maintenance?" If the answer to this question is "no," then a conventional gravity collection system is indicated. Water carriage sewage collection facilitates the modern convenience of indoor toilet facilities provided in each community household. This convenience may not be required or even desired, however, in a given community where a community latrine would be a more easily accepted public waste collection strategy. Likely public acceptance of collection system strategies should be assessed through well advertised public meetings in the community, distribution of explanatory material, and community opinion surveys.

DOMESTIC WASTEWATER TREATMENT

Choosing technologies for domestic waste disposal is a complex process involving many factors. Figure 6-2 is a decision tree for selecting an appropriate treatment technology for domestic wastewater. The tree is intended to help the reader arrive at an appropriate technology for a given community (here defined as a cost-effective technology that provides adequate treatment and that the local community has the finances and skilled labour force to operate and maintain.) Selecting the most appropriate technology for a given community requires an analysis of cultural factors, a site evaluation, and a cost analysis. The decision tree is intended as an aid in identifying appropriate technology. For a final selection, however, it must be supplemented with a detailed analysis for each community based on local factors and needs.

Decision-Tree Criteria

Below are the most important criteria for selecting appropriate technologies. The relevance of each criterion in the decision process and its implementation in the decision tree is discussed. The main factors in choosing a domestic wastewater treatment technology are water availability, presence of a collection system, housing or population density, availability of skilled management and operating personnel, land availability, availability and cost of power, receiving water requirements, hydrogeologic conditions and climate, and availability of opportunities for effluent reuse.



KCM 1917 First Avenue Seattle, Washington 98101	United Nations Environment Programme APPROPRIATE TECHNOLOGY FOR SEWAGE POLLUTION CONTROL IN THE WIDER CARIBBEAN REGION	Figure 6-2. DECISION TREE FOR APPROPRIATE DOMESTIC SEWAGE TREATMENT

Water Availability

The first question in the decision tree is whether piped water is supplied to homes and businesses to be served. If little or no piped water is available, the volume of wastes generated will be minimal, and excreta and other household wastes can be disposed of in household systems, such as pit latrines or other non-water carriage toilets. Septic tanks should not be considered in such cases because they will operate the same as latrines or composting toilets, due to lack of fluid, but cost much more to install. Typically, not enough wastewater volume is generated to use a septic tank when residents do not have piped water supplies.

Collection System

If no waste collection system exists, a home or small community has few options for waste treatment and disposal. A community with a collection system has many more options. For use in this decision tree, the definition of collection system includes septic tanks as well as community sewers.

Housing or Population Density

For dispersed rural homes, central sewage collection facilities are not economical due to the high cost of piping wastewater to the central treatment facility. The housing density at which central systems become more economical compared to on-site systems varies widely. It depends upon the prevailing soil type, land cost, evaporation/precipitation balance, ground water hydrology, and local costs for construction materials. No density can be specified that will serve to make a hard and fast selection of the desirability of on-site versus central treatment systems for all community types.

Availability of Skilled Labour and Management

The complexity of a treatment technology that a community can expect to operate and maintain successfully is determined by the local availability of skilled labour. This is an important consideration; many activated-sludge package treatment plants in the U.S. and the Caribbean do not function properly because they are not operated or maintained correctly. In many small rural communities, where there are no skilled workers to operate an activated sludge process properly, a simpler process such as a lagoon or a wetland should be used. As a rule, low-maintenance technologies should be preferred over high-maintenance technologies, even if some treatment efficiency is sacrificed. This rule is reflected in the decision tree—all of the technologies applicable to communities without skilled labour must be easy to operate and maintain. Availability of a management infrastructure to process and collect user charges and manage expenses in another prerequisite for effective operation of more complicated sewage treatment processes. To some extent, all treatment systems must be part of an effective management infrastructure, but land-intensive, low power treatment systems are more forgiving of operations and management breakdown and should be the preferred technology where management systems are developing.

Land Availability

Where land is abundant and low cost natural treatment systems are usually appropriate, since they require little maintenance, are easy to operate and provide adequate treatment. Where land is scarce and expensive, mechanised, energy-intensive treatment processes, which require less land, may be more cost-effective than natural systems.

Receiving Water Requirements

Water quality requirements for the effluent receiving water (e.g., a lake, a stream, groundwater, an estuary, or open ocean) or effluent reuse significantly affect treatment requirements. Two criteria affect water quality requirements for the receiving water and, consequently, how much effluent can be discharged to the receiving water:

- Volume of receiving water—Large bodies of water have more assimilative, or diluting, capacity than smaller bodies of water.
- The intended use of the receiving water—Drinking water, shellfish harvesting, primary contact recreation, and irrigation all have different water quality requirements.

Appropriate treatment technologies for rural communities will provide adequate contaminant removal for most receiving waters or reuse needs. Consideration of the effluent receiving water is much more important for urban communities due to the volume of waste they generate. Selection of an appropriate treatment technology for urban communities requires knowledge of the degree of treatment required for the receiving water. If the effluent is discharged through a submarine outfall to an open ocean, primary treatment may be sufficient. If the effluent is discharged into an estuary, bay, lake or stream, eutrophication is a concern, and nutrient removal must be considered. If there is uncertainty about how much waste can be discharged into a receiving water, a mixing zone analysis should be conducted.

Hydrogeologic Conditions and Climate

Because treatment processes for low- and medium-density communities rely on natural systems more than those for high-density communities, some are more affected by hydrogeologic conditions of the treatment site than large systems.

For subsurface treatment or disposal processes, the following hydrogeologic conditions must be known:

- Soil permeability—Soil permeability sometimes with depth and location. If the soil is not permeable enough to accommodate the effluent flow rate, effluent will flow to the ground surface. This is known as ponding.
- The seasonal high water table—Adequate treatment of effluent requires sufficient travel time in the unsaturated zone above the water table to prevent groundwater contamination and allow oxidation.

In an arid climate, evaporation ponds can be considered for effluent disposal. For this to work, average annual evaporation must be greater than average annual precipitation, which is not common in the Caribbean basin.

Social Considerations

Residents' knowledge, attitude, opinions, and prejudices about waste disposal can determine whether a treatment technology will work in a particular culture. For example, some cultures have an aversion to any contact with human wastes, so a composting toilet would be inappropriate for their communities. Local consultants and government officials should account for cultural issues when choosing a treatment technology.

Effluent Volume

The volume of effluent to be discharged determines appropriate effluent disposal methods. Low and medium effluent volumes can often be discharged below the ground if local soil conditions are suitable. If the effluent is high in contaminants, and the local drinking water source is groundwater, a different option should be considered. For higher volumes, marine outfall disposals may be more suitable because of the large diluting capacity of the open ocean. Planners must ensure that water quality standards for the receiving water are met.

Opportunities for Reuse

In many locations in the Caribbean properly treated effluent and sludge from wastewater treatment plants can be reused for beneficial purposes. Reuse has the double benefit of removing a discharge of nutrients and other contaminants from receiving waters while reducing pressure on water supply systems by providing an alternate water source. Wastewater can be used for many purposes including street washing, cooling water, and other industrial uses, irrigation of feed or fodder crops, landscaping irrigation, use in separate toilet water flushing systems, or in indirect or direct potable reuse.

The scope of this report does not provide for detailed development of reuse requirements and controls. Wastewater reuse for irrigation requires careful design of the overall water management program including, often, provisions for wastewater storage when irrigation demands are low. Wastewater loading may be limited by several factors including nutrients, hydraulic needs, or heavy metal or total dissolved salt content in the wastewater. In many cases wastewater application rates are determined by hydraulic requirements. Often sludge application rates are controlled by crop uptake rates for sludge nitrogen or by heavy metal content in the sludge.

Depending on the use, effective disinfection is a key requirement for reuse systems. Regulations for reuse in many states in the United States require effluent filtration and nearly complete removal of pathogen indicators prior to unrestricted use of wastewater effluent for irrigation. Indirect wastewater reuse for potable purposes is practised in many locations where wastewater effluents enter groundwater, either through direct infiltration or through exfiltration from lakes and streams, which becomes a subsequent source of water supply. In these cases, removal of nitrates is often required to limit build-up of nitrate concentrations in the ground water.

Assumptions Used to Develop the Decision Tree

The following assumptions were used in developing the decision tree for domestic sewage treatment processes:

- A reasonable attempt should be made to reduce the amount of wastewater generated. The less wastewater generated, the less costly the treatment.

- For low-income, rural communities, nutrient removal and advanced treatment may not economically or socially feasible. Many low-technology processes, like wetlands or lagoons, can be effective in removal of nitrogen without need for sophisticated operations control. These processes are not so effective in removal of phosphorus, however.
- For many communities in the WCR, land-intensive, low-cost, and low-maintenance technologies (natural systems) are appropriate. Hydrogeologic conditions affect the selection of an appropriate treatment technology. Most of the technologies provide excellent treatment, but some fail to remove nutrients. If the effluent is discharged into an estuary, bay, lake, or stream and eutrophication is a concern, nutrient removal processes should be considered.
- For urbanised areas with effective management control and access to skilled labour, conventional, energy-intensive technologies may be appropriate because land is too expensive for natural systems. The most appropriate technology for a given problem depends in this case on receiving water requirements.
- For discharge to non-sensitive areas such as to open marine water through a long outfall pipe, primary or lagoon treatment may meet discharge receiving water requirements and no further treatment is necessary. If discharge is to a river or estuary which is sensitive to dissolved oxygen depletion, then secondary treatment, as a minimum, is called for. If effluent is discharged to an environment that is sensitive to nutrients, such as a coral reef, estuary or lake, then nutrient removal may be needed to avoid destruction of the coral reef community or eutrophication of the lake.
- Conventional, mechanical treatment technologies do not necessarily provide better treatment efficiency than natural treatment systems such as lagoons, wetlands, or sand filters. Where natural systems would be effective and space is available, they are always recommended over mechanical systems because they are easy to operate and virtually maintenance-free.

The decision tree is intended to be used as a guide for selection of appropriate technologies for domestic wastewater treatment for communities in the Wider Caribbean Region. Unusual needs or circumstances, however, may make it appropriate to use technologies for a given community which would not be indicated by the decision tree. Planners need to use their own good judgement when special circumstances arise to identify and select the most appropriate technologies for a given community.

The questions listed in the decision tree, such as “Is inexpensive land available?” or “Is high power use cost-prohibitive?” were intended to be relative. Different options need to be compared to establish the right technology for a given community. For a given community a land-based alternative such as lagoons or wetlands could be initially compared to a conventional alternative, either secondary treatment or primary treatment and outfall discharge, depending on the receiving water requirements. Whether power use is “cost-prohibitive” or not depends not just on the local cost of power, but also on the relative cost of other alternatives. Only after the local costs and impacts of different alternatives have been compared can the relative questions in the decision tree be finally answered. In this way a series of alternatives can be screened to isolate the single alternative that is best for the community.

INDUSTRIAL WASTEWATER TREATMENT

Domestic dry-weather sewage flows to municipal treatment facilities are fairly uniform in daily volume, pollutant type, and pollutant concentration. BOD and TSS concentrations range from 150 to 400 mg/L, and there are seldom excessive concentrations of toxic chemicals. For this reason, municipal treatment facilities are designed to handle domestic wastewater that falls within a narrow range of pollutant composition. The range for different types of industrial wastewater is much broader.

Industrial wastewater is the liquid waste generated by industries such as oil refineries, metal processing plants, leather tanneries, medical facilities, bottling factories, distilleries, and sugar processing plants. Industrial wastewater has a very wide range of volume, pollutant type, and pollutant concentration. The pollutants can be extremely complex, and often include more harmful chemicals and toxics than found in domestic sewage. The wide range of pollutant composition in industrial wastewater, along with the number of available processes and combinations of processes, precludes a brief, simple description of all the treatment processes used for its treatment. Even similar industries produce wastewater of highly varying composition, depending on the production processes used.

The methodology presented here focuses on removal of pollutants considered to be priority contaminants in the WCR; the scope of this study did not allow consideration of all important pollutants and processes for removing them. The absence of discussion about an industrial pollutant in this report is not intended to indicate that removal of that pollutant can be overlooked in selecting treatment technologies. The following steps should be taken before beginning the process of identifying appropriate technologies for an industrial waste stream:

- An extensive survey must be completed of waste stream characteristics. Because the pollutant composition of wastewater from every factory or industry is unique, it is crucial to identify the wastewater content precisely.
- Provisions should be made for spill containment.
- Every effort should be made to minimise the amount of waste produced. This involves experimentation, alteration, and fine-tuning of the production process. It is often less expensive to reduce waste than to treat it. Treated wastewater should be reused within the plant whenever it is cost-effective. Many factories and oil refineries can reuse treated wastewater as cooling water or for housekeeping, but this usually requires a very high quality effluent.
- It must be determined where the treated wastewater will be disposed and the degree of treatment needed to preclude adverse impacts to human health and the environment. If it will be disposed in the surrounding environment, the wastewater must be treated to a high degree of purity. This is often uneconomical. It is required, of course, where there is no municipal facility to accommodate the wastewater. Where discharge is to a municipal facility, pre-treatment is necessary because municipal treatment facilities are designed to handle waste within a narrow range of pollutant composition. Since industrial wastewater rarely falls into this range, its discharge without treatment could impair municipal treatment processes. Therefore, the goal of industrial sewage treatment processes is not always to produce a high quality effluent, but to make the wastewater suitable for municipal treatment.

- Identification of the appropriate treatment processes, using the decision tree described below, should take place after characterising the wastewater composition and determining the level of treatment needed.
- When an appropriate treatment process has been identified, pilot, or small-scale, tests should be run to find out how effective the process is on the waste to be treated. It is crucial to continue monitoring the effluent to find out the effectiveness of the treatment process. After fine-tuning the process, the selected treatment technology should be applied to the entire waste flow.

Decision Tree Criteria

Figure 6-3 provides a simplified decision tree for selecting an appropriate treatment technology for industrial wastewater. Using the tree generates a list of technologies that can be used as the best available technology. The decision tree for industrial wastewater treatment identifies processes that remove specific pollutants that typical industries in the WCR produce. It requires knowledge of the pollutants present in the waste stream. Selecting an appropriate technology from the decision-tree list requires an in-depth analysis of the wastewater constituents in the waste stream and the degree of treatment needed before discharge into a municipal sewer. Fact sheets in the appendix to this report describe the technologies and list references for more detailed analysis. The main pollutants that industrial pre-treatment processes must remove before discharging to public sewers are oils, metals, volatile and refractory organic materials, dissolved and suspended solids, and concentrated BOD loads. Only the most common unit processes for treatment of industrial wastes common in the WCR are included in the decision tree. See the section “Other Processes” below for consideration of some of the unit processes that have been omitted.

Oils and Greases

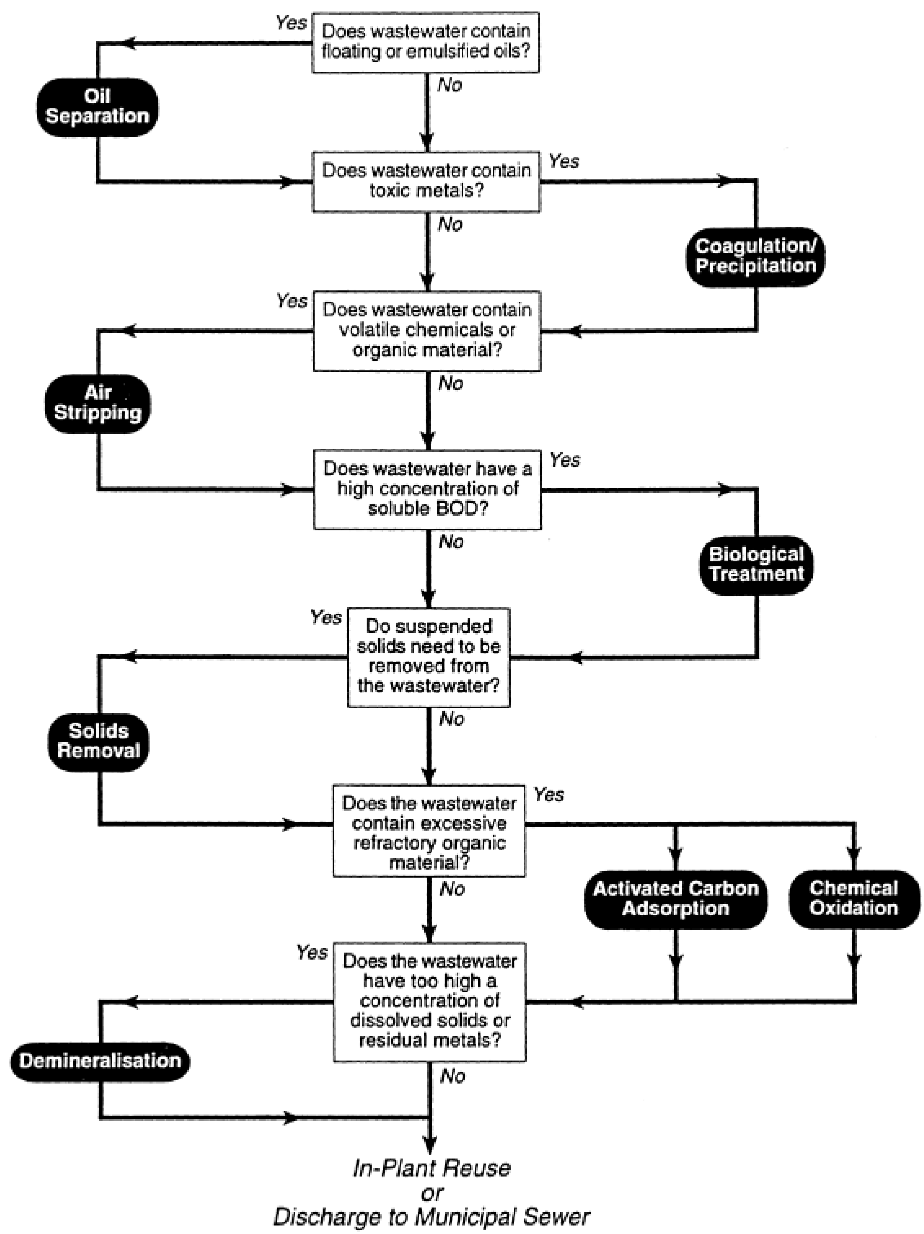
Of all WCR industries, oil refineries discharge the greatest BOD load to marine waters. Other industries, such as slaughterhouses and food processing factories, also produce large quantities of oil and grease. Not only do oils generate a high BOD demand on receiving waters, they also are toxic to aquatic life, clog screens and filters, and reduce activated sludge efficiency in downstream municipal treatment processes. Oil-water separation devices are very effective for oily waters, but are not effective for emulsified oils. Emulsified oils and particularly greases can accumulate in sewers and conveyance lines, causing a severe reduction in flow capacity.

Metals

The primary sources of metals are metal-processing and plating plants, hospital or medical facilities, oil refineries, tanneries, pesticide producers, and the paint industry. Most metals are highly toxic to aquatic life and humans, so they should be removed prior to biological treatment. Metals can accumulate in aquatic life, so even if effluent discharges contains metal concentrations below toxic levels, concentrations in aquatic animals, particularly shellfish can accumulate to dangerous levels. Some strains of microbiology are able to continue functioning when metals are present in significant concentrations, but they always function more efficiently if the wastewater is free from metals. Coagulation/precipitation and demineralisation processes remove metals from waste streams.

Volatile Compounds

Volatile organic compounds and other volatile chemicals will eventually be removed by natural processes. However, some of these compounds are odorous or hazardous, and should be removed into a controlled environment rather than into the open atmosphere. Air stripping and aerated biological processes remove volatile compounds.



KCM 917 First Avenue Seattle, Washington 98101	United Nations Environment Programme APPROPRIATE TECHNOLOGY FOR SEWAGE POLLUTION CONTROL IN THE WIDER CARIBBEAN REGION	Figure 6-3. DECISION TREE FOR APPROPRIATE INDUSTRIAL SEWAGE TREATMENT

High Soluble BOD Loads

Municipal wastewater facilities are designed to remove biochemical oxygen demands in the 150 to 400 mg/L range. If BOD concentrations are not significantly higher than this, then industries don't need to remove BOD before discharging to a municipal sewer. However, many industries, particularly food processing and bottling industries, distilleries, chemical manufacturing plants, slaughterhouses, and meat packing plants produce high-strength wastewater with BOD concentrations up to 50,000 mg/L. If such a high-strength wastewater entered a municipal treatment process, it would overload the biological processes, may not be treated adequately, and could be discharged as an effluent of very poor quality. Anaerobic and aerobic biological processes remove high soluble BOD loads.

Suspended Solids

Most factories and industries produce waste streams high in suspended solids concentrations. High suspended solids concentrations have an adverse effect on the environment and make other wastewater treatment processes less efficient. Sedimentation processes remove large amounts of suspended solids, and filtration processes are effective as polishing processes.

Refractory Organics

Refractory organics are not biodegradable, so they are difficult to remove through biological treatment. Phenols are the primary refractory organic in industrial wastewater. Very high concentrations of phenols are found in wastewater from food processing plants, oil refineries, metal processing and plating factories, and many other industries found in the WCR. Refractory organics are extremely toxic to aquatic life and will inhibit biological treatment of the degradable pollutants. High concentrations of refractory organics are typically treated with solvent extraction processes while activated carbon adsorption or chemical oxidation is commonly used to remove refractory organics at more moderate concentrations.

Dissolved Solids

Effluent with high dissolved solids concentrations is not only harmful for freshwater aquatic life, it creates a scaly build-up and other corrosion problems as it travels through pipes and conduits. This is a problem if the effluent is discharged to public sewers or reused within the plant. If reuse water at a plant is consistently high in dissolved solids, the scaly build-up in the plant reuse piping will quickly cause complications. Demineralisation processes remove dissolved solids.

Other Processes

As previously mentioned, several processes used to treat industrial wastewater are not addressed in the decision tree or the fact sheets provided with this report. Some of these include the following:

- Equalisation is a very important process for most industrial wastewater treatment plants. An equalisation basin serves as a holding tank that controls fluctuations in wastewater flows to ensure good performance of processes downstream. The basin receives the wastewater, which varies in composition and volume, and discharges a steady flow of uniform composition. Mechanical mixing is usually provided. The main purposes of equalisation for industrial treatment processes are as follows:

- To dampen surges in the flow volume
- To control pH
- To provide a continuous feed of wastewater to biological systems even when no wastewater is being generated
- To prevent a "slug" of toxic material from upsetting downstream biological processes.

- Neutralisation, or pH control, occurs naturally to some extent in equalisation basins. If the waste stream is not neutralised, lime, caustic, or acid can be added to lower or elevate the pH. Most biological treatment processes operate optimally when the wastewater is within the range of 6 to 9 pH units. The purpose of pH control is to ensure that the wastewater is within this range.
- Supplemental nutrients may be necessary with certain industrial wastewater. Because some industries produce wastes with extremely high BOD loads, and relatively low concentrations of nutrients (nitrogen and phosphorus), nutrients may need to be added to ensure proper operation of biological processes. Biological processes will be impaired if nutrients are deficient.
- Chemical oxidation is a process used to break down pollutants, such as pesticides, that are ordinarily difficult to biodegrade. Common chemical oxidants are chlorine, ozone, hydrogen peroxide, and potassium permanganate.

Assumptions Used to Develop the Decision Tree

The following assumptions were used in developing the decision tree for industrial sewage treatment processes:

- Most appropriate treatment technologies require a medium to high level of operator skill. It is assumed that personnel qualified to operate industrial treatment facilities are available.
- Some of these processes are expensive, but cost is not explicitly addressed in the decision tree.
- The order in which the decision tree questions appear is the order in which the treatment chain usually progresses. However, there are exceptions. An example is that refractory organics can be removed in biological activated sludge processes by adding powdered activated carbon. They also can be removed with granular activated carbon filtration units, which are used later in the treatment process so that suspended solids do not clog the filtration media. Other examples are given in the facts sheets.
- There is some overlap in the role of each of the removal mechanisms. Coagulation processes remove not only toxic metals, but also suspended solids. Biological treatment removes not only soluble BOD, but also some volatile organic material. The user should be aware of this overlap.
- With the exception of lagoon systems, most industrial sewage treatment processes can not use natural systems as many domestic sewage treatment processes do. Most industrial sewage treatment processes are energy-intensive, mechanised processes. Therefore, industrial sewage treatment processes are more immune to environmental conditions than domestic sewage treatment processes.

SOLIDS TREATMENT AND DISPOSAL

All technologies for removing pollutants from sewage and industrial wastewater generate residual materials in the form of waste solids, or sludge. In developed countries in northern climates, sludge treatment typically requires as much capital and operating and maintenance cost as treatment processes for liquid flows. In developing regions in equatorial climates, sludge management typically consists of sludge lagoons and drying beds with disposal of residuals to the land, which is generally less expensive to build and operate than liquid treatment technologies. If the liquid treatment technology is lagoon treatment, sludge treatment facilities normally are not required, since sludge is left to stabilise on the bottom of the lagoon. Periodic removal by dredging is the only sludge disposal practice required. For more mechanised liquid treatment technologies such as activated sludge and fixed film processes, however, significant quantities of residual sludge are generated that must be treated and disposed.

This discussion addresses only the basic sludge treatment technologies of thickening, stabilisation, and dewatering. For industrial sludge and for special needs in treatment works for high density population centres, high temperature processes such as incineration, heat drying, and high temperature wet air oxidation may be appropriate, but these technologies are not discussed in this report.

Loadings

The first step in planning for sludge treatment and disposal is to identify the quantity of sludge produced by the liquid process. The following formula is useful for predicting sludge quantities for a number of activated sludge secondary treatment processes:

$$TSS_p = TSS_{in} + (Y * SBOD_r - k_d * INV_{vss})/VSS_r - E_T$$

where

TSS_p = Total sludge production, kg per day (kg/d)
TSS_{in} = Total suspended solids influent to the secondary treatment process, kg/d
Y = Yield coefficient (0.5-0.8), kg volatile sludge produced per kg soluble BOD removed
$SBOD_r$ = Soluble BOD removed in the liquid treatment process, kg/d
k_d = Decay coefficient, 1/day = 0.03 - 0.08
INV_{vss} = Inventory of volatile solids in the liquid treatment process, kg
VSS_r = Ratio of volatile to total solids in the liquid treatment inventory
E_T = Effluent suspended solids, kg/d

For systems that operate with a very long sludge age, so that volatile solids influent to the liquid treatment process have an opportunity to break down, the following formula may be more appropriate:

$$TSS_p = (Y * TBOD_r - k_d * INV_{vss})/VSS_r - E_T$$

where

Y = Yield coefficient (0.5-0.8), kg volatile sludge produced per kg total BOD removed
$TBOD_r$ = Total BOD removed in the liquid treatment process, kg/d
k_d = Decay coefficient, 1/day = 0.03 to 0.08

For fixed growth processes, the following formula is suggested (U.S. EPA, 1979):

$TSS_p = P_x + TSS_{in} - E_T$

where

$P_x = Y * BOD_r - k_d *Am$

Am = Media surface area in the reactor, square meters

For primary and other physical or chemical treatment processes, solids mass balances must be performed and chemical reactions considered to predict the appropriate quantity of sludge that will be produced under full-scale operation.

Decision Tree Criteria

Figure 6-4 presents a simple decision tree for selection of basic solids treatment and disposal technologies.

Thickening

Sludge wasted from the liquid treatment process may be very dilute. Since sludge stabilisation treatment reactors can be very expensive and are frequently designed on the basis of hydraulic residence time, it is advantageous to reduce the water content of sludge sent to solids treatment. A waste sludge from the aeration tank of an activated sludge process, for example, will typically have a concentration of 2,000 to 3,000 mg/L or 0.2 to 0.3 percent dry solids by weight. Thickening processes can increase the solids content of such sludge to 6 to 8 percent, an increase of over 30-fold. This decreases the size of subsequent treatment reactors by a corresponding amount.

Stabilisation

If sludge is to be beneficially reused as a soil amendment or otherwise come in contact with the community, it is imperative that putrescible materials in the sludge be decomposed to prevent odours at the application site and attraction of rodents and other "vectors" that can spread contaminants to the human population. In the United States, the Environmental Protection Agency has completed an exhaustive process of regulatory review leading to the promulgation of sludge disposal regulations that include requirements for reducing "vector attraction" in sludge that will be applied to the land. Typical stabilisation processes are anaerobic or aerobic digestion, composting, and sludge lagoon storage.

Dewatering

Disposal or reuse of sludge may be more economical or efficient with further reduction in water content following treatment. Processes similar to those used for thickening sludge may also be used to dewater them further prior to final disposal or reuse.

Cold Digestion/Drying Lagoons

A sludge management technique that is especially cost-effective for WCR applications in hot climates with a prolonged dry season are cold digestion/drying (CDD) lagoons. CDD lagoons fulfil all of the functions of sludge thickening, stabilisation, dewatering, and storage in a series of earthen basins. Waste activated sludge can be pumped to CDD lagoons in relatively dilute form and converted to a dried product of 25-30 percent solids concentration after a fill period of one year and a drying period of an additional year. Where land area is available CDD lagoons are a highly appropriate technology for the WCR. Although not shown in the decision tree in Figure 6-4, a fact sheet for CDD lagoons is provided in Appendix C.

Land Application

Wastewater treatment sludge may have agronomic value. It can provide nutrients—especially nitrogen and phosphorus—and organic material that contribute to soil tilth by building the humic resources of the soil. Sludge disposal by land application is therefore a widespread and sound method of disposal which may provide for beneficial reuse of sludge nutrient and organic value. Land application may be by tank truck, by spraying through large bore sprinklers, by injection, ridge and furrow application, or by spreading of dewatered material. Consideration of detailed land application methodologies and limiting loading rates is beyond the scope of the current report. In general, sludge appreciation to agricultural land is limited by sludge nitrogen uptake by the agricultural or silivicultural crop. Heavy metal content, however, may also limit long-term loading rates. The EPA sludge disposal regulations provide good background data and a methodology for determining limiting sludge loading rates.

Landfill

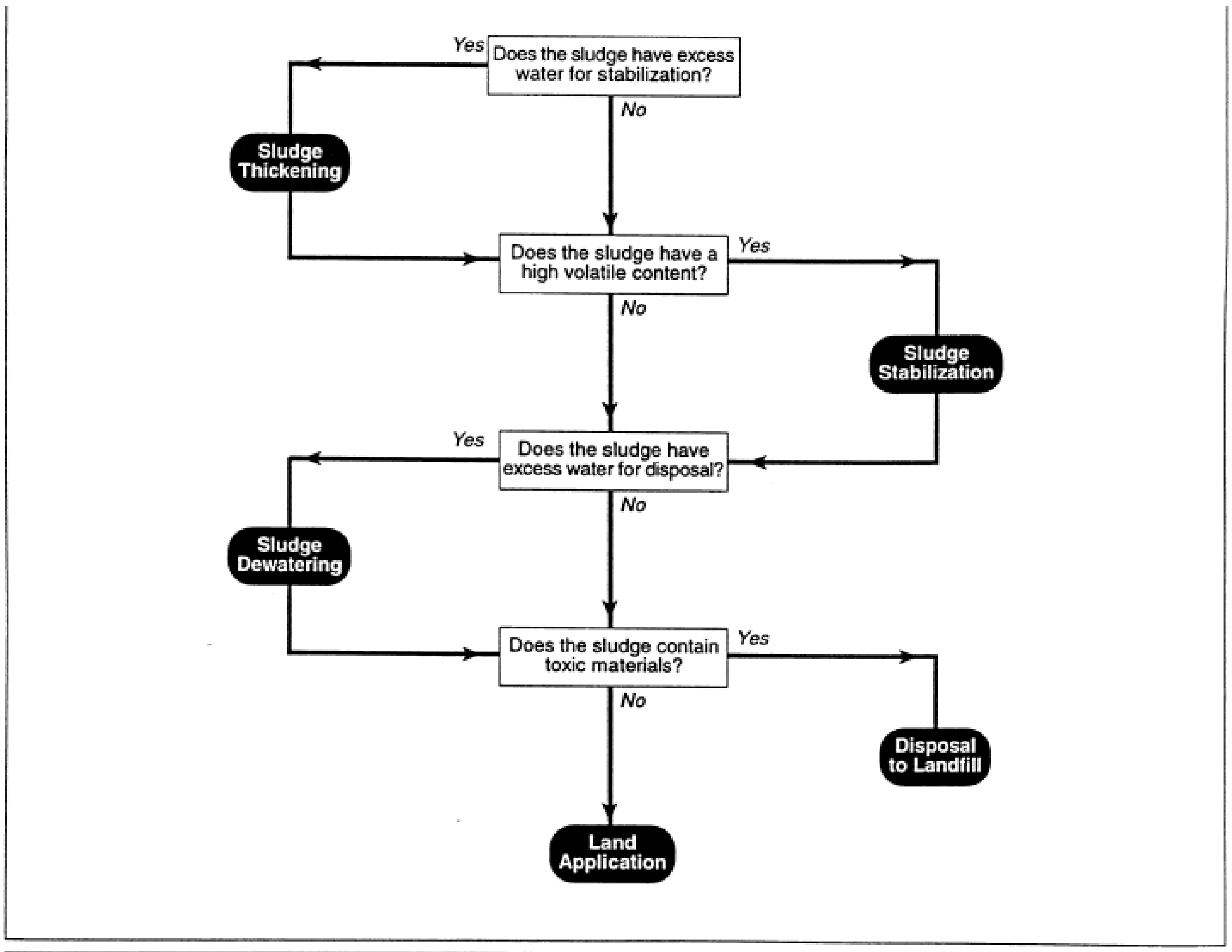
Sludge that contains heavy metals or other toxic materials that prevent its use as a soil amendment must be disposed of in a landfill. Sludge landfilling can be achieved in various ways—sludge only trench fill, sludge only area fill, and codisposal with refuse. See EPA 1979 for detailed criteria.

Septage Handling and Disposal

With a large percentage of the populace in the WCR served by septic tank systems, the need exists for consideration of septage handling and disposal. A common practice at present is for septage to be dumped at landfills and sewage treatment plants. The Bahamas has a septage treatment facility which has worked effectively. The Arima Sewage Treatment Works in Trinidad has a septage handling tank that is aerated and equipped with pumping units to transfer septage to the anaerobic digesters. It was beyond the scope of the current effort to evaluate technologies for septage handling in detail. A US EPA handbook, *Septage Treatment and Disposal* (EPA 1984) gives design data for septage characterisation, receiving station design, land disposal of septage, cotreatment of septage and sewage, and independent treatment of septage. It also provides fact sheets for receiving stations, land disposal, lagoons, composting, lime stabilisation, and odour control.

COSTS

A crucial element in the process of selecting an appropriate technology for wastewater treatment is to identify realistic costs for alternatives. Cost estimating is local by its nature. With over 29 countries included in the WCR speaking at least four major languages and with widely varying levels of economic development, it has not been possible to provide comprehensive cost data for wastewater treatment technologies that would be applicable throughout the region.



KCM *1917 First Avenue* *Seattle, Washington 98101*	United Nations Environmental Programme APPROPRIATE TECHNOLOGY FOR SEWAGE POLLUTION CONTROL IN THE WIDER CARIBBEAN REGION	Figure 6-4. DECISION TREE FOR APPROPRIATE SOLIDS TREATMENT AND DISPOSAL

The literature review prepared as a part of this report did not uncover any comprehensive cost guides that would be helpful to local planners in the WCR. The U. S. EPA in the 1970s prepared a series of cost curves that were used widely in wastewater technology fact sheets that have been referenced in this report. An example would be the Innovative and Alternative Technology Assessment Manual (US EPA February 1980.) This manual contains fact sheets for approximately 100 different wastewater treatment technologies. Most of these fact sheets contain cost curves for construction and operating and maintenance costs. These costs were based on the surveys conducted by EPA in the mid 1970s. Today these data are of limited value, since comparable studies have not been completed to update the costs to current conditions. Furthermore, these cost data were gathered in the United States and would not be applicable to different countries where costs for labour and imported equipment vary greatly from the conditions found in the United States. By necessity, therefore, cost comparisons of technologies for wastewater treatment in the WCR must be prepared locally, by planners and engineers with an understanding of the local economy and construction industry.

ACHIEVABLE TREATMENT EFFICIENCIES

This report has not considered receiving water quality needs based on chemical, oceanographic, or ecological requirements of the marine waters of the Caribbean region. The report has rather considered wastewater treatment technologies and their potential to remove contaminants. To the extent that effluent standards are based on the capabilities of available technology, however, this report can serve as supporting documentation for the standards setting process for the WCR. Table 6-1 provides a guide to treatment efficiencies that can be expected for the domestic treatment processes described in the fact sheets in Appendix C. To achieve these efficiencies, the treatment processes must be designed and operated properly, and must not be hydraulically or organically overloaded.

TABLE 6-1.
ACHIEVABLE EFFICIENCIES FOR DOMESTIC WASTEWATER TREATMENT PROCESSES

	Effluent Concentration or Process Removal Efficiency				
	BOD	TSS	Ammonia	Phosphorus	Faecal Coliform
Septic tank	100-150 mg/L	40-70 mg/L	40-60 mg/L	6-7 mg/L	1-2 log removal
Septic tank + soil	0-10 mg/L	0-10 mg/L	0-40 mg/L	0-2 mg/L	6-7 log removal
Holding tank	N/A	N/A	N/A	N/A	N/A
Household Systems	N/A	N/A	N/A	N/A	N/A
Lagoons	20-30 mg/L	30-80 mg/L	20-30 mg/L	5-7 mg/L	3-5 log removal
Wetlands	5-30 mg/L	5-20 mg/L	5-15 mg/L	0-10 mg/L	1-3 log removal
Land treatment	2-15 mg/L	0-20 mg/L	0-5 mg/L	0-6 mg/L	4-6 log removal
Sand filtration	2-25 mg/L	0-10 mg/L	0-10 mg/L	0-2 mg/L	3-4 log removal
Preliminary treatment	0% removal	0-10% removal	0% removal	0% removal	0 log removal
Primary treatment	25-40% removal	40-70% removal	0-10% removal	0-10% removal	0-1 log removal
Secondary treatment	5-40 mg/L	5-40 mg/L	1-10 mg/L	5-10 mg/L	1-2 log removal
Nutrient removal	5-30 mg/L	5-30 mg/L	0.1 -5 mg/L	0.1-1 mg/L	0-1 log removal

Disinfection	0% removal	0% removal	0% removal	0% removal	5-6 log removal

CHAPTER 7.
EFFLUENT STANDARDS WORKSHOP

Chapter 6 presented methodologies for selecting appropriate sewage pollution control technologies for the WCR. This chapter presents a discussion of recommendations for wastewater treatment effluent standards developed at a meeting of regional experts on pollution control. The meeting was held from 19 to 21 January 1998 in Castries, St. Lucia.

The meeting was attended by professionals in the WCR who are active in planning, design, and managing wastewater treatment systems and have an understanding of the technical, economic, and social issues associated with pollution control systems for the region. Their input was sought to assist UNEP-CAR/RCU, as Secretariat to the Cartegena Convention and its Protocols, in developing a draft Annex on appropriate wastewater treatment technologies under the *draft Protocol Concerning Pollution From Land-Based Sources and Activities*.

The experts discussed a draft version of the current report prepared prior to the meeting and provided input and comments on the draft report. They also identified issues that need to be addressed by negotiators of the land-based sources protocol. Sewage treatment standards were recommended for 11 parameters. A list of the participants is presented in Appendix E.

REPORT COMMENTS

The following general comments on the draft report were offered. Specific report comments were given to KCM.

- Decision trees were modified to take into account effluent reuse, operation and maintenance requirements, cost factors, and human health considerations.
- Siting, operation, and maintenance of facilities should be discussed.
- Septic tanks and other on-site systems need to be covered in more detail.
- Fact sheets need to be as technically correct as possible.
- "Most Appropriate Technology" needs to take into account the environmental quality of the water into which effluent is being discharged.
- Evapotranspiration needs to be addressed as an alternate disposal method for septic tank effluent.
- The inefficiency of package plants should be emphasised since they seldom work properly.
- Each sewage treatment plant should develop a preventative maintenance programme for proper facility operation and maintenance.
- Monitoring costs must be taken into consideration for <u>all</u> facilities.

ADDITIONAL ISSUES

The experts panel discussed the following issues that need to be discussed by negotiators for each country involved in development of the Final Protocol :

- Proper reuse needs to be an option for effluent disposal.
- Suggested treatment standards and alternatives need to be practical.
- Proper siting, installation, operation, and maintenance of sewage treatment systems are critical.
- The technologies in the report are suggested ways to meet the standards and for each standard there are appropriate technologies that can be used to meet them.
- Faecal streptococcus is a reasonable alternative measure of disinfection failure.
- There should be no direct discharge to sensitive areas from industrial facilities.
- The technologies in the report should be referenced in the Protocol Annex.

EFFLUENT DISCHARGE CONTROL PARAMETERS

After much discussion, the experts panel established a set of discharge parameters and a set of effluent standards for each parameter that domestic sewage treatment plants should be designed to meet. The experts panel decided that it would be best to distinguish between sensitive and non-sensitive receiving waters.

It was decided that sensitive receiving waters should be defined as those that are especially susceptible to degradation or destruction by human activities, due to inherent and/or unique environmental characteristics and/or a fragile biological or ecological situation. This definition was based on the definition used in the wastewater standards of Trinidad and Tobago. Sensitive areas in the WCR include the following:

- Mangrove swamps
- Coral reefs
- Sea grass beds
- Nursery areas (feeding and breeding areas for fish and shellfish, including migratory species)
- Recreational waters such as beaches.

All other receiving waters would be considered non-sensitive under the system recommended by the experts panel.

The experts panel felt that standards should be applied not only to facilities discharging to sensitive areas, but also to facilities discharging to waters impacting a sensitive area, such as an upstream area whose drainage discharges to a coral reef through an estuary.

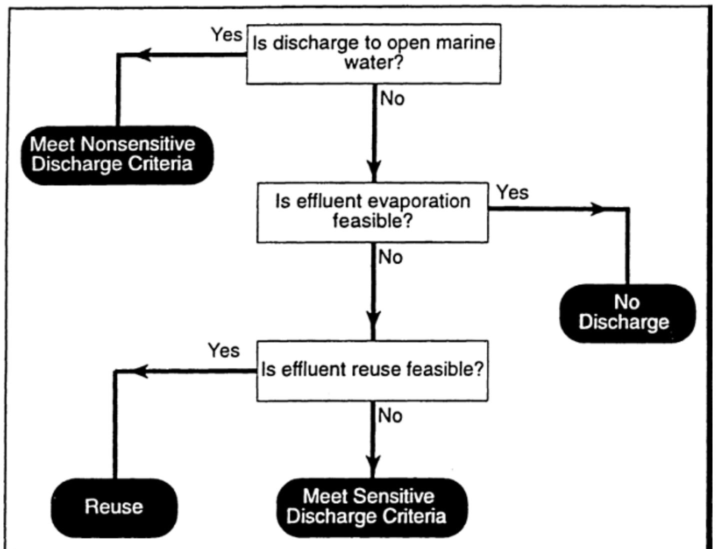


Figure 7-1. Decision Tree for Effluent Standards.

Figure 7-1 presents a decision tree for effluent disposal developed at the experts meeting. The experts felt that discharge to non-sensitive waters should be the first alternative for wastewater disposal. If it is not possible to discharge to non-sensitive waters, effluent evaporation or reuse should be considered. If it is necessary to discharge to sensitive waters (the last resort), the standards for sensitive waters should be met.

Table 7-1 lists the parameters and standards recommended at the experts meeting. It was the intention of the experts panel to propose standards that could be met using appropriate technology as developed in the current report. Technologies that could be expected to meet the standards for non-sensitive discharges, for example, are either primary sedimentation or anaerobic or facultative lagoon systems. For sensitive discharges, standards could be achieved using a combination of either an integrated lagoon system or secondary treatment with disinfection by chlorination/dechlorination, ultraviolet light, or lagoon polishing ponds.

The most critical parameters for the technologies developed in this report are the suspended solids and ammonia removal requirement for lagoon systems. Experience has shown that well-operated lagoon systems yield suspended solids concentrations greater than 30 mg/L due to the presence of algae. Data available at the workshop from the Rodney Bay advanced integrated pond system on St. Lucia, for example, revealed effluent concentrations for suspended solids consistently in the range of 30 to 60 mg/L. Lagoon systems in cooler climates are often ineffective in removing ammonia. Data from the Rodney Bay system, however, indicated that the pond system was consistently producing an effluent with an ammonia-N concentration less than the proposed 5 mg/L standard.

It was not the intention of the experts to exclude well-designed and operated lagoon systems in settling the standard. It was suggested, therefore, that the standard contain a footnote, or potential for waiver, permitting the suspended solids standard to be exceeded as long as the solids are primarily algae. For receiving waters that would be damaged by suspended solids concentrations in the range of 30 to 75 mg/L—typical of well-designed and operated lagoon systems—polishing processes should be used with lagoons, such as wetland or sand filtration systems, or conventional secondary treatment should be used. It was felt that for most systems in the WCR the year-round temperature is warm enough to permit conservatively sized lagoon systems to nitrify and that the 5 mg/L ammonia-N limit would not be unnecessarily stringent.

TABLE 7-1.
PARAMETERS AND STANDARDS FOR
DOMESTIC AND INDUSTRIAL WASTEWATER DISCHARGES IN THE WCR

Parameter	Standard for Non-Sensitive Waters	Standard for Sensitive Waters
Total Suspended Solids	100 mg/L	30 mg/L[a]
Biochemical Oxygen Demand (5 day)	150 mg/L	30 mg/L
COD	300 mg/L	150 mg/L
Faecal Coliform[b]	No standard established	43 MPN/100 mL in shellfish harvesting areas 200 MPN/100 mL in all other areas
Total Inorganic Nitrogen	No standard established	10 mg/L in nutrient sensitive waters
Soluble Phosphorus	No standard established	1 mg/L in nutrient sensitive waters
pH	6 to 10	6 to 10
Fats, Oils, And Greases	50 mg/L	2 mg/L
Ammonia as N	No standard established	5 mg/L
Total Chlorine Residual	No standard established	0.1 mg/L
Floatables	No visible floatables	No visible floatables

a. Does not include algae from treatment ponds
b. Faecal strep should be considered as an alternate

INDUSTRIAL WASTEWATER DISPOSAL

The experts discussed industrial wastewater in the context of industrial facilities that discharge to municipal wastewater treatment plants. The group agreed that there should be no direct industrial discharges to sensitive waters. The standards developed for municipal discharges would still apply if a plant is accepting wastewater from an industrial discharge. It would be up to the operators of the treatment facility accepting the waste to set the influent standards so that the effluent standards can be met. Industrial facilities that handle hazardous substances and wastes should have spill containment and contingency plans.

TIMING

The experts agreed that the annex should establish a target date by which the standards will be in effect for both sensitive and non-sensitive receiving waters.

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APPENDIX A.

TABLES 9 TO 12 OF CEP TECHNICAL REPORT NO. 33
DISTRIBUTION OF CARIBBEAN POLLUTION SOURCES

Appropriate Technology for Sewage Pollution Control
in the Wider Caribbean Region
March 1998

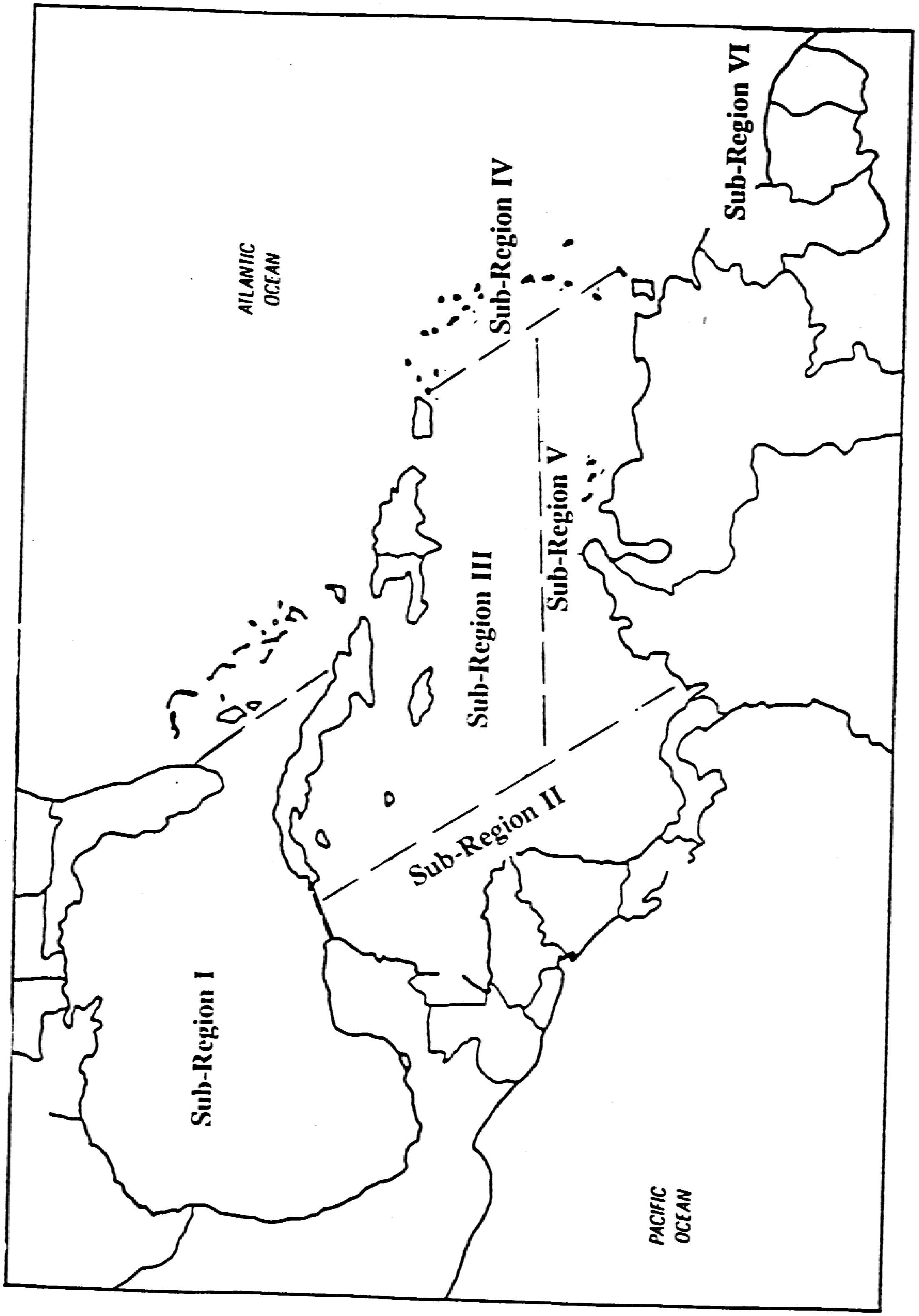


Figure 2: Sub-Regions in the Wider Caribbean Region

TABLE 9 **Waste Loads from Domestic Sources in the Wider Caribbean Region by Sub-Region (t/y)**

Country/Sub-Region	BOD	TSS	TN	TP	Oil and Grease
Sub-Region I					
Cuba(NE Coast)	53,734	50,811	4,198	5,915	5,985
Mexico(Gulf Coast)	24,529	20,964	4,184	1,810	8,379
USA(Gulf Coast)	37,393	44,552	25,688	11,416	27,006
Sub-Total	115,656	116,327	34,070	19,141	41,370
Sub-Region II					
Belize	1,905	2,100	650	320	240
Costa Rica	530	1,079	210	25	20
Honduras	9,626	8,235	625	823	450
Mexico(Car. Coast)	3,756	3,232	607	261	1,256
Panama	969	1,781	327	38	35
Sub-Total	16,785	16,427	2,419	1,467	2,001
Sub-Region III					
Cuba (Car. Coast)	9,413	3,481	572	296	112
Dom. Republic	40,573	60,000	3,027	4,182	5,125
Jamaica	4,227	6,658	1,097	133	350
Puerto Rico	16,819	20,000	530	890	500
Turks & Caicos Is.	47	75	13	2	2
Sub-Total	71,079	90,214	5,239	5,503	6,089
Sub-Region IV					
Antigua & Barbuda	29	45	7	1	1
Barbados	3,838	3,300	290	378	290
Brit. Virgin Is. Dominica	85	145	26	3	2
Grenada	51	81	13	2	2
St. Lucia	86	136	22	3	2
St. Kitts & Nevis	25	40	29	2	1
St. Vin. & Gren.	250	390	66	9	5
US Virgin Islands	26	40	7	1	1
	400	440	250	132	200
Sub-Total	4,790	4,617	710	531	504
Sub-Region V					
Aruba	61	52	20	4	1
Colombia	26,300	42,120	7,118	986	620
Netherlands Ant.	85	5	40	1	1
Trinidad & Tobago	1,000	1,567	1,585	59	28
Venezuela	232,725	185,000	77,575	32,425	18,325
Sub-Total	260,171	228,744	86,338	33,475	18,975
GRAND TOTAL	**506,482**	**456,329**	**128,796**	**60,117**	**68,939**

TABLE 10. Industrial activities and number of plants in the Wider Caribbean Region

Country/Sub-Region	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Total
Sub-Region I																
Cuba	1	20	3	10	3	1	2	2	1		4		2	5	5	59
Mexico	2	6	2	8		13					2				33	66
USA	72	151	2	119	24	314		100	3	2,194	1	75			1,673	4,775
Sub-Total	75	177	7	137	27	328	2	102	4	2,194	7	75	2	5	1,711	4,850
Sub-Region II																
Belize		2	1	5									1			9
Costa Rica	1		2	1				2								4
Honduras	2	2	2	6	1	1			1							17
Mexico (Caribbean)	2	6	2	8		13							2			33
Panama	1			10		2							3		4	20
Sub-Total	6	10	7	30	1	16		2	1				6		4	83
Sub-Region III																
Cuba (Caribbean Coast)	2	20	2	9	2	6	1		2	2		3	3	2	2	56
Dominican Republic	1	13	13	152	11	8	6	9	2	24	8	6	9	8	95	365
Jamaica	1	9	2	17		3	1	1	2	1	3		4		12	56
Puerto Rico	4			7		2							3		5	21
Turks and Caicos																
Sub-Total	8	42	17	185	13	19	8	10	6	27	11	9	19	10	114	498
Sub-Region IV																
Antigua and Barbuda		1		4									2	1		8
Barbados	1	3	4	5			5		3		3	4			10	38
British Virgin Islands				5									1			9
Dominica		1		4									2	1		8
Grenada		2	3	7									1			13
St. Lucia		1	3	4					2				3		2	15
St. Kitts and Nevis		2	2	5			1				1		1	1		13
St. Vincent & Grenadines		1	3	10												14
U.S. Virgin Islands		1											1			2
Sub-Total	1	12	15	44			6		5		4	4	11	3	12	117
Sub-Region V																
Aruba	1		2	2		1		1	1				1			9
Colombia	1	2	7	51	1	17	.5	2	3		5	8	3		5	110
Netherlands Antilles	1		3	2					3							9
Trinidad & Tobago	2	5	7	40	1	13	1	6	5				1		33	114
Venezuela	8	8	8	134	2	41	8	10	12		6	5	2	18	24	286
Sub-Total	13	15	27	329	4	72	14	19	24		11	13	7	18	62	528
TOTAL	100	250	74	618	46	422	30	133	42	2,221	101	26	46	30	1,881	6,011

A= Oil Refineries; B= Sugar factories, refineries, distilling and blending of spirits; C= Malt, liquor, and soft drinks; D= Food processing plants (sic codes 1110, 3111, 3112, 3113, 3114, 3115 and 3116); E= Pulp paper; F= Chemical industries and pesticides; G= Textiles; H= Basic industries (iron and steel, non-ferrous metals, machinery); I= Soap and cosmetics; J= Mining K= Plastics; L= Tonneries; M= Power plants; N= Electroplating; O= Others

TABLE 11. Waste loads from industrial sources in the Wider Caribbean Region

Country/Sub-Region	BOD	TSS	TN	TP	Oil & Grease	Hg	Ni	Pb	Cu	Cr	Zn	Phenols
Sub-Region I												
Cuba	103,438	79,732	3,261	1,424	4,474	X	X		X	X	X	X
Mex. (Gulf Coast)	2,073,666	27,496,000	673	42	625,630		X			X	X	X
USA (Gulf Coast)	68,658	246,152	13,300	16,251	10,077	X	X	X	X	X	X	X
Sub-Total	2,245,762	27,821,884	17,234	17,717	640,181	X	X	X	X	X	X	X
Sub-Region II												
Belize	870	1,150	290	80	70							
Costa Rica	6,359	5,572	1,057	288	2,138							X
Honduras	119,345	142,510	39,125	4,150	6,320							
Mexico (Carib.)												
Panama	284	655	54	1	83					X		X
Sub-Total	126,858	149,887	40,526	4,519	8,611							
Sub-Region III												
Cuba (Car. Coast)	79,862	27,350	3,890	4,156	104				X			X
Dom. Republic	57,826	113,516	19,200	8,500	4,350	X		X	X		X	X
Jamaica	5,753	3,098	175	6	620							X
Puerto Rico	214,000	850,000	20,000	28	123,000			X	X	X	X	X
Turks and Caicos												
Sub-Total	357,441	993,964	43,265	12,690	128,074							
Sub-Region IV												
Antigua & Barbuda	55	120	1	1	1			X	X	X	X	
Barbados	92,000	266,000	37,000	15,000	41,000		X		X	X	X	X
British Vir. Is.	5	23	2	1	2				X			
Dominica	1,650	2,512	200	100	180							
Grenada	252	178	55	30	10						X	
St. Lucia	190	895	38	34	10						X	X
St. Kitts & Nevis	201	73	5	3	1					X	X	
St. Vin. & the Grenadines	331	424	3	2	2							
U.S. Vir. Islands	23	45	2	1	21	X				X		
Sub-Total	94,707	270,270	37,306	15,171	41,227							
Sub-Region V												
Aruba	270	180	40	12	115							
Colombia	14,693	23,738	4,300	2,100	1,693					X		X
Netherlands Antilles	2,977	876	290	2	1,050					X		X
Trinidad & Tobago	299,000	1,060,000	111,000	172	146,000					X		X
Venezuela	286,430	1,600,154	95,477	30,251	13,750		X	X		X	X	X
Sub-Total	603,370	2,684,948	211,107	32,537	162,608							
TOTAL	3,428,138	31,920,953	349,438	82,634	980,701							

x = Data indicates that this pollutant is being dishcarged into the marine environment

TABLE 12. Relative BOD_5 Contribution per type of industry

Country/ Sub-Region	Food Processing		Sugar Fact. Alcohol Dist		Oil Refineries		Chemical Industries		Beer & Soft Drinks Ind.		Paper Industries		Country Total	
	t/y	%	t/y	%	t/y	%	t/y	%	t/y	%	t/y	%	t/y	%
Sub-Region I														
Cuba	-	-	115,479	63.0	14,600	8.0	-	-	21,446	11.7	19,979	10.9	171,504	93.6
Mexico	-	-	-	-	1,799,942	86.8	-	-	-	-	-	-	1,799,942	86.8
USA	2,100	3.0	7,722	11.0	7,026	10.0	14,855	22.0	-	-	20,417	30.0	52,120	76.0
Sub-Total	2,100	0.1	123,201	5.2	1,821,568	78.3	14,855	0.6	21,466	0.9	40,396	1.7	2,023,566	87.0
Sub-Region II														
Belize	140	16.0	540	62.0	-	-	-	-	120	14.0	-	-	800	92.0
Costa Rica	5246	82.5	-	-	-	-	-	-	-	-	-	-	5,246	86.5
Honduras	4705	4.0	6,400	5.0	10,140	8.0	3,261	3.0	92,230	77.0	-	-	116,736	97.0
Panama	-	-	-	-	243	85.7	-	-	-	-	-	-	243	85.7
Sub-Total	10,091	7.95	6,940	5.4	10,383	8.0	3,261	2.5	92,350	73.0	-	-	123,025	97.6
Sub-Region III														
Dominican Rep.	8,900	15.0	14,173	25.0	11,217	20.0	-	-	21,000	36.0	-	-	55,830	96.0
Jamaica	1,208	21.0	2,819	7.0	402	7.0	-	-	604	10.5	-	-	5,033	87.5
Puerto Rico	-	-	-	-	212,000	99.0	-	-	-	-	-	-	212,000	99.0
Turks & Caicos	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Sub-Total	10,108	3.6	17,532	6.3	223,619	80.5	-	-	21,604	7.6	-	-	272,863	98.0
Sub-Region IV														
A/Barbuda	9	16.0	45	82.0	-	-	-	-	-	-	-	-	54	98.0
Barbados	-	-	-	-	71,760	78.0	-	-	-	-	-	-	71,760	78.0
British VI	4	80.0	-	-	-	-	-	-	-	-	-	-	4	80.0
Dominica	1,582	95.0	40	2.0	-	-	-	-	-	-	-	-	1,622	97.0
Grenada	-	-	78	31.0	-	-	-	-	172	68.0	-	-	250	99.0
St. Lucia	152	80.0	30	16.0	-	-	-	-	-	-	-	-	182	96.0
St. K/Nevis	12	6.0	154	77.0	-	-	-	-	31	15.0	-	-	197	98.0
St. V/Gren.	92	28.0	180	54.0	-	-	-	-	58	17.0	-	-	330	99.0
US V.I.	-	-	22	96.0	-	-	-	-	-	-	-	-	22	96.0
Sub-Total	1,851	2.0	703	0.6	71,760	76.1	-	-	261	0.2	-	-	74,575	78.8
Sub-Region V														
Aruba	30	11.0	-	-	136	50.0	-	-	60	22.	-	-	226	83.0
Colombia	1,755	12.0	1,580	11.0	844	6.0	4,500	30.0	2.610	18	-	-	11,289	77.0
Neth. Antilles	-	-	-	-	2,768	93.0	-	-	-	-	-	-	2,768	93.0
Trinidad/Tobago	-	-	-	-	279,864	93.6	-	-	-	-	-	-	279,864	93.6
Venezuela	121,467	42.0	32,681	11.0	3,500	0.7	8,700	3.0	23.200	8	19.760	7	209,108	72.0
Sub-Total	123,252	20.4	34,261	5.6	286,932	47.5	13,200	21.1	25,670	4.2	19,760	3.2	503,255	83.1
TOTAL	147,402	4.3	152,924	4.4	2,414,442	70.0	31,316	1.1	178,207	5.0	60,162	1.7	2,984,453	86.5

APPENDIX B.
WATER QUALITY STANDARDS
FROM THE U.S. AND OTHER COUNTRIES

Appropriate Technology for Sewage Pollution Control
in the Wider Caribbean Region
March 1998

Table 3

MICROBIOLOGICAL QUALITY OF WATER GUIDELINES/STANDARDS 100 mℓ

Country	Shellfish harvesting		Primary contact recreation			Protection of indigenous organisms		References
	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Other	Total Colif.	Fecal Colif.	
USEPA, United States		14[a] 90% < 43			Enterococci 35[a] (see Table 1)			USEPA (1986) Dufour y Ballentine (1986)
California, United States	70[a]		80% < 1000[i,j] 100% < 10000[k]	200[a,j] 90% < 400[i]				Cal. Sta. Water. Res. Board (sin fecha)
EEC[c], Europe			80% < 500[a] 95% < 10,000[d]	80% < 100[a] 95% < 2,000[d]	Fecal estreptococci 100[a] Salmonella 0/liter [d] Enteroviruses 0 PFU/liter[d] Enterococci 90% < 100			EEC (1976) CEPPOL (1991)
UNEP/WHO		80% < 10 100% < 100	50% < 100[a] 90% < 1000[a]					WHO/UNEP, 1978
Brazil			80% < 5000[m]	80% < 1000[m]				Brazil. Minister... del Interior. (1976)
Colombia			1000	200				Colombia. Ministerio de Salud. (1979).
Cuba			1000[a]	200[a] 90% < 400				Cuba. Ministerio de Salud. (1986)
Ecuador			1000	200				Ecuador. Ministerio de Salud Publica. (1987).
Mexico	70[a] 90% < 230		80% < 1000[f] 100% < 10,000[h]			10,000[a] 80% < 10,000 100% < 20,000		Mexico. SEDUE. (1983)
Peru	80% < 1000	80% < 200	80% < 5000[f]	80% < 1000[f]		80% < 20000	80% < 4000	Peru. Ministerio de Salud. (1983)
Puerto Rico	70[h] 80% < 230			200[h] 80% < 400				Puerto Rico. JCA. (1983)
Venezuela	70[a] 90% < 230	14[a] 90% < 43	90% < 1000 100% < 5000	90% < 200 100% < 400				Venezuela. (1978)

Table 3

MICROBIOLOGICAL QUALITY OF WATER GUIDELINES/STANDARDS 100 mℓ (continued)

Country	Shellfish harvesting		Primary contact recreation			Protection of indigenous organisms		References
	Total Colif.	Fecal Colif.	Total Colif.	Fecal Colif.	Other	Total Colif.	Fecal Colif.	
France			< 2000	< 500	Fecal Estreptococci < 100			WHO (1977)
Israel			80% < 1000[a]					Argentina. INCYTH. (1984)
Japan	70		1000			1000		Japan. Environmental Agency. (1981)
Poland					E. Coli < 1000			WHO (1975)
U.R.S.S.					E. Coli < 100			WHO (1977)
Yugoslavia			2000					Argentina, INCYTH (1984)

a. Logaritmic average for a perio.' of 30 days of at least 5 samples
b. Minimum sampling frequency - fortnightly
c. Guide
d. Mandatory
e. Monthly average
f. At least 5 samples per month
g. Minimum 10 samples per month
h. At least 5 samples taken sequencially from the waters in a given instance
i. Period of 30 days
j. Within a zone bounded by the shoreline and a distance of 1000 feet from the shoreline or the 30 foot depth contour, whichever is further from the shoreline
k. Not a sample taken during the verification period of 48 hours should exceed 10,000/100 mℓ
l. Period of 60 days
m. "Satisfactory" waters, samples obtained in each of the preceeding 5 weeks

APPENDIX C.
ABSTRACTS ON SELECTED WORKS FROM LITERATURE REVIEW

Appropriate Technology for Sewage Pollution Control
in the Wider Caribbean Region
March 1998

ABSTRACTS ON SELECTED WORKS FROM LITERATURE REVIEW

Abstracts for some of the works reviewed for this report are provided below, in alphabetical order by title. The complete list of works is provided in the report's reference list.

Title: *15 Years of Practical Sewage Treatment in Venezuela*
Author: Mark Lansdell
Source: Water Science Technology, 1996
Abstract: A summary of 15 years of experience of the design, operation and performance of several Venezuelan municipal wastewater treatment systems to serve a population of 5 million is presented.

Title: *Actual Experiences with the Use of Reed Bed Systems for Wastewater Treatment in Single Households*
Author: Perfler, R., Haberl, R.
Source: Water Science Technology, Vol. 28, No 10, 1993
Abstract: Within a long-term project from 1991 to 1996 investigations on the use of constructed wetlands for pollution control in rural areas will be carried out especially regarding the rather strict limiting values for nutrient elimination. The actual discussion is also relevant for very small systems applied to single households. Three reed bed systems - one vertical flow, single stage; one vertical flow double stage (parallel and in-series operation possible); one horizontal flow, double stage have been constructed in 1991 regarding all the new experiences on optimising this technology. Some results of inlet and outlet sampling and from sampling points within the bed, of tracer experiments and microbiological and virological testing are presented. In addition a short review on the installation costs is given. In general, the experiences of one year of operation seem to prove the opportunity to meet the tightened limits by waste water treatment in constructed wetlands.

Title: *The Advantages of a Compact Filter for Individual or Semi-Collective Wastewater Treatment*
Author: A. Fazio, G. Warot, and P. Vander Borght
Source: Wat. Sci. Tech. Vol. 27, No. 1, pp. 41-50, 1993.
Abstract: In certain rural areas, collective water treatment is not an economically viable solution due to the cost of the water collection facilities (difficult terrain, distance between the house); for various reasons, however, the traditional individual water treatment system is not highly regarded (bad installation , insufficient maintenance, ...) and thus, work has been carried out to develop a high-performance and compact alternative solution for domestic wastewater treatment. This alternative system makes use of a compact sand filter installed downstream from the septic tank, the filter's performance is based on supply regulation and improvement of the waste's surface distribution. Hydraulic laboratory studies and follow-up on a testing stand using real effluent have enabled us to develop a standardised compact system which is suitable for use in most terrains. The filter's purification performance is outstanding; at a daily support rate of 150 l/m^2, the average purification yields are over 90% for COD, BOD, NH_4, N_{KT}. From the bacteriological point of view, bacterial contamination is also significantly reduced. Laboratory tests are being carried out at present, with the aim of further improving purification by inducing a denitrification process enabling reduction of nitrate levels. This systems' compact overall dimensions and relatively low cost mean that it can be used not only for individual wastewater treatment but also for effluent treatment for small communities ($\leq$ 400 inhabitant equivalent).

Title: *Alteration in Sewage Characteristics Upon Aging*
Author: Wang Kaijun, G. Zeeman, G. Lettinga
Source: Wat. Sci. Tech. Vol. 31, No. 7, pp. 191-200, 1995.
Abstract: To improve the understanding of the nature of sewage changes upon ageing during transport or storage, simulation experiments were conducted using batch reactors under a number of well defined conditions, i.e. anaerobic, aerobic and micro-aerophilic at 10°C, 20°C and 30°C. Important characteristics of the studies sewage were the visual appearance, various chemical properties and odour. The effect of temperature on the degradation processes and reaction kinetics of different polluting fractions of the sewage is studied under mainly micro-aerophilic and anaerobic conditions. The results of non-inoculated batch simulating experiments reveal that micro-aerophilic conditions are suitable for both pre- and post-treatment of sewage, while anaerobic

conditions will suffice for pre-treatment. At low temperatures, anaerobic conditions mainly serve for pre-acidification. On the basis of the results obtained, we recommend putting emphasis on further research dealing with on-site and on-line treatment systems, combined with a central wastewater treatment plant. Such processes look attractive in improving the organic removal efficiency and in reduction of operating cost and capital outlay of wastewater treatment systems.

Title: *Alternative Approaches for Upgrading Effluent Quality for Lagoon Based Systems*
Author: Evans, Brian; Nutt, Stephen; Ho, Tony; Melcer, Henry
Source: Water Science and Technology Design and Operation of Small Wastewater Treatment Plants Proceedings of the 2nd International Conference on Design and Operation of Small Wastewater Treatment Plants June 28-30 1993 v 28 n 10 1993 Trondheim, Norw Publ by Pergamon Press Inc. Tarrytown NY USA p. 201-205.
Abstract: The province of Ontario is Canada's most populous province with over 8 million residents out of a total population of 27 million. The province has 512 sewage treatment plants out of which 137 or 27% are lagoons. Improved environmental effluent quality standards since the introduction of lagoons has resulted in many of these being unable to achieve proper effluent quality. Typical effluent quality requirements across the province require a minimum of secondary treatment, that 15 mg/l of BOD and suspended solids and 1 mg/l of total phosphorous. The movement towards a clean environment has resulted in phosphorous levels as low as 0.3 mg/l TP and in an increasing number of cases full nitrification year round. Because many of these lagoons serve small populations in the 100-3,000 population equivalents category, the cost of upgrading such lagoons to tertiary quality effluent is significant. Two approaches for upgrading conventional lagoon systems were evaluated. They are called the Sutton New Hamburg processes after the towns in Ontario where they were first installed. The Sutton process consists of extended aeration plant, followed by polishing lagoons with waste sludge set directly to the lagoons, while the New Hamburg process consists of conventional lagoons followed by intermittent sand filtration.

Title: *Anaerobic/Aerobic Combination Treats High-Strength Wastewater*
Author: Roeland P. Ulrix
Source: Water Engineering and Management, February 1994
Abstract: Innovative process developed in Germany for high-strength wastewater

Title: *Anaerobic Codigestion of Agricultural Industries' Wastewaters*
Author: H.N. Gavala, I.V. Skiadas, Nikolaos A. Bozinis and G. Lyberatos
Source: Wat. Sci. Tech. Vol. 34, No. 11, pp. 67-75, 1996.
Abstract: Wastewaters generated from agricultural industries are usually hard to treat due to a high organic content. The basic treatment process to be used can only be anaerobic digestion, a process with the additional advantages of (I) limited production of stabilised sludge and (ii) utilisation of the produced biogas. The cotreatment of such seasonally produced wastewaters is proposed in order to secure the economically favourable and stable year-round operation of a treatment plant, with the additional benefits of smaller capital costs (due to the use of centrally located rather than distributed treatment facilities) and the exploitation of complementarity in waste characteristics (e.g. avoidance of nutrients (N, P) addition when a codigested wastewater contains nutrients in excess). A mathematical model for codigesting piggery, olive-mill and dairy wastewaters was developed based on batch kinetics experiments. An organic loading rate of 3.84 g COD/l-d was found to be safe for a digester operating on a year round basis, fed sequentially with piggery, piggery-olive-mill and piggery-diary wastewaters. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

Title: *Anaerobic Digestion of High Strength Molasses Wastewater Using Hybrid Anaerobic Baffled Reactor*
Author: R. Boopathy and A. Tilche
Source: Water Research, Vol. 25, No 7, 1991
Abstract: The anaerobic digestion of high strength molasses wastewater (molasses alcohol stillage and raw molasses) in a hybrid anaerobic baffled reactor was studied. At an organic loading rate of 20 kg COD/m^3.d, the reactor performed effectively achieving total and soluble COD removals in excess of 70 %. Granulation of biomass was observed in the reactor and the granules grew in size with time as the experiment progressed. The predominant methanogens similar to Methanothrix and Methanosarcina species were observed in the granules. Nitrogen and phosphorus were supplemented whenever needed. Biomass retention inside the reactor was very good. Gas production was 5 v/v of the reactor day.

Title: *Application of Anaerobic Digestion to the Treatment of Agroindustrial Effluents in Latin America*
Author: Borzacconi, L., Lopez, I., Vinas, M.
Source: Water Science Technology, Vol. 32, No 12, 1995
Abstract: A 994 survey of high rate anaerobic reactors, employed in the treatment of agroindustrial effluents in Latin America is presented. Data including number, volume and type of reactors, their evolution with time and type of effluents are discussed. Latin America has an increasing and significant participation in the application of anaerobic treatment to agroindustrial effluents. In particular, the design parameters of already operating reactors and the impact of applying this technology to the most typical effluents are analysed. The equivalent energy of biogas that can be produced through this technology is given. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

Title: *Application of Constructed Wetlands to Treat Some Toxic Wastewaters under Tropical Conditions*
Author: C. Polprasert, N.P. Dan and N. Thayalakumaran
Source: Wat. Sci. Tech. Vol. 34, No. 11, pp. 165-171, 1996
Abstract: This study evaluated the potential of a free water surface constructed wetland system in treating some toxic wastewaters (i.e. phenolic and heavy metals). In a temperature range of 22 - 30^{o}C, the constructed wetland units, whose hydraulic retention times (HRT) were 5 - 7 days, could remove more than 99% of the input phenol when they were operated at or below the organic loading rates (OLR) and influent phenol concentrations of 270 kg COD/(ha.d) and 400 mg/l, respectively. The effluent dissolved oxygen (DO) levels were 4 - 7 mg/l at OLR of 40 - 140 kg COD/(ha.d), but these DO levels decreased to 0.2 - 0.3 mg/l when the OLR were increased to 165 - 270 kg COD/(ha.d). Under similar operating conditions, the constructed wetland units could remove more than 99% of the applied chromium (Cr) and nickel (Ni), when either the Cr or Ni influent concentrations were 1 - 50 mg/l. The phenolic and heavy metal compounds were found to accumulate mostly at the roots of *Typha*, followed by the stems of leaves. Copyright © 1996 IAWQ. Published by Elseveir Science Ltd.

Title: *Appropriate Wastewater Treatment Technology for Small Communities*
Author: J.F. Kreissl, National Risk Management Research Laboratory
Source: USEPA Manual
Abstract: Description of the terms appropriate technology and provides some examples

Title: *Biodegradation of Petroleum Refinery Wastewater in a Modified Rotating Biological Contactor with Polyurethane Foam Attached to the Disks*
Author: R.D. Tyagi, F.T. Tran, Chowdhury
Source: Water Research, Vol. 27, No 1, 1993
Abstract: A laboratory scale study was conducted to assess the feasibility of a modified rotating biological contactor (RBC) with polyurethane foam (PUF) attached to the disks as porous support media to biodegrade a petroleum refinery wastewater. PUF of 1 cm thickness was attached to both sides of each disk. Two parallel RBC-PUF units (each having 24.8 L working volume) were operated simultaneously at different hydraulic loading rates 0.01, 0.02, 0.03 and 0.04 met cubed/m sq.d and at a rotational speed of 10 rpm. For all hydraulic loadings studied, the removal efficiency of the total chemical oxygen demand (TCOD) and oil were above 87 and 80 %, respectively. The biomass concentration within the RBC-PUF system was also investigated. The efficiency of the RBC-PUF system for the treatment (removal of organics, ammonia nitrogen, phenol, oil and grease and suspended solids) of the petroleum refinery wastewater at various hydraulic loadings was investigated. The results obtained in terms of biodegradation of COD, NH3N, phenol, hydrocarbons and suspended solids in the modified RBC were generally better than a conventional RBC.

Title: *BOD 5 Removal in facultative Ponds: Experience in Tanzania*
Author: Mayo, Aloice W.
Source: Water Science Technology, Vol. 34, No 11, 1996
Abstract: This paper discusses the removal of BOD 5 in facultative ponds under tropical conditions. Data was collected from pilot and field ponds at the University of Dar es Salaam and was compared to other ponds in Dar es Salaam. Results showed deviations of performance, in some cases, from assumptions made during the design. The permissible organic loading rate for ponds in Dar es Salaam was 450 kg BOD 5 / ha / d. To reduce concentration of algae in the final effluent, a sunken outlet structure was suggested.

Title: *Brewery Wastewater Treatment in UASB Reactor at Ambient Temperature*
Author: Yue-Gen Yan, Joo-Hwa Tay
Source: Journal of Environmental Engineering, Vol. 122, No 6, June 1996

Abstract: Granulation was examined in the 12.2L upflow anaerobic sludge blanket reactor at the average ambient temperature of 21.8 °C. Brewery wastewater with an average chemical oxygen demand (COD) of 2030 mg/L and biochemical oxygen demand of 1150 mg/L was used as substrate, and anaerobic digested sludge as inoculum. During start-up, the sludge loading rate was gradually increased when 80% of soluble COD removal efficiency was achieved. The granules were initially developed after 4-month operation and fully grown after 6-month operation. At 21.8 degrees, the influent alkalinity seemed to have played a positive role in the granulation process by improving the biogas release from the sludge, with the appropriate value of 1200 mg $CaCO_3$/L. The granules cultivated ranged from 0.4 mm to 1.5 mm in diameter, with specific methanogenic activity of 0.92 gCH_4-COD/g VSS.d and sludge volume index of 14 mL/g of suspended solids. After granulation, the upflow anaerobic sludge blanket reactor performed stably with soluble COD and biochemical oxygen demand removal efficiencies of 89.1% and 91.3%, respectively, under the volumetric loading rate of 12.2 gCOD/L.d and hydraulic retention time of 4 hours.

Title: *Closed-Loop System Recycles VOC's from Refinery Wastewater*
Author: Ann Hasbach, Senior Editor
Source: Pollution Engineering, May 15, 1992
Abstract: Methods used in removal of Volatile Organic Compounds (VOCs) in refinery wastewater. Includes air stripping, relative humidity modification, and activated carbon adsorption. (Short 1 page article)

Title: *Comparison of the Purifying Efficiency of High Rate Algal Pond with Stabilization Pond*
Author: Picot, B., Bahlaoui, A., Moersidik, B., Baleux, B., Bontoux, J.
Source: Water Science Technology, Vol. 25, No 12, 1992
Abstract: Due to its high sanitary efficiency, treatment of wastewater by Stabilisation Ponds (SP) is proposed for sensitive coastal areas (proximity to bathing areas, shellfish farming lagoons). This process, suitable for small communities with high summer populations, requires large surface area. The objective of this study is to compare High Rate Algal Pond (HRAP) purifying efficiency with that of SP. We have experimented with a HRAP process, which by generating algal growth reduces the required surface area; our studies suggest this to be by a factor of 5. This process is particularly interesting for nutrient removal, especially nitrogen, and could be useful in coastal areas susceptible to eutrophication. Its sanitary performance is comparable to that of SP. Environmental factors and pond depth play a more important role in HRAP efficiency than retention time of water in the basins.

Title: *Constructed Reed Beds: Appropriate Technology for Small Communities*
Author: Green, M.B., Upton, J.
Source: Water Science Technology, Vol. 32, No 3, 1995
Abstract: Reed bed treatment is put in the context of a major water company's need to provide reliable, high quality, effluents from small sewage treatment works whilst seeking to minimise running costs. Design and operational information is given for reed bed applications in Severn Trent Water. Performance details are provided for application to secondary, tertiary and storm overflow treatment. The results give particular confidence in the system's ability to deliver very high quality effluents when used for tertiary treatment, the company's biggest application. Reed beds work well against less demanding criteria for secondary treatment at small sites and show great promise for storm overflow treatment.

Title: *Control of Pollution in Organized Industrial Districts: A Case Study from Turkey*
Author: Ayse Filibeli, Füsuun Sengül and Aysen Müezzinoglu
Source: Wat. Sci. Tech. vol. 34, No. 12, pp. 127-133, 1996.
Abstract: At Manisa Organised Industrial District (OID) chosen as pilot study area, a detailed wastewater profile and pollution control study has been realised. A pre-treatment strategy was determined and a wastewater management plan was prepared. Existing central treatment plant was studied and cost items were determined. These evaluations were compared with the redesign options generated from our own wastewater management plan. Same treatment units and their combinations were successively designed for variable flow rates between 100-500 m^3/d. Thus data for new OIDs of similar nature as Manisa, an optimised treatment scheme as well as its approximate cost varying with the wastewater inflow was generated. Proposals for preparing environmental criteria to be considered and applied in newly establishing or planned OIDs are summarised. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

Title: *The Cyclic Activated Sludge System for Resort Area Wastewater Treatment*
Author: Goronszy, M., Slater, N., Konicki, D.
Source: Water Science Technology, Vol. 32, No 12, 1995
Abstract: Significant load variation is imposed on wastewater treatment infrastructure at resort centres. The type of resort centre plays a large part in both hydraulic and organic loading dynamics. Climatic conditions may also be a determining factor on the loading pattern. holiday patterns also have a large impact upon loading dynamics. Performance of the Portage/Catawba Cyclic Activated Sludge System, located on the shores of Lake Erie, is described relative to the loading dynamics of the Summer/Winter populations.

Title: ***Demonstration of Constructed Wetlands for Treatment of Municipal Wastewaters, Monitoring Report for the Period, March 1988 - October 1989.***
Author: Choate. K.D; Watson, J.T.; Steiner, G.R.
Source: Environmental Pollution Control and water pollution and control (68D)
Abstract: To evaluate the constructed wetland technology, the Tennessee Valley Authority (TVA) implemented a municipal wastewater demonstration project in western Kentucky. Using combined city, State, and TVA appropriated funds, three constructed wetland systems were built at Benton, Hardin, and Pembroke, Kentucky. Demonstration objectives include evaluating relative advantages and disadvantages of these types of systems; determining permit compliance ability; developing, evaluating, and improving basic design and operation criteria; evaluating cost effectiveness; and transferring technology to users and regulators. A demonstration monitoring project was implemented with a partnership of funds from the Environmental Protection Agency (EPA) Region IV, other EPA funds through the National Small Flows Clearinghouse (NSFC), and TVA appropriations. TVA is managing the project in co-operation with an interagency team consisting of EPA, Kentucky Division of Water and NSFC. This report, which supersedes the first monitoring report (Choate, etc. al., 1989) of these demonstration projects, describes each constructed wetland system, its status, and summarises monitoring data and plans for each system.

Title: *Developing Alternative Approaches to Urban Wastewater Disposal in Latin America and the Caribbean*
Author: Carl R. Bartone, Henry J. Salas
Source: PAHO Bulletin, Vol. 18 No 4, 1984
Abstract: Rapid Urbanisation and industrialisation in Latin America and the Caribbean has aggravated serious wastewater disposal problems in that region. This article describes some of the more promising methods available for dealing with these problems --- including use of submarine outfall, reuse of treated sewage effluent, and application of unconventional technology in poverty-stricken urban neighbourhoods.

Title: *Development of a Biofilter Using an Organic Medium for On-Site Wastewater Treatment*
Author: Talbot, P., Belanger, G., Pelletier, M., Laliberte, G., Arcand, Y.
Source: Water Science Technology, Vol. 34, No 3-4, 1996
Abstract: In recent years, many authors identified peat-based systems as very promising technology for on-site wastewater treatment. In that context, Premier Tech has been working, since 1988, on the development and commercialisation of a peat-based biofilter suitable for on-site wastewater treatment. This research and development programme comprised three major phases: an experimental phase where on type of peat out of 21 was chosen to be used in biofilters: a second phase where two prototype biofilters were installed in the field and their performances followed for 5 years; and a third phase where 4 biofilters were installed in order to demonstrate the adaptability of the system. The results obtained in this three-phase programme allowed the introduction on the market of a compact, reliable and easy to operate biofilter requiring little investment from the home owner. In this paper an overview of the research and development programme carried out in the last 8 years in relation to on-site treatment is given.

Title: *Development of a Land Limited Wastewater Treatment Plan for Small and rural Communities in the Tropics*
Author: P. Y. Yang, H. Chen and T. Ma
Source: Wat. Sci. Tech. Vol. 29, No. 12, pp. 1-12, 1994.
Abstract: The treatment systems for strict and moderate land limited approaches were investigated. Both synthetic glucose and actual wastewater (domestic wastewater) were studied. For the strict land limited approach, a packed entrapped mixed microbial cell (PEMMC) process using cellulose triacetate as the polymer carrier was tested for synthetic wastewater. For the moderate land limited approach, a combined aquatic weed on the water surface and a bio-fixed film in the lower portion of the pond system was investigated for both the synthetic and actual wastewater. The actual domestic wastewater was examined in a single pond system with vertical flow under the BOD_5 loading rate of 135 Kg/ha/day. BOD_5 and nitrogen removal efficiencies of more than 85% and 70%, respectively, were received. The glucose synthetic wastewater was examined in a single pond system with horizontal flow at a BOD_5 loading rate of 130 Kg/ha/day. BOD_5 and nitrogen removal efficiencies of 92% and

60%, respectively, were received. For the strict land limited treatment approach, it was found that more than 90% and 85% of soluble COD and total COD (including effluent suspended solid), respectively, could be removed at the loading rate of 1.6 g COD/L/day. The hydraulic retention time of 3.5 hours and the influent COD concentration of 200-250 mg/L were maintained and operated. This is comparable with the process performance of the conventional activated sludge for treating the domestic sewage under the same operational conditions. The PEMMC process also provides the advantages of maintaining a high SRT (Solid Retention Time) without external sludge recycling and a short starting period of less than 10 days. Application of the present two systems will be dependent on the land and/or energy requirement. It is appropriate to use the treatment system of combining the aquatic plant with the bio-fixed film for moderately available land and in tropical areas. A strict land limited treatment system, of course, requires additional energy input.

Title: *Effect of Sunlight on Faecal Coliforms in Ponds: Implications for Research and Design*
Author: Curtis, T.P.; Mara, D.D.; Silva, S.A.
Source: Water Science and Technology Proceedings of the 16th Biennial Conference of the International Association on Water Pollution Research and Control - Water Quality International '92 May 24-30 1992 v 26 n 7-8 1992 Washington, DC. USA Publ by Pergamon Press Inc. Tarrytown NY USA P. 1729-1738.
Abstract: Empirical and theoretical models of the effect of light on faecal coliforms (FC) in waste stabilisation ponds are used to show that: (I) light can only have an impact on FC if complemented by high dissolved oxygen (DO) concentrations and a high pH; (ii) the tendency of algae to impede light penetration is offset by their ability to raise the pH and DO; and (iii) that visible light is more important than UV. Therefore, the DO concentration and pH should be included in models of the effect of light in ponds. In the absence of light, pH values < 9.3 may have less impact than previously discussed. The implications for design and research are discussed.

Title: *Efficiency of Faecal Bacterial Removal in Waste Stabilisation Ponds in Kenya*
Author: Mills, S.W., Alabaster, G.P., Mara, D.D., Pearson, H.W., Thitai, W.N.
Source: Water Science Technology, Vol. 26, No 7-8, 1992
Abstract: Results for faecal coliform die-off rates are presented for seven different waste stabilisation pond systems in Kenya, which were sampled as part of a national pond monitoring and evaluation study carried out during 1988-1989. The results showed that average die-off rates through each pond series were considerably lower than those predicted from traditional design equations which are based on temperature (Marais, 1974). Die-off rates were surprisingly higher in the primary ponds, which are designed for pathogen removal. God correlations were found between faecal coliform first order removal rate constants and (a) temperature for the pond series as a whole, and (b) influent faecal coliform concentration for individual ponds.

Title: *Efficiency of Removal in Stabilisation Ponds I. Influence of Climate*
Author: Benilde S. Mendes, M. Jenny do Nascimento, M. Irene Pereira, Gerard Bailey, Nuno Lapa, Joao Morais, and J. Santos Oliveira
Source: Wat. Sci. Tech. Vol. 31, No. 12, pp. 219-229, 1995.
Abstract: Owing to the existing or predictable water deficiencies in the South of Portugal, it is necessary to carry out the appropriate management of water resources, by reducing and/or minimising the negative impacts of untreated/treated domestic effluents in the aquatic environment. As Portugal has a great diversity of ecoclimatic areas, five different stabilisation pond systems were chosen to carry out a control study during one year (from March 1991 to March 1992). According to Pina Manique and Albuquerque the ecological classification of these stations is different, varying from Ibero-mediterranean (continental) up to Mediterranean (maritime). The physical and chemical parameters studies were: temperature, pH, dissolved oxygen, conductivity, BOD, COD, nitrates, nitrites, ammonia and total nitrogen, total suspended and volatile solids, total phosphorus and orthophosphates. The microbiological parameters studies were: total and faecal coliforms, faecal *Streptoccoci, Clostridum perfringens* and *Pseudomonas aeruginosa.* The correlations between climatic parameters and the efficiency of the removal of organic matter were analysed..

Title: *An Evaluation of the Efficiency and Impact of Raw Wastewater Disinfection with Peracetic Acid Prior to Ocean Discharge*
Author: Ruiz, C., Royano, S., Monzon, I.
Source: Water Science Technology, Vol. 32, No 7, 1995
Abstract: Peracetic acid (PAA) is the active component of a series of disinfectant products developed for the treatment of wastewater. These products have only recently been introduced onto the market so little published information

exists about their efficiency. In this work the disinfection efficiency of PAA has been experimentally studies on raw wastewater, along with eventual regrowth after the ocean discharge of the treated water. Great variability has been observed in the inactivation of total coliforms by PAA, the influence of the pH of the wastewater was noteworthy. The disinfection action takes place in short time (around 5 to 10 minutes). After disinfection and mixing with real sea water the total coliforms present greater T_{90} values and disappearance times, having increased their concentration under laboratory conditions and in darkness.

Title: *Evaluation of Innovative Wastewater Treatment Technology*
Author: Qasim, Syed R.; Parker, Clinton E.
Source: International Journal of Environmental Studies: Section A Environmental Studies v 44 n 1 1993 p 45-52.
Abstract: The Clean Water Act of 1997 (PL 95-217) defined and authorised special construction grant provisions for wastewater treatment called Innovative and Alternative (I/A) Technology Program. The grant provisions allow for increased grant funding for application of non-conventional systems which provide reduced costs for environmental benefits. Technologies that come under this program are treatment processes or components which have not been fully proven and can be used to achieve: reuse and recycle of wastewater and sludge, reduction of cost and energy compared to conventional treatment methods, or provide simple and economical treatment for small communities. Funding for field testing to evaluate emerging technologies before funds are committed to a full scale system was included in the program by the 1991 Clean Water Act Amendments. The field test provision provides an opportunity to evaluate emerging, high risk technologies which offer a very high potential for advancing treatment technology.

Title *Evaluation of On-Site Disposal Options*
Author: P.M. Geary
Source: Wat. Sci. Tech. Vol. 27, No. 1, pp 59-62, 1993.
Abstract: A number of on-site disposal options were evaluated for a small community in northern NSW. Individual allotments were assessed in relation to land capability constraints to on-site disposal. The feasibility of a community-based on-site scheme using a number of alternative options was examined and compared to a proposal for a centralised sewerage scheme for the town.

Title: *Experimental Plants for very Small Communities: Choice and Design Criteria for Five Different Processes*
Author: Boutin, C., Lienard, A., Ramain, J.L., Beyeler, L.
Source: Water Science Technology, Vol. 28, No 10, 1993
Abstract: Waste Stabilisation ponds and land treatment seepage, which are generally used for very small communities, are being used less frequently due to their specificity and their lack of suitability in certain cases (ground characteristics, available space, fragile receiving bodies, etc..) This article gives the choice criteria for the proposed new series for 5 communities sized between 50 and 400 person equivalents, together with a detailed description of the facilities: septic tank + covered infiltration bed; horizontal settling-digestion tank + covered infiltration bed; settling-digestion tank (Imhoff) + trickling filter + infiltration bed; pond + covered infiltration bed; reed-bed filters.

Title: *Exploring Wastewater Treatment --- A Treasure Chest of Technologies*
Author: J.C. Goldman Jr. and Paul T. Bowen
Source: Pollution Engineering, September 1, 1992
Abstract: General overview of industrial wastewater treatment technologies.

Title: *Feasibility of Anaerobic Sewage Treatment in Sanitation Strategies in Developing Countries*
Author: G.J. Alaerts, S. Veenstra, M. Bentvelsen and L.A. van Duijl
Source: Wat. Sci. Tech. Vol. 27, No. 1, pp. 179-186, 1993.
Abstract: Sanitation strategies in the growing cities may aim at protection of shallow groundwater, public health protection, removal of oxygen-consuming substances and removal of nutrients. It is shown that anaerobic treatment of municipal wastewater in UASB type reactors has become a feasible treatment option in those strategies. This study investigates the merits of the technology for on-site management of black and grey wastewater, and for off-site centralised treatment. At on-site scale where effluent is leached into the ground, anaerobic reactors offer no advantage over cheaper leaching pits. At larger centralised scale, anaerobic reactors have performed well and reliably over longer periods. Post-treatment may be required, but the total treatment is financially advantageous in warm climates; if land cost is low long-retention ponds may be more attractive, however. In addition, the technology's characteristics open the possibility to develop "intermediate" solutions at township-level based on low-cost (shallow and small-bore) sewerage and reactors for communities of typically 100 up to 1000 households.

Sludge, produced in lower quantity, dries easily. Pathogen removal is limited, and biogas production only a minor asset.

Title:	*Feasibility Studies and Design of a Public Sewage Collection, Treatment and Outfall Scheme for the South Coast of Barbados*
Author:	Herbert, J.C.; Fries, M.K.; Archer, A.B.
Source:	Water Science and Technology Proceedings of the IAWPC Specialized Conference on Wastewater Management in Coastal Areas Mar 31-Apr 2 1992 v 25 n 1 2 1992 Montpellier, Fr p 3-12.
Abstract:	In 1988, as part of commitment to maintain and improve the quality of beaches and nearshore waters along Barbados' densely populated south and west coasts, the Government of Barbados commissioned Reid Crowther International to carry out feasibility studies and the detailed engineering design of a public sewage collection, treatment and outfall scheme for the south coast. The studies and designs were completed in 1990 and the Government is now negotiating with the Inter-American Development Bank for funding to pay for the construction of the project. The paper describes project background, estimation of design flows and loads, and treatment plant/outfall design including the detailed marine studies undertaken for the project. Interesting aspects of the sewage collection system design, including the proposed use of "No-Dig" trenchless sewer technology and the project's environmental impact assessment are also described.

Title:	*Guidelines for Improving Wastewater and Solid Waste Management Technical Report*
Author:	Andrews, R.N.; Lord, W.B.; O'Toole, L.J.; Requena, R.F.; Brantley, E.
Source:	Sponsored by Agency for International Development, Washington, D.C., Office of Health; Performed by CDM-Washington Project, Arlington, VA
Abstract:	Pollution from wastewater and solid waste is a significant problem for developing countries, especially in urban and peri-urban areas. The report presents a methodology for improving waste management within these limitations. According to the methodology, there are three possible points of intervention; the individuals and institutions responsible for pollution, those responsible for waste management (e.g., environmental resource and water treatment plant managers), and policies and actions to diminish the adverse effects of pollution. The methodology has four steps: (1) determining the health, environmental, social, and economic impacts of poor waste management; (2) identifying key groups and institutions whose decisions and actions affect waste management; (3) examining technologies, policy instruments, and institutions (the three key components of any waste management program); and (4) developing, from the best combination of these three components, a strategy for a national program or a project funded by international donors. Such a strategy should be guided by five principles: health risk reduction, pollution prevention by reducing waste at the source of recycling, provision of efficient services, cost recovery from those who benefit, and selection of appropriate treatment and disposal technologies

Title:	*History and Application of Microbiological Water Quality Standards in the Marine Environment*
Author:	Henry J. Salas
Source:	Second Meeting of Experts on Land-Based Sources of Pollution in the Wider Caribbean Region
Abstract:	The history and application of microbiological water quality standards in the marine environment for primary contact recreation and shell fish harvesting are presented.....

Title:	*How Appropriate are "Appropriate Waste Management Technologies?" --- Defining the Future Challenge*
Author:	Bhamidimarri, R., Shilton, A.
Source:	Water Science Technology, Vol. 34, No 11, 1996
Abstract:	The growing concerns of resource depletion and the consequential environmental degradation coupled with the ever widening gap between the developed and the developing countries has produced a need for a critical evaluation of waste management technologies. The conventional-criteria based definition of appropriate technologies is unsatisfactory. The principle of sustainability must be incorporated along with issues such as infrastructure capacity and the technology gap. It was concluded that a relevant technology based on holistic principles is more "appropriate" than one based on a set of criteria.

Title:	*The Impact of Industrial Waste on Venezuelan Marine Water*
Author:	Frank Roberts, Carmen Guarino and Marlene Arias
Source:	Wat. Sci. Tech. Vol. 29, No. 8 pp. 51-60, 1994.

Abstract: The Puerto Cabello-Moron coastal area of Venezuela is an ideal location for industries that require large land areas, water, marine transportation, minimum habitation, cooling water and waste disposal options both on land and sea. However, mercury spills between 1957 and 1976 have produced concern in the entire coastal zone from Puerto Cabello to Chichiriviche (70 kilometres of coastline) and the National Park area. MARNR, the Ministry of Environment and Renewable Natural Resources in Venezuela requested Bechtel to evaluate the impact of the major industries in this area. Bechtel's investigation included chemical, biological and toxicity analysis of the rivers, and key locations along the coast and the sea and industrial effluents. In addition, a literature search was made of any previous work to assist in the evaluation and recommendations for any necessary corrective action. The investigation identified negative impacts due to the effluent discharge of the major industries. Recommendations for wastewater management included installation of wastewater stabilisation lagoons for treatment and ocean outfalls for final effluent disposal.

Title: *Innovative Technologies for Treatment of Oily Wastewater*
Author: Andrew Benedek
Source: Iron and Steel Engineer, June, 1992
Abstract: Two innovative, economical processes for treating oily wastewaters are in operation that meet stringent discharge regulations and avoid the production of large volumes of sludge. One system involves ultrafiltration followed by reverse osmosis and the other is based on membrane treatment followed by a biological process.

Title: *Integrated Constructed Wetland for Small Communities*
Author: Urbanc-Bercic, O., Bulc, T.
Source: ?????????
Abstract: Constructed wetlands proved to be an effective and low-cost technology to control environmental pollution. The introduction of such low-tech systems is supported by the Slovenian Government. The aim of our research project was to intensify the reduction of nutrients (nitrogen compounds mainly) prior to discharging the effluents into the rivers, a contribution to the common target of the global environmental policy. The construction of the integrated system was completed in Autumn 1993 to treat domestic sewage for 10 PE. The system consists of three interconnected beds with vertical and horizontal flows. The vertical flow at the first stage is intermittent, while the horizontal one is continuous. The system is flexible due to mode of operation and the quality of the influent. Ten analyses were made during the initial months of operation. In bed B nitrification was taking place and the reduction of all other parameters but NO3-N was documented. In bed A denitrification was on in spite of intermittent vertical flow. Since the reed stand was scarce, recultivation was needed. The system showed its characteristics more clearly when more concentrated domestic wastewater was led in. Further investigation should reveal further details on proper media, surface area, and flow sequence selection. Reduction of some parameters was as follows: NH3-N 97.5%, NO3-N 74.5%, org-N 84.4%, P-tot 97.1% and COD 94.4%.

Title: *Land Treatment of Wastewater - Technology with Exciting Potential*
Author: Goldstein, Nora
Source: Bio Cycle v 22n 1 Jan-Feb 1981 p 34-37
Abstract: The paper reports on wastewater treatment, highlights several innovative and alternative wastewater treatment facilities and discusses spray irrigation as a method of wastewater treatment.

Title: *Lateral-Flow Sand-Filter System for Septic-Tank Effluent Treatment*
Author: Check, G.G.; Waller, D.H.; Lee, S.A.; Pask, D.A.; Mooers, J.D.
Source: Water Environment Research v 66 n 7 Nov-Dec 1994 Water Environment Federation Alexandria VA USA p 919-928.
Abstract: The lateral-flow sand filter (LFSF) is an alternative system for household septic-tank effluent treatment that utilises periodic or continuous surface discharge. The purpose of this study was to document the LFSF system, evaluate its treatment capabilities in laboratory models, and optimise design parameters. Three 5.0-meter-long laboratory models, each with a different permeability sand fill, were dosed with septic-tank effluent for six months. After an initial development period, percentage removals for biochemical oxygen demand (BOD), total organic carbon (TOC), suspended solids, and coliform bacteria from all the models were excellent. Orthophosphate initially was attenuated but showed increasing values after a few months. Recommendations are made as to a suitable permeability range of sand fills to use in the LFSF system, adequate depth of sand fill and overall system dimensions. Laboratory modelling, shows that the LFSF system is capable of providing a high level of treatment to household wastewater and that it should be suitable as a remedial or alternative system for household wastewater disposal.

Title: *Long-Term Impacts of Sewage Effluent Disposal on a Tropical Wetland*
Author: P.L. Osborne and R.G. Totome
Source: Wat. Sci. Tech. Vol. 29, No. 4, pp. 111-117, 1994.
Abstract: Waigani Lake, near Port Moresby, Papua New Guinea, is part of an extensive wetland dominated by the Laloki and Brown Rivers. The wetland has received sewage effluent from stabilisation ponds for over 25 years. Water quality of the sewage, Waigani Lake and its outflow assessed in 1985 indicated that the wetland was significantly reducing suspended solid loads and the concentrations of dissolved nitrogen and phosphorus. Aerial photographs of Waigani Lake taken between 1966 and 1991 document the complete loss of submerged and floating-leaved plants and the decline in the extent of the littoral, emergent vegetation. These changes are related to sewage effluent disposal and, possibly, alterations in the magnitude of annual water level fluctuations. This study of a tropical wetland to which very large quantities of sewage effluent have been added demonstrates that the capacity of wetlands for water purification is limited and that further study on tropical wetlands is imperative before management strategies developed for temperature wetlands are applied directly to them.

Title: *Low-Tech Systems for High Levels of BOD_5 and Ammonia Removal*
Author: Rich, Linvil G.
Source: Public Works v 127 n 4 Apr 1996 Public Works Journal Corp Ridgewood NJ USA p 41-42
Abstract: High levels of BOD_5 and ammonia removal are generally associated with high-technology treatment systems. Such performance is rarely expected from low-tech system especially from those whose past application most often have been in situations where the flow rates are relatively low. However, the performance of three low-tech water treatment systems located in South Carolina is surprising. This paper discusses in general terms the design, performance, and operation of these systems.

Title: *Mexican Project Combines Industrial and Municipal Wastewater Treatment*
Author: ????????
Source: Water Engineering & Management, October 1994
Abstract: Discussion on how a treatment plant treats wastewater from a city of 500,000 people and oily wastewater from an oil refinery in Mexico. (Short 1 page article)

Title: *Natural Treatment Systems*
Author: Andrew P. Kruzic
Source: Water Environment Research, June, 1994
Abstract: Natural treatment systems for wastewater can be divided into two broad categories: soil-based systems, which include subsurface, rapid infiltration / soil aquifer treatment, overland flow, and slow rate systems; and aquatic systems, which include ponds, aquatic systems with floating plants, and wetland systems. Each system type has different constraints, operating conditions, and design criteria.

Title *A New Process to Treat Strong Biological Waste*
Author: D.P. Henry and R.H. Thomson
Source: Wat. Sci. Tech. Vol. 27, No. 1, pp. 213-218, 1993
Abstract: Strong brewery waste was trickled through a vertical curtain consisting of two 3 mm layers of reticulated polyurethane foam bonded to a reinforcing nylon cloth core. A filamentous fungus, *Geotrichum fragrans* adhered to the curtain and provided a matrix for other yeasts and aerobic bacteria which included *Kloeckera lindneri* and *Candida sp.*, and a *Corynebacterium sp.* The organisms grew as a lawn. To avoid anaerobiosis the lawn was harvested periodically by passing the curtain through rollers, leaving a viable representative residue of the population. Passage through 6 m of curtain reduced a TOD of 555,000 mg/L^{-1} to 3,330 mg/L^{-1} (94%). Probably the length of the curtain could be reduced to 4 m with a residence time of 9.6h. One m^2 of curtain with a 4 m fall can treat 15 L/day^{-1}. A further waste from pigs (2% solids) was acidogenically fermented to produce organic acids. The acids during clarification were used to kill the bacterial pathogens in the waste. The liquor was run through a curtain inoculated with suitable organisms. These removed the unpleasant odour and 88% of the TOD in a 4m passage through the curtain. Treatment time: fermentation 5d, clarification and removal of pathogens 2d, treatment in curtain 0.3d, total 7.3d.

Title: *The Option of Appropriate System for Wastewater Treatment in Low-Density Areas*
Author: Ukita, M., Shirota, H., Nakanishi, H.

Source: Water Science and Technology, Vol. 28, No 10, 1993

Abstract: The method for selecting the appropriate treatment system in low-density areas was studied by statistical data analyses and questionnaire surveys. The main results obtained are as follows: 1) The efficiency of sewerage service has been decreasing. With decrease of the population density in served areas, treatment cost is increasing from 7000 yen/household in 1961 to near 40000 yen/household in 1989. 2) By considering the external cost of treated water quality, the marginal house density beyond which collective systems become advantageous, was estimated to be 9.5 houses/ha compared to the original value of 13 houses/ha. 3) Improvement of water quality, saving energy, and efficient uses of sludge are considered to be important for the environmental impact of sewerage systems. Suitable allocation of optional treatment systems, energy saving technology and prevention of sludge contamination must be the important issues for the sewerage service on a small scale.

Title: *Petrochemical Wastewater Treatment with Aerated Submerged Fixed-Film Reactor (ASFFR) Under High Organic Loading Rate*

Author: T.J. Park, K.H. Lee, D.S. Kim, and C.W. Kim

Source: Wat. Sci. Tech. Vol. 34, No. 10 pp. 9-16, 1996.

Abstract: An aerated submerged fixed-film reactor (ASFFR) was developed to treat a petrochemical wastewater with high organic loading rate, where stationary submerged biofilms were attached to net-type media (SARAN 1000D) under diffused aeration. The specific surface area of SARAN 1000D was 40 m^2/m^3 approximately. The organic removal ability of the reactor was tested in three lab-scale ASFFRs. The reactor demonstrated 91.8-96.6% removal of efficiencies of soluble chemical oxygen demand (SCOD) and exhibited efficient and stable performance of organic loadings of 1.02-6.21 kg COD/M^3 day. When the media packing ratio increased the COD removal efficiency increased, while the effluent COD and SS concentrations were stable. The organic removal rates were dependent on the effluent SCOD concentration and the reaction orders were the same as or lower than 0.5. Based on the experimental results, the ASFFR should be very suitable for treating petrochemical wastewater with relatively high organic loading rate. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

Title: *Planning Replicable Small Flow Wastewater Treatment Facilities in Developing Nations*

Author: Gaber, A.; Antill, M.; Kimball, W.; Wahab, Abdel R.

Source: Water Science and Technology Design and Operation of Small Wastewater Treatment Plants Proceedings of the 2nd International Conference on Design and Operation of Small Wastewater Treatment Plants Jun 28-30 1993 v 28 n 10 1993 Trondheim, Norw.

Abstract: The implementation of urban village wastewater treatment plants in developing countries has historically been primarily a function of appropriate technology choice and deciding which of the many needy communities should receive the available funding and priority attention. Usually this process is driven by an outside funding agency who views the planning, design, and construction steps as relatively insignificant milestones in the overall effort required to quickly better a community's sanitary drainage problems. With the exception of very small scale type sanitation projects which have relatively simple replication steps, the development emphasis tends to be on the final treatment plant product with little or no attention specifically focused on community participation and institutionalising national and local policies and procedures needed for future locally sponsored facilities replication. In contrast to this, the Government of Egypt (GOE) enacted a fresh approach through a Local Development Program with the United Stated AID program. An overview is presented of the guiding principles of the program which produced the first 24 working wastewater systems including gravity sewers, sewage pumping stations and wastewater treatment plants which where designed and constructed by local entities in Egypt. The wastewater projects cover five different treatment technologies implemented in both delta and desert regions.

Title: *Planted Soil Filter, A Wastewater Treatment System for Rural Areas*

Author: Netter, Robert

Source: Water Science and Technology Design and Operation of Small Wastewater Treatment Plants Proceedings of the 2nd International Conference on Design and Operation of Small Wastewater Treatment Plants Jun 28-30 1993 v 28 n 10 1993 Trondheim, Norw.

Abstract: Three planted soil filters for wastewater treatment (constructed wetlands with subsurface water flow) were investigated over an extended period of time. Each of them was filled with different kinds of soils. The filters were planted with helophytes, and loaded with septic tank effluent, with pre-treated combined sewerage respectively. The hydraulic surface loading varied from 4 to 60 mm/d and the specific BOD_5 mass loading from 0.9 to 8.7 g per square meter per day. The purification efficiency varied between 5 and almost 100%. The removal rate of the total bacterial count, coliforms, faecal coliforms and faecal streptococci was significant.

Title: *Public Health Significance of Coastal and Sea Pollution*
Author: E. Giroult, WHO
Source: Water Science Technology, Vol. 32, No 9-10, 1995
Abstract: Pollution of the sea and coastal areas is outlined in terms of the health risks to the residents of coastal areas, tourists and marine workers. The activities of WHO, separately or in collaboration with other bodies is described.

Title: *Review on the present state of marine pollution by sewage and present monitoring and control practices in the wider Caribbean.*
Author: CEPPOL
Source: CEPPOL Seminar on Monitoring and Control of Sanitary Quality of Bathing and Shellfish-Growing Waters in the Wider Caribbean
Abstract: This document was prepared to provide a general reference on the status of marine pollution by sewage in the Wider Caribbean and its monitoring and control

Title: *Rotavirus Removal in Experimental Waste Stabilisation Pond Systems with Different Geometrics and Configurations*
Author: J. I. Oragui, H. Arridge, D.D. Mara, H.W. Pearson and S.A. Silva
Source: Wat. Sci Tech. Vol. 31, No. 12, pp. 285-290, 1995.
Abstract: Rotavirus removal in waste stabilisation ponds is a relatively slow process: in a series of ten ponds (a 1-d anaerobic pond followed by nine 2-d ponds) its numbers were reduced from 1.4×10^5 per litre to zero, and in an "innovative" series (a 1-day anaerobic pond, 3-d facultative pond, 3.8-d, 3-d and 5-d maturation ponds) from 5.1×10^4 per litre to <5 per litre. Faecal coliforms were better indicators of rotaviruses than was *Clostridium perfringens*.

Title: *Skimming Oily Wastewater*
Author: Tom Hobson
Source: Pollution Engineering, October 1996
Abstract: Brief discussion on advantages of skimming and reuse of fugitive oil sources in industrial wastes..

Title: *Small Diameter Sewer -- A Cost Effective Technology for Wastewater Collection in Latin American Countries*
Author: Charles Vanderlyn
Source: Seminar on Appropriate and Innovative Wastewater Technologies for Latin American Countries
Abstract: Small Diameter Sewer --- This technology, because of its relatively lower capital cost, is appropriate for the collection of wastewaters in the industrialised countries of South America as well as the newly developing countries

Title: *Strategies in Agroindustrial Wastewater Treatment*
Author: M. Sendic
Source: Water Science Technology, Vol. 32, No 12, 1995
Abstract: In this paper, the wastewater treatments of the three most significant agroindustries in Uruguay, slaughterhouse, woolscouring and tannery, are described. Different strategies are used depending on: type of industry, localisation, economical possibilities, innovative disposition of management officers. Although more work must be done to improve with "reasonable" costs the wastewater treatments of these industries, actual results are presented. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

Title: *Submarine Outfalls - general overview, basic design concepts and data requirements for Latin America and the Caribbean.*
Author: UNEP
Source: Second Meeting of Experts on Land-Based Sources of Pollution in the Wider Caribbean Region
Abstract: Submarine Outfalls - general overview, basic design concepts and data requirements for Latin America and the Caribbean.

Title: *Submarine outfalls - a viable alternative for sewage discharge of coastal cities in Latin America and the Caribbean.*
Author: UNEP
Source: Second Meeting of Experts on Land-Based Sources of Pollution in the Wider Caribbean Region
Abstract: An overview of present sewage disposal practices in Latin America and the Caribbean is given as well as a brief outline of the main alternatives available for sewage disposal in coastal cities.

Title: *Treatment and Disposal of Domestic Sewage Sludge and Nightsoil Sludge for Bangkok*
Author: U. Stoll and K. Parameswaran
Source: Wat. Sci. Tech. Vol. 34, No. 11, pp. 209-217, 1996.
Abstract: In the recent past, treatment and disposal of sewage sludge has become an expensive and environmentally sensitive problem in western countries. It is becoming a growing problem world-wide with its focus on the megacities in the newly developed countries, since sludge production will continue to increase as new sewage treatment plants are built and environmental quality standards become more stringent. With some traditional disposal routes coming under pressure, the challenge facing the wastewater treatment authorities is to find cost-effective and environmentally sound solutions whilst responding to increasing public awareness. This paper describes the development of a plan for integrated management of municipal sludge (sewage sludge, nightsoil/septage sludge) which has high security for medium-and long-term sludge utilisation and disposal as the goal. It concludes that incineration and agricultural use should be implemented and operated in parallel as first priority options. Copyright © 1996 IAWQ. Published by Elsevier Science Ltd.

Title: *Treatment of Septage Using Single and Two Stage Activated Sludge Batch Reactors Systems*
Author: Andreadakis, A., Kondili, G., Mamais, D., Noussi, A
Source: Water Science Technology, Vol. 32, No 12, 1995
Abstract: The cyclic or sequencing batch activated sludge process was applied for the treatment of septage originating from cesspools serving non-sewered areas. Single and two stage systems were investigated in benth scale units. The single stage aerated system was capable in removing practically all the biodegradable COD and producing a well stabilised excess sludge with excellent settling and thickening characteristics. With respect to nitrogen the average removal rate was to the order of 70%, but the performance was unstable due to periodic strong inhibition of the nitrification process. Subsequent treatment in a second stage aerated unit improved nitrification but did not result in higher nitrogen removal rates due to the increased concentrations of oxidised nitrogen. An anoxic second stage post dentification unit resulted in an overall nitrogen removal of 88%, through a substantial reduction of nitrates. Further improvement of the system, with nitrogen removal of about 95% and average effluent nitrogen concentrations lower than 10 mg/L^{-1}, can be achieved by adoption of a two stage system consisting of a first aerated stage unit, followed by a second stage unit with alternating aerated and anoxic cycles and addition of external carbon during the anoxic cycle.

Title: *Treatment of Slaughterhouse Wastewater*
Author: Martinez, J., Borzacconi, L., Mallo, M., Galisteo, M., Vinas, M.
Source: Water Science Technology, Vol. 32, No 12, 1995
Abstract: In this paper an evaluation of the effluent treatment plant of a slaughterhouse which processes 650 head of cattle a day is presented. Some problems in the operation of the anaerobic reactor and anaerobic lagoons caused by the presence of fats and suspended solids in the effluent were detected. A flotation system by pressurised air injection was tested at the plant. The fat removal efficiency obtained was 63% and 37% for red water and green water, respectively. In order to improve the hydrolysis of particulate matter, a system of two UASB reactors with recirculation, connected in series, was tested at laboratory scale. Removal efficiency was 77% for soluble COD and 82% for insoluble COD, at a volumetric load of 1.8 $kgCOD/m^3/d$. Based on the results of these studies, several modifications in the treatment plant were proposed. Copyright © 1996 IAWQ. Published by Elsevier Science LTD.

Title: *Treatment System of Wastewater from Rural Settlements with Batch Activated Sludge*
Author: Yuyama, Y.; Kujino, K.; Miyamoto, Y.; Oonishi, R.
Source: Water Science and Technology Design and Operation of Small Wastewater Treatment Plants Proceedings of the 2nd International Conference on Design and Operation of Small Wastewater Treatment Plants Jun 28-30 1993 v 28 n 10 1993 Trondheim, Norw Publ by Pergamon Press Inc. Tarrytown NY USA p 223-232.
Abstract: The treatment system for rural communities with Batch Activated Sludge process was improved. The focus was on removal of nitrogen by intermittent aeration. Following the experimental results, treated waste quality lower than 10 mg/l of BOD and T-N was ensured throughout the year, under the operational conditions of hydraulic retention time in aeration tank longer than 24 h and ML SS higher than 2,500 mg/l. Treated water quality of T-N was less than 5 mg/l within cumulative frequency of 66%. Removal capacity of T-N did not reach its limit under conditions less than 0.5 kgN/M+3/d of influent load. Estimating from the nitrogen removal rate, consumption of alkalinity, characteristics of biomass growth and the amount of nitrogen content in MLSS. 77% of influent nitrogen was identified, 18% of that was discharged as treated water and 5% of that was extracted as excess sludge or SS in treated water. Fluctuation patterns of DO and ORP in a cycle by seasonally changed water temperature were effective indices for regulation of operation. A remote monitoring system was helpful to support the

measurement, because it enabled maintenance staff to judge urgency of management from the latest real time data.

Title: *Treatment of Wastewater from Oil Manufacturing Plant by Yeasts*
Author: K. Chigusa, T. Hasegawa, N. Yamamoto, and Y. Watanabe
Source: Wat. Sci. Tech. Vol. 34, No. 11, pp. 51-58, 1996.
Abstract: Nine strains of yeasts capable of decomposing oil were isolated in order to directly treat wastewater from oil manufacturing plants with no pre-treatment. The oil decomposing ability of these yeast strains was evaluated in terms of lipase activity and B-oxidation activity. Since the mixture of the isolated yeasts was superior to any single strain in the oil removal rate, a pilot plant utilising the mixed strains was operated at the soybean oil factory. Following a one year pilot plant operation, it was found that 10,000 mg/L^{-1} of hexane extracts in the raw wastewater could be reduced by yeast treatment to a concentration of about 100 mg/L^{-3}. This concentration was further treated by the activated sludge process to 2 mg/L^{-1}. The dominant yeasts in the pilot plant were found to form mycelial or pseudomycelial pellets and have low fermenting ability. Copyright 1996 IAWQ. Published by Elsevier Science Ltd.

Title: *Treatment of Wastewater by Stabilisation Ponds --- Application to Tunisian Conditions*
Author: Ghrabi, A., Ferchichi, M., Drakides, C.
Source: Water Science Technology, Vol. 28, No 10, 1993
Abstract: An experimental study of the domestic wastewater treatment in a series of four pilot-scale stabilisation ponds was conducted. The objective was to adapt the treatment by waste stabilisation ponds (WSP) to Tunisian conditions. The obtained results show that the average values of removal are about 72% for BOD, 65% for COD and more than 50% for ammonia nitrogen. The phosphate concentration was influenced by release of phosphate from decomposition sediment. The elimination of total coliform, faecal coliform and faecal streptococci is between 99.3% and 99.99%. The most rate reduction was registered during the warm months which coincide with the irrigation season. The sediment accumulation is taken mainly in the first pond: the deposition rate is high (5 cm/year). In the three maturation ponds, it ranges from 1.3 to 1.6 cm/yr. The WSP can be designed to satisfy Tunisian conditions. Because of favourable climate, loading can be much higher than those reported in the literature and some of the disadvantages of the ponds system can be reduced. So we can economise in evaporation of effluent which is considered as a resource of irrigation in agriculture and we can reduce the surface area.

Title: *Upgrading of a Small Wastewater Treatment Plant: Design and Operation Aspects*
Author: Hatziconstantinou, G., Kalergis, C., Grivas, A
Source: Water Science Technology, Vol. 32, No 7, 1995
Abstract: This paper presents the case of a small wastewater treatment plant taken out of service due to insufficient design and equipment installed. Design assumptions and decisions made for plant restoration based on treatment requirements are outlined and plant operation aspects regarding revealed wastewater characteristics, process efficiency, sludge settling behaviour and equipment control, are discussed. The importance of wastewater characterisation as a necessary procedure prior to plant design and construction, is stressed and the feasibility of nutrient removal in small wastewater treatment plants under minimum supervision is assessed. A simplified mathematical model, as a useful tool to operators, for plant performance evaluated and prediction, is presented.

Title: *Use of Wetlands for Water Pollution Control in Australia: An Ecological Perspective*
Author: Mitchell, D.S.; Chick, A.J.; Raisin, G.W.
Source: Water Science and Technology Proceedings of the 1994 4th International Conference on Wetland Systems for Water Pollution Control Nov 6-10 1994 v 32 n 3 1995 Guangzhou, China Pergamon Press Inc. Tarrytown NY USA p. 365-373.
Abstract: The potential use of natural and constructed wetlands to treat rural and urban wastewaters and run-off has been under active investigation in Australia by the authors and others associated with them for about 15 years. The results of these investigations will be briefly summarised in relation to factors affecting their performance and their application for management of water pollution. Investigations have included rigorous experimentation with wetland microcosms, calculation of nutrient balances for natural and artificial wetlands, fundamental research on the role of wetland plants, the construction of experimental wetlands of various designs at a pilot scale, and the installation of operating systems. The results confirm the potential of wetland systems to ameliorate water quality

but do not demonstrate how to do this consistently under normal day-to-day operating conditions. Issues that now need to be addressed include hydraulic short-circuiting, the role and management of the wetland plants, the extent to which constructed systems should mimic natural systems, and problems associated with scaling up from successful experimental systems to full scale operating treatment plants.

Title: *Using an Anaerobic Filter to Treat Soft-Drink Bottling Water*
Author: J.L. Carter, R. Bills, B. Youger
Source: Water Environment & Technology
Abstract: Shasta Beverage Inc. and Coca-Cola Bottling Company of Mid-America, Inc. bottling plants are located in the Lenexa Industrial Park, Kansas, which is just west of metropolitan Kansas City, MO. The wastewater from this industrial park discharges to the Johnson County Unified Wastewater Districts Middle Basin wastewater treatment plant.

Title: *Wastewater Disposal in the Caribbean: Status and Strategies*
Author: Arthur B. Archer
Source: PAHO Bulletin, Vol. 24, No 2, 1990

Title: ***Wastewater Treatment / Disposal for Small Communities, Manual***
Author: Bowker, R.; Frigon, G.; Kreissl, J; Otis, R.
Source: EPA, Cincinnati, OH
Abstract: The manual describes the key issues that must be addressed by small communities in developing a wastewater management program: planning, management, site evaluation, wastewater characteristics, and technological alternatives. Small community planners and management officials can use the manual as a project development guide. It can also be used with more detailed technical resource documents to guide consulting engineers and state regulators through project design and construction.

Title: *Wastewater Treatment of Greater Agadir (Morocco): An Original Solution for Protecting the Bay of Agadir by Using Dune Sands*
Author: Bennani, A.C., Lary, J., Nrhira, A., Razouki, L., Bize, J., Nivault, N.
Source: Water Science Technology, Vol. 25, No 12, 1992
Abstract: The wastewater treatment by infiltration-percolation plant at Ben Sergao (a suburb of Agadir, Morocco) foreshadows the installation which will be able to be built for greater Agadir (first fraction, 40,000 m^3/d). The present plant treats 1,000 m^3/d of highly concentrated raw effluents which after being decanted in an anaerobic stabilisation pond are infiltrated into 5 infiltration basins of 1,500 m^2 each constituted by a bed 2 metres thick of eolian sand drained at its base. The decanted water infiltrates at a rate of one metre per day. With this process, 100 % of the suspended matter, and 95% of the COD are removed, 85% of the nitrogen is oxidised. The parasites are entirely eliminated and the number of faecal coliforms and streptococci is made 10,000 to 100,000 times smaller. A series of experiments of irrigation by the treated effluents is under way.

Title: *Wastewater Treatment Meets Third World Needs*
Author: Alan B. Nichols
Source: Journal. Water Pollution Control Federation, Vol. 59, No. 8
Abstract: A revolution is sparking major changes in the environmental conditions of the Third World has taken place at the World Bank. This unilateral lending institution, with billions of dollars in assets --- the leader in municipal infrastructure loans --- has, for the past 12 years, begun to stress the importance of preserving the environmental integrity of a geographic location while improving the area's infrastructure.

Title: *Wastewater Treatment Optimization Model for Developing Nations I: Model Development*
Author: K.V. Ellis, S.L. Tang
Source: Journal of Environmental Engineering, Vol. 117, No 4, July/August 1991
Abstract: This paper concerns techniques of systems analysis and operations research used to select the optimal --- or most appropriate --- wastewater treatment in the developing world. Existing treatment optimisation models apply techniques of linear programming, dynamic programming and non-linear mathematical programming but do not deal with the influences of sociocultural and environmental conditions. In this paper subjective or intangible factors are included with technical and economic considerations. Twenty parameters identified include technical, economic, environmental and sociocultural factors. A model including these 20 parameters is developed to rank a definite number (n) of wastewater treatment alternatives (decision variable). The model applies a recently developed systems analysis technique called the analytical hierarchy process to integrate a 20 x 20 parameter

matrix with 20 n x n decision variable matrices to obtain the final ranking of the treatment alternatives. The model was tested with data from treatment plants in Malaysia, Thailand, Taiwan and Hong Kong.

Title: *Wastewater Treatment Optimization Model for Developing World. II: Model Testing*
Author: S.L. Tang, K.V. Ellis
Source: Journal of Environmental Engineering, Vol. 120, No 3, May/June 1994
Abstract: This paper describes the testing of a wastewater treatment optimisation model for the developing world (described by Ellis & Tang in 1991) in applications to four existing wastewater treatment units (in Puchong, Malaysia; Shatin, Hong Kong; Min Shen, Taiwan; and Pattaya, Thailand). In each case, a reciprocal matrix of a suitable number of wastewater-treatment alternatives (decision variables) was developed for each of 20 technical and socio-economic parameters. These 20 parameters are flow capacity, influent and effluent characteristics, size of treatment site, nature of site, land cost for site, local/foreign money for construction, local skill for construction, community support, power source, availability of local material, cost of operation and maintenance, professional/technical skill for operation and maintenance, administration set up, training, professional ethics climate, waterborne diseases, and endemic vector-borne diseases. The matrices were then integrated by a computer program to obtain a final ranking of the original alternatives using the analytical hierarchy process mathematical technique. The model was also tested for its sensitivity in predicting changes to an appropriate technology selected as socioeconomic parameters change with time.

Title: *Wastewater Treatment and Reuse Aspects of Lake Valencia, Venezuela*
Author: Mark Lansdell & Luis M. Carbonell
Source: Water Science Technology, Vol. 24, No 9, pg 19-30, 1991
Abstract: The environmental problems of the Lake Valencia Basin are described. A multipurpose project for the treatment and reuse of 9.5 meters cubed / sec of wastewater, which has received approval for international funding, is discussed along with technological adaptations to local opportunities and limitations.

Title: *Wastewater Treatment Technologies*
Author: J. Kevin Farmer
Source: Pollution Engineering, September, 1991
Abstract: Wastewater treatment technologies for food processing plants.

Title: *Waste Water Treatment Technologies - Pit Latrines and Derivatives*
Authors: Dr. Bernd J. Kaltwasser
Source: CEHI (Caribbean Environmental Health Institute)
Abstract: Discussion of pit latrines. Includes design considerations, theory of operation and appropriate applications

Title: *Waste Water Treatment Technologies - Septic Tanks*
Author: Dr. Bernd J. Kaltwasser
Source: CEHI (Caribbean Environmental Health Institute)
Abstract: Discussion of septic tanks. Includes design, sludge handling, effluent disposal and its appropriate applications.

APPENDIX D.
FACT SHEETS ON SPECIFIC SEWAGE POLLUTION CONTROL TECHNOLOGIES

Appropriate Technology for Sewage Pollution Control
in the Wider Caribbean Region
March 1998

Appropriate Technology for Sewage Pollution Control in the Wider Caribbean Region

Appendix D.
Fact Sheets on Specific Sewage Pollution Control Technologies

TABLE OF CONTENTS

Solids Treatment and Disposal

CONVENTIONAL GRAVITY SEWERS

DESCRIPTION

Conventional gravity sewers carry raw sewage from households, public facilities, and businesses. Pipes are 200 mm or more in diameter to prevent clogging. Conventional gravity sewers are installed at a slope so as to maintain a flow of 20 cm/s minimum velocity by gravity. When this is not possible, pump stations are used to pump the sewage. Conventional gravity sewers are expensive to build and can be difficult to maintain, but they are the most common collection systems being built today.

APPLICATIONS

Conventional gravity sewers are appropriate in large urban centres with a high population density or for more dispersed development. They have historically been the primary method of sewage collection and transport.

DESIGN CRITERIA

- Peak flow rate should be determined in designing a collection system. Inflow and groundwater infiltration (I&I) into the sewer pipes should be accounted for in existing systems. In new construction, I&I should be limited. Inflow connections should be allowed.
- Sewers conveying raw sewage should be at least 200 mm in diameter.
- Sewers should be designed so that sewage has a mean velocity not less than 60 cm/second in average flow conditions so that solids do not settle and build up in the pipes. Excessive velocities are not desirable.
- Manholes should be installed at the end of each line, at a change of grade or pipe size, and at least every 100 m.

Tabulated below are the minimum slopes recommended for conventional concrete sewers to maintain a minimum 60 cm/second velocity in the sewer pipes. The last column gives the flow required to fill the pipe at the given diameter and slope.

MINIMUM SLOPES FOR CONVENTIONAL GRAVITY SEWERS		
Sewer Diameter (mm)	Minimum Slope (rise/run)	Flow (m^3/day)
200	0.0038	1,820
250	0.0030	2,730
300	0.0022	3,940
380	0.0015	6,400
450	0.0012	9,130
600	0.00078	15,530
750	0.00058	24,620
900	0.00045	37,000

PERFORMANCE EFFICIENCY

Conventional gravity sewers effectively convey the wastewater flows they are designed for. However, I&I entering the sewer lines through the manholes and pipe joints creates an additional volume of waste that must be treated. I&I can be controlled with modern designs.

DISADVANTAGES

The biggest disadvantage of conventional gravity sewers is their high capital cost. In areas with high water tables, extensive subsurface rock formations, or unstable soil conditions, conventional gravity sewers are even more expensive to build due to the excavation and dewatering costs. Also, because conventional gravity sewers carry solids, a minimum velocity or slope is needed to prevent excessive solids deposition. This means that excavations can end up being very deep in order to maintain necessary slopes, or that pump stations will be needed, which can be expensive to maintain.

RESIDUALS GENERATED

N/A

OPERATION & MAINTENANCE

Sewer pipes need to be periodically flushed out to prevent solids accumulation. If pump stations are used, normal mechanical maintenance is required. Special provisions should be made for any grit accumulation in wet wells.

WCR INSTALLATIONS

Conventional gravity sewers are used throughout the WCR.

REFERENCES

Herbert, J.C. et al. 1992; Inter-American Development Bank 1992; Kaijun, W. et al. 1995; U.S. Department of Commerce 1991; U.S. EPA February 1980; U.S. EPA October 1991.

PRESSURE SEWERS

DESCRIPTION

Pressure sewers consist of several pressurized inlet points feeding to a single treatment facility or gravity sewer. The inlet points are from homes. The two main types of pressure sewer systems are the *septic tank effluent pump* (STEP) and *grinder pump* (GP) systems.

In STEP systems, septic tank effluent flows to an intercepter tank, which is basically a septic tank. At a specified high water level, the effluent is pumped to its destination. In GP systems, a grinder pump grinds the solids before pumping the flow to a central line or its final destination. In both systems, the connection lines and pressure mains are made of inexpensive polyvinyl chloride (PVC) or similar platic piping.

APPLICATIONS

Pressure sewers are typically used in low density areas where the terrain does not permit gravity flow to a central location or treatment facility. They can also be used where soil conditions are rocky or unstable, or where the groundwater level is high. Construction costs are much lower for these small diameter sewers because the material costs less, excavations do not need to be as deep (to prevent pipes from damage), and PVC piping is flexible, making pipe-laying easier.

DESIGN CRITERIA

- Connection lines are typically made of PVC (or other plastic) piping and are typically 25 to 50 mm in diameter.
- Pressure mains are made of PVC (or other plastic) piping and are typically 75 mm in diameter or larger.
- A minimum design velocity is not important in STEP systems as in gravity or GP systems because few solids are transported.
- To avoid solids accumulation in GP systems, flow must attain a minimum velocity of 90-150 cm/second once a day for a period long enough to scour the system clean. This duration varies with pump capacity and overall system size.

PERFORMANCE EFFICIENCY

Pressure sewers experience much less inflow and infiltration than conventional sewers.

DISADVANTAGES

The main disadvantage of pressure sewers is the maintenance of mechanical equipment at each entry point to the system.

RESIDUALS GENERATED

N/A

OPERATION & MAINTENANCE

Sewage conveyance in pressure sewers relies on pump operation. Because there is a pump at each entry point, maintenance costs are significant, but less than a conventional gravity system with pump stations.

WCR INSTALLATIONS

KCM has no knowledge of installations in the WCR.

REFERENCES

Inter-American Development Bank 1992; U.S. Department of Commerce 1991; U.S. EPA October 1980; U.S. EPA October 1991; U.S. State Department 1994.

VACUUM SEWERS

DESCRIPTION

Vacuum sewers use a central vacuum source to convey sewage from individual households to a central collection station. A valve separates the atmospheric pressure in the home service line from the vacuum in the collection mains. The valve periodically opens based on volume stored to allow wastewater and air to flow into the vacuum collection mains. The wastewater is propelled in the collection main from the differential pressure of a vacuum in front and atmospheric pressure in the back. Eventually the air pressure in the collection main equalises, and all flow ceases until the next valve from a service line is opened. Through this process, wastewater is conveyed to a central collection tank. From there, it can be conveyed by gravity or by a pump station through a force main to its final destination.

APPLICATIONS

Like pressure sewers, vacuum sewers are typically used in low population density areas where the terrain will not permit gravity flow to a central location or treatment facility. They can be used in mildly undulating terrain, but perform better with relatively flat topography because the vacuum systems are limited in the amount of lift they can generate. They can also be used where soils are rocky or unstable or where the groundwater level is high. Construction costs are much lower for these small diameter sewers because the material costs less, excavations do not need to be as deep (to protect the pipe from damage), and the PVC piping used is flexible, making pipe-laying easier.

DESIGN CRITERIA

- A vacuum of 0.5 to 0.8 atmospheres is maintained in the central collection mains.
- The lateral piping is typically made from PVC of 80 mm in diameter, while mains start at 100 mm.

PERFORMANCE EFFICIENCY

Vacuum sewers experience much less inflow and infiltration than conventional sewers because they are air tight.

DISADVANTAGES

Vacuum pumps can only generate a maximum lift of 10 metres of water. This limits the terrain in which vacuum pumps can be used. Also, there can be an odour problem from the venting of odourous off-gases. A minimum of about 70 dwellings is required to utilize this system effectively.

RESIDUALS GENERATED

N/A

OPERATION & MAINTENANCE

Vacuum sewer stations require dailiy maintenance and yearly inspection of the valves at all connection points. The vacuum and discharge pumps typically require major repair or replacement every 10 years.

WCR INSTALLATIONS

KCM has no knowledge of installations in the WCR.

REFERENCES

Inter-American Development Bank 1992; U.S. Department of Commerce 1991; U.S. EPA October 1980; U.S. EPA October 1991; U.S. State Department 1994.

SMALL-DIAMETER GRAVITY SEWERS

DESCRIPTION

Small-diameter gravity (SDG) sewers convey septic tank effluent by gravity to a centralised treatment location. Because the septic tanks remove most of the suspended solids in the wastewater, there is little clogging, so the piping can have a smaller diameter than for conventional sewers. PVC piping is typically used for SDG sewer installations.

APPLICATIONS

SDG sewers are typically used in low to medium population density areas where the terrain permits gravity flow to a central location or treatment facility. They require less slope than conventional gravity sewers and can be used where it would be difficult to provide adequate slope for conventional sewers. They also can be used where soil is rocky or unstable or the groundwater level is high. Construction costs are much lower than for conventional sewers because the material costs less, excavations do not need to be as deep (to protect the pipes from damage), and the PVC piping that is used is flexible, making pipe-laying easier.

DESIGN CRITERIA

- Typical pipe diameters for SDG sewers are 80 mm or more.
- The slope of the piping should be adequate to carry the daily peak hourly flows
- SDG sewers do not need to be designed to meet a minimum velocity.
- The depth of the piping should be the minimum necessary to prevent damage from anticipated loadings. If no heavy loadings are anticipated, a depth of 600 to 750 mm is typical.
- Cleanouts need not be placed at any regular interval short of that dictated by the sewer cleaning technique employed. A cleanout is a pipe that forms a tee with the collection main, providing access to the main. Cleanouts are used instead of manholes because SDG sewers are not designed to carry solids or grit, and manholes are a source of solids and grit to collection mains. Cleanouts also are much cheaper to construct and maintain than manholes.

PERFORMANCE EFFICIENCY

Small-diameter gravity sewers experience much less inflow and infiltration than conventional sewers.

DISADVANTAGES

The main disadvantage of SDG sewers is they are an emergent technology. Some previous applications have performed inadequately because of poor design and construction practices.

RESIDUALS GENERATED

N/A

OPERATION & MAINTENANCE

The main operation and maintenance needs of SDG sewer systems are removing septage from the septic tanks and occasionally checking collection main connections.

WCR INSTALLATIONS

KCM has no knowledge of installations in the WCR.

REFERENCES

Herbert, J.C. et al. 1992; Inter-American Development Bank 1992; U.S. Department of Commerce 1991; U.S. EPA 1980; U.S. EPA 1991.

SEPTIC TANK SYSTEMS

DESCRIPTION

A large percentage of homes within the WCR dispose of wastewater using on-site systems. An on-site system is here defined as wastewater treatment and disposal system located immediately adjacent to a house or residential complex. These are systems with piped water to the house and on-site treatment and disposal of all waste drainage from toilets, sinks , tubs, and showers. Household systems for residences without piped water are discussed in a separate fact sheet.

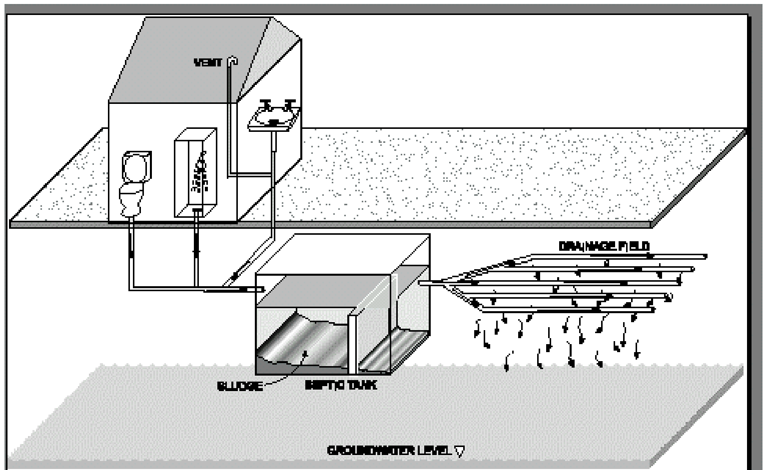
The most typical onsite system in the WCR is the septic tank followed by a drainage field or absorption pit. In many areas soil drainage systems are inappropriate for onsite wastewater disposal because of poor soil permeability or high ground water. Alternative systems for wastewater disposal in these circumstances include mound and evapotranspiration systems. Other more mechanised systems for on-site treatment are available besides septic tanks including rotating biological contactors, recirculating gravel filters, intermittent filters and other systems which aim to treat water for discharge to a surface water. These systems are in most cases onsite versions of wastewater treatment technologies discussed in other fact sheets and they are not discussed here. Three types of systems are discussed in the current fact sheet :

- Septic tanks with drainfields
- Septic tanks with mounds
- Septic tanks with evapotranspiration beds

Septic tanks with drainfields. A septic tank followed by a drainage field for effluent disposal should be the first low-density treatment option considered if soil conditions are appropriate. Septic tanks are used for single households as well as small clusters of homes. Wastewater from toilets, showers, sinks, and other household utilities flows via pipe into a buried, watertight, tank. The tank should be large enough to keep the flow velocity low, allowing the solid particles to settle to the bottom. Solids build up as a sludge layer in the tank over time. However, anaerobic micro-organisms (bacteria growing in the absence of oxygen) feed on the organic material in the sludge layer, effectively slowing down the sludge build-up.

The clarified effluent flows out of the tank for final treatment and disposal in a drainage field, which can be as simple a hole filled with gravel. More elaborate drainage fields include piped distribution systems, which spread the discharge over more surface area. Drainage field trenches are usually 300 to 1500 mm deep and 300 to 900 mm wide. The distribution pipes need to be laid over at least 150 mm of coarse (20 to 60 mm) gravel. The area needed for effluent disposal depends on the flow rate and soil percolation rate.

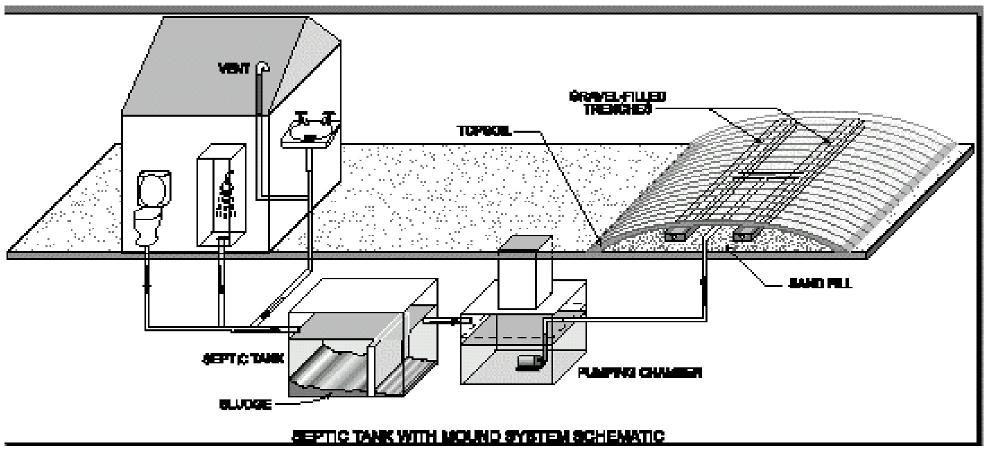
If possible, drainage fields should be used intermittently to allow a drying out period. Drying also can be accomplished by providing two drainage fields and alternating between the two. This will significantly improve performance and lengthen the life span of the drainage field.



SEPTIC TANK WITH DRAINAGE FIELD SYSTEM SCHEMATIC

Septic tanks with mounds. A septic tank discharging its effluent to a mound system for disposal is a treatment option when subsurface conditions are not suitable for a septic tank with a drainage field. The system consists of a septic tank, a small pump or siphon, a dosing chamber, distribution piping, and an elevated mound. The wastewater flows into the septic tank, where solids are settled to the tank floor, and the clarified effluent overflows through the other end into a dosing chamber. Anaerobic digestion of organic solids slows down sludge build-up in the tank. When the fluid level reaches a specified height in the dosing chamber, the effluent is pumped or siphoned to an above-ground elevated mound. The mound consists of sand and coarse aggregate. As the effluent percolates through the mound, it is treated as in a conventional drainage field. A geotextile may be laid around the distribution piping to distribute effluent distribution more evenly in the mound.

Septic tanks with evapotranspiration beds. Septic tanks can also be used with evapotranspiration (ET) beds. ET beds are a sand bed with an impermeable liner and wastewater distribution piping. Wastewater fills the pores in the sand and rises to the upper portion of the bed by hydraulic pressure and capillary action. In the upper portion of the bed the water evaporates in the soil through direct vaporisation and through the leaves of rooted vegetation grown on the surface of the bed. In evapotranspiration/absorption (ETA) systems the liner is omitted and water can also escape by seepage into the underlying soil. A further modification of the evapotranspiration system is to drain toilet drainage only to the ET bed and to discharge drainage from sinks and showers ("grey water") to soil absorption pits or surface discharge. A serious limitation of evapotranspiration systems is that they function only when evaporation exceeds precipitation during every month of the year.



SEPTIC TANK WITH MOUND SYSTEM SCHEMATIC

APPLICATIONS

Septic tanks with drainage fields are used primarily in rural or suburban areas for single households or for small clusters of homes. Septic tanks with mound systems are used when soil conditions are not suitable for an underground drainage field, primarily in rural or suburban areas for single households or small clusters of homes. Mounds are appropriate when soil permeability is less than 25 mm/hour, the bedrock is shallow, or the water table is close to the ground surface. ET systems are applicable only in climates where evaporation exceeds precipitation for every month of the year.

DESIGN CRITERIA

For conventional septic tanks with drainage fields

- Septic tanks must have sufficient liquid volume for a 24-hour fluid retention time at maximum sludge depth and scum accumulation. For a single home, a tank volume of 2 to 3 times the daily flow is adequate.
- Shallower tanks generally provide better performance than deep tanks.
- Tanks with multiple compartments remove BOD and suspended solids better than single-compartment tanks.
- Septic tanks with drainage fields require a minimum groundwater percolation rate of 25 mm/hour.
- Seasonal high groundwater level should be at least 600 mm below the bottom of the drainage field.
- The area required for the drainage field is based on flow rate and soil percolation rate, as shown in the following table:

ABSORPTION FIELD AREA REQUIREMENTS	
Percolation Rate (mm/hour)	Area Required Per Flow Rate (m^2/m^3/day)
1500	11.5
500	16.4
300	20.3
150	27.0
100	31.1
50	40.9
40	49.0
25	53.9

For septic tank systems with mounds

- Mound systems are effective where soil permeability is between 15 and 25 mm/hour.
- The mound height in the centre should be between 900 and 1500 mm, and the side slopes should be no steeper than 3:1 horizontal-to-vertical.
- The sand fill depth for mound systems is 300 to 600 mm beneath the distribution piping, depending on the groundwater level.
- Effluent should be applied to the mound at a rate of 4 to 50 L/m^2/day.
- The frequency of discharge to the mound should be once every 1 to 4 days.

For ET systems :

- For non-discharging systems, the hydraulic loading rate should be determined by an analysis of the monthly net evaporation (pan evaporation minus precipitation) experienced during the wettest year of a 10-year period. Under these conditions loading rates of 1.2 to 3.3 L/m^2/day have been found acceptable for arid regions.
- Where occasional discharge is acceptable, loading rates may be less restrictive than for non-discharging systems, for example, based on the minimum net ET in a normal year.
- Distribution piping networks should be constructed of 100 mm diameter perforated plastic or clay pipes in drain rock and surrounded by filter fabric.
- Sand bed depth should be 600 to 900 mm covered with 0 to 100 mm of topsoil.
- Clean and uniform sand in the size of D50 = 0.1 mm (50% by weight smaller than or equal to 0.1 mm) is desirable.

- Synthetic liners should have a thickness of at least 10 mil. It is preferable to use a double thickness of liner to permit staggering of seams, if seams are not avoidable.
- Synthetic liners should be cushioned on both sides with layers of sand at least 50 mm thick to prevent puncturing during construction.

PERFORMANCE EFFICIENCY

The performance of a septic tank with absorption system is a function of design, construction techniques, type of soil (permeability and composition), and loading. In properly designed systems, the soil removes BOD, suspended solids, bacteria, viruses, phosphates, and heavy metals from the effluent. However, nitrates and chlorides easily pass through coarser soils. A septic tank alone will remove 30 to 50 percent of BOD, 40 to 60 percent of suspended solids, about 15 percent of phosphorus, and 70 to 80 percent of oils and grease. The performance efficiency of a mound system is similar to that of a septic tank with drainage field. ET systems have no discharge.

DISADVANTAGES

Treatment efficiency of soil absorption systems is highly dependent on soil permeability and depth to the water table. Hard, impermeable soils make poor drainage fields. High effluent flow rates can quickly clog the soil, causing the effluent to pond at the surface. In well-aerated soils, nitrate concentrations in the groundwater may increase. When the soil's capacity is surpassed, groundwater becomes contaminated. Sludge cannot be used as fertiliser unless no fresh waste has been added for at least one week.

Mound systems are significantly more expensive than a septic tank with drainage field. Mound systems require more area than underground absorption fields and cannot operate properly when soil permeability is less than 1.5 cm/hour. A siphon or pump is required to raise the effluent, which is an additional operation and maintenance cost.

ET systems require much lower loading rates than either drainage fields or mounds and are applicable only in arid climates.

RESIDUALS GENERATED

The residual associated with a septic tank system is sludge build-up in the septic tank of about 0.04 m^3 per person per year.

OPERATION & MAINTENANCE

Sludge must be removed from the septic tank every two to three years. Mound systems have associated costs for pump energy consumption and maintenance.

WCR INSTALLATIONS

Septic tanks with drainage fields are widely used throughout the Caribbean islands. KCM has no specific knowledge of mound systems in use in the region. ET systems have been used successfully in Jamaica.

REFERENCES

EPA, February 1980; EPA, October 1980; Kaltwasser, 1995; U.S. Department of Commerce, 1991.

HOLDING TANK

DESCRIPTION

A holding tank receives and stores wastewater from homes or commercial establishments until it is pumped out and hauled to a wastewater treatment facility. The tank must be watertight and airtight and have an alarm to indicate high fluid levels. It should have capacity for at least two days of use after the alarm engages.

APPLICATION

Holding tanks are used primarily in areas where septic tanks with drainage fields or mounds are not feasible. They also are used in environmentally sensitive areas, where nutrients must be prevented from entering the groundwater.

DESIGN CRITERIA

- The most important criterion for a holding tank is that its volume not exceed the capacity of the pump truck that will service it.
- The alarm should set off when the tank has capacity remaining for about two days of use.
- Water conservation devices should be used to minimise how often the tank must be pumped.
- A typical family of four in the U.S. with piped water supply will need a 4-m^3 tank pumped about once a week.

PERFORMANCE EFFICIENCY

Some anaerobic digestion occurs in the tank, like in a septic tank. Otherwise, the system is highly reliable if designed and built properly and if proper servicing techniques are maintained.

DISADVANTAGES

Pumping can be very expensive if the tank is far from a wastewater treatment facility. The pumping service must be reliable and a suitable treatment facility is also needed.

RESIDUALS GENERATED

The only residual associated with a holding tank is the wastewater hauled to a treatment facility.

Frequent pumping and travel costs are associated with the pumping truck as well as the costs of discharge and treatment.

WCR INSTALLATIONS

KCM has no knowledge of specific installations in the WCR.

REFERENCES

EPA, September 1992; U.S. Department of Commerce, 1991.

HOUSEHOLD SYSTEMS

DESCRIPTION

Household systems for wastewater disposal consist of a variety of non-water carriage toilets. The main types of non-water carriage toilets are pit latrines, incinerating toilets, composting toilets, and oil-recirculating toilets. These systems can be used in areas where there is no piped water or sewage collection system or separate disposal is desired for black-water (excreta) and grey-water (other household wastes).

- ***Pit latrines*** are holes in the ground where small amounts of excreta and wastewater are stored and liquids leach slowly into the ground.
- ***Incinerating toilets*** are small units that incinerate excreta and other wastes. The waste collects in a chamber and is incinerated periodically with fossil fuel or electricity.
- ***Composting toilets*** are designed to aerobically convert the organic matter from wastes into a safe humus that can be applied to soils. The waste is mixed and heated to evaporate excess liquids and to stimulate the biological activity needed for composting. Composting can take place in a chamber included with the toilet or in a larger, separate unit, and generally requires external mixing and aeration energy.
- ***Oil recirculating toilets*** use a petroleum fluid to flush wastes into a collection chamber. The solids are separated from the petroleum fluid and stored for subsequent disposal.

APPLICATION

Household systems are appropriate in areas with little or no piped water supply and waste collection system.

DESIGN CRITERIA

Pit Latrine

- Pit latrine volume should accommodate a solids accumulation of 0.05 to 0.06 m^3 per year per person.
- Typical pits are 0.3 to 1.1 m^2 in area and 2400 to 3000 mm deep.
- It is usually cheaper to build two smaller latrines than one very large; this approach minimises the need for wall support and maximises distance from groundwater.
- Adequate holes should be provided for ventilation of odour and solar heating.

Incinerating Toilet

- Criteria and fuel requirements vary with manufacturer.

Composting Toilet

- The criteria for sizing the composting chamber, aeration, mixing, and bulking agent addition vary with each manufacturer.

Oil Recirculation

- Criteria vary with manufacturer; required holding tank volume can be up to 1.4 m^3.

PERFORMANCE EFFICIENCY

Pit latrines provide excellent treatment if designed and loaded properly. The degree to which the effluent is treated before reaching groundwater depends on the soil characteristics, i.e. depth to groundwater, soil permeability, and soil composition. The benefit of incinerating toilets, composting toilets, and oil recirculation toilets is that their pollutant load is removed from the grey wastes, thus making their treatment easier and less costly.

DISADVANTAGES

Pit latrines can only handle small flows of wastes. They are not suitable in environmentally sensitive areas. They need to be properly designed for adequate treatment. Odour and pestilence or vector problems can develop. Incinerating toilets have a capacity of about three uses per hour. Frequent maintenance is required for both fuel- and electric-powered designs. Electric-powered toilets have high energy costs. Composting toilets with separate composting units serve households of only up to five people. Smaller, non-separated units can serve households of only about two people. These toilets require knowledge and care for proper usage. Oil-recirculating toilets require filtration equipment to separate solids from the petroleum-flushing fluid. Solids disposal is difficult because the solids are very oily, and no successful domestic applications are known. All of these systems may be aesthetically displeasing.

RESIDUALS GENERATED

Pit latrines generate 0.05 to 0.06 m^3 of sludge per person per year. Incinerating toilets generate a harmless ash which must be disposed. Composting toilets can generate a soil conditioner provided the sludge is stabilised properly. Oil recirculating toilets generate an oily-solids residual that is difficult to dispose of properly.

OPERATION & MAINTENANCE

Pit latrines require decommissioning or sludge pumping every few years. Incinerating toilets require a high level of maintenance in the form of cleaning and have significant energy costs. Composting toilets require the periodic addition of mulch, grass, or some other vegetation for bulking agents. Mixing will be required to obtain aerobic conditions. Oil-recirculating toilets require cleaning or replacing exhausted filtration media, disinfection, and replacing lost oil.

WCR INSTALLATIONS

Pit latrines are widely used in rural areas in the WCR. The other disposal facilities have not gained acceptance in the region.

REFERENCES

EPA, October 1980; U.S. Department of Commerce, 1991; World Bank, 1982.

LAGOONS (STABILISATION PONDS)

DESCRIPTION

When sewerage is available for communities where land costs are low and skilled labour is not abundant in a warm climate, lagoons, also called stabilisation ponds, should be considered. They are often the most cost-effective and efficient way of treating domestic sewage flows when land is not prohibitively expensive and receiving water effluent quality limitations are not severe. Wastewater flows into a lagoon, where bacteria transfer and remove pollutants such as BOD, nutrients, suspended solids, and pathogens.

There are many types of lagoons. *Aerated lagoons* use mechanical equipment to maintain aerobic conditions. Organic matter is degraded by organisms that use oxygen. *Facultative lagoons* usually have longer detention times than aerated lagoons. They are not mechanically aerated. Oxygen is provided through photosynthetic growth of algae in the surface layer of the lagoons. They are designed so that the top of the lagoon is aerobic, while the bottom layers are without oxygen. *Anaerobic lagoons* usually are without oxygen for their entire depth. They are the deepest and most heavily loaded (in terms of pollutants) of all the lagoons. *High rate algae ponds (HRAP*) are shallow ponds used as part of an integrated pond system which may include paddle-wheel or axial flow pump mixers to encourage algae growth. *Maturation ponds* are designed for pathogen removal. Maturation ponds are most effective as a series of ponds in succession. The *Advanced Integrated Pond System (AIPS)* uses a combination of anaerobic, facultative, high rate algae, settling, and maturation ponds with effluent recirculation to the anaerobic cells.

After treatment, effluent can be disposed in one of three ways. Continuous discharge is the simplest and most common method of effluent discharge. Controlled release is discharge of effluent only when its water quality is good or during high flows in the receiving water (if discharge enters a stream or river). The third option is to dispose of effluent by evaporation and percolation into the soil rather than discharging to a receiving water. This can be done only when the combined rate of evaporation and percolation equals or exceeds the wastewater influent flow.

APPLICATIONS

Lagoons are a versatile wastewater treatment process. They can be used for domestic and industrial sewage. Aerobic, facultative, and anaerobic lagoons may be used as the first step in a treatment process, without pre-treatment, but the influent should be screened to remove floating materials. Facultative or aerobic lagoons also can be used as a final process to polish the effluent before final discharge. Maturation ponds are usually designed to allow sufficient detention time and contact with sunlight for pathogen removal or die-off. Anaerobic lagoons are especially useful for industrial wastes with high BOD loads. Anaerobic lagoons usually need to be followed by an aerobic or facultative lagoon since effluent will need further treatment.

DESIGN CRITERIA

Design criteria for lagoons in warm climates (greater than 15 degrees C lowest month winter temperature) are summarised in the table below:

Type	Detention Time Days	BOD Loading kg/d/ha	Depth Meters
Aerated	5-15	Not Applicable	2-4
Facultative	5-30	40-250	2-3
High Rate Algae	1-3	100-800	1-2
Anaerobic	5-20	500-1500	3-5
Maturation	Less than 5	Not Applicable	1-2

PERFORMANCE EFFICIENCY

Anaerobic lagoons remove about 40 to 60 percent of influent BOD. The other types of lagoons can reliably achieve an effluent BOD concentration of 30 mg/L, and even better if designed well. Suspended solids (SS) concentrations are typically higher than 30 mg/L. Some lagoons can achieve final SS concentrations of 20 to 30 mg/L, however most can only achieve effluent SS concentrations between 30 and 90 mg/L. Effluent faecal coliform concentration varies greatly.

Detention time, exposure to sunlight, pH, and lagoon geometry all affect coliform removal. If maturation ponds are used as a polishing step, faecal coliform counts as low as 200 to 400/mL can be reliably achieved without chlorination. Some nitrogen removal is achieved through uptake in algae, and through nitrification (ammonia conversion to nitrates) and denitrification (nitrate uptake in carbonaceous BOD removal.)

DISADVANTAGES

The primary disadvantage of lagoon systems is their large land requirement. Relatively high levels of effluent suspended solids compared to well-operated conventional mechanised treatment plants are another disadvantage. If land is abundant and the receiving water is not sensitive to discharge of moderate levels of suspended solids, lagoons or ponds are appropriate treatment options for most communities. If a high level of removal is required, polishing processes are needed. Algae is often the main contributor to suspended solids in the effluent. If low levels of suspended solids are needed, algae can be filtered or removed by other processes such as dissolved air flotation. One potential solution to the problem of excess algae production in lagoons is to use several maturation ponds in series, each with a detention time too short to allow the growth of algae. Discharge to wetland systems for polishing is another potential solution. In pond systems where algae control is a problem effluent should be withdrawn from well below the surface, since most algae float. Flies can be a nuisance in some tropical climates. Talapia, a hardy fish species, can help control this problem, as well as strategic placement of lagoons in breezy, open areas, and vegetation maintenance to eliminate insect habitats.

RESIDUALS GENERATED

It has been reported that sludge is generated in aerobic or facultative lagoons at a rate of about 0.04 cubic metres per person per year. Many lagoons do not experience a significant build-up of sludge, however, even after decades of loading. Others, like the Beetham Lagoons in Port of Spain, Trinidad, fill up rapidly. Designs must take into consideration sludge removal requirements based on rational calculations of sludge build-up under design conditions of loading. Small barge-mounted dredge pumps can be used effectively to remove sludge from lagoons, if sludge build-up is modest.

OPERATION & MAINTENANCE

Lagoons may require sludge removal every few years and regular vegetation maintenance. Regular maintenance of mechanical components, such as recirculation pumps, mixers, or aeration equipment, is also required for some lagoon designs.

WCR INSTALLATIONS

Lagoons are commonly used throughout the Caribbean region wherever space is available. The Los Guayos plant in Valencia, Venezuala is an lagoon system with pimary anaerobic cells, facultative cells, and effluent recirculation, designed to serve an ultimate population of 1.5 million. The Rodney Bay wastewater treatment plant in St. Lucia is an AIPS which has performed effectively. The Beetham Lagoons in Port of Spain, Trinidad were designed in the late 1950s as anaerobic and facultative lagoons to serve 150,000 persons.

REFERENCES

Archer, A.B., 1990; Archer, J.P., 1983; Curtis, T.P., 1992; Ellis, K.V., 1991; Evans, B., 1993; Ghrabi, A., 1993; Kruzic, A., 1994; Lansdell, M., 1996; Lansdell, M., 1987; Lansdell, M., 1991; Mayo, A.W., 1996; Mendes, B.S., 1995; Millette, W.M., 1992; Mills, S.W., 1992; Oragui, J.H., 1995; Phelps, H.O., 1973; Picot, B., 1992; Rich, L.G., 1996; Sweeney, V., 1996; U.S. EPA, 1983; U.S. EPA, 1992.

CONSTRUCTED WETLANDS

DESCRIPTION

Constructed wetlands are an excellent treatment process for removing BOD and suspended solids, as well as other particulates, from domestic and industrial sewage. Two types of wetlands are commonly used in wastewater treatment: free-water surface and subsurface flow. In a *free-water surface* (FWS) wetland the wastewater flows through a shallow bed or channel and is in contact with emergent vegetation and the atmosphere. The wastewater is treated by the anaerobic microbial community associated with the plant stems and root mounds, as well as by aerobic communities in the open water zones. In *subsurface flow* (SF) wetlands, a foot or more of gravel or coarse sand is used to support the root zone of emergent vegetation. The wastewater is treated primarily by the microbial community in the root zone and the rocks below. Subsurface flow wetlands usually have a clay barrier or membrane liner between the flow being treated and the groundwater to prevent contamination. The effluent can be collected or, more commonly, discharged to a river or ocean. Wetlands require a large land area but they can be easily managed and operated by unskilled labour. FWS systems are best suited following lagoons, while SF systems should follow septic tanks or other treatment systems.

APPLICATIONS

Wetlands can treat anything from septic tank effluent to effluent from secondary treatment. They can be used as buffer zones to treat urban stormwater runoff and because they are excellent solids removal systems, they are capable of removing metals from the waste stream. Wetlands provide excellent removal of BOD and suspended solids as long as they are not overloaded (hydraulically or in pollutant load). Both wetlands also remove faecal coliforms and other pathogens. Constructed wetlands are most appropriate for medium- or low-density communities where sewage is collected, and where adequate land is available for construction. They are easiest to build on flat terrain, but can be built successfully in a tiered form on hillsides. They are both excellent denitrifiers and can provide good nitrogen removel when following nitrification systems.

DESIGN CRITERIA

There is no consensus in the U.S. on design criteria for constructed wetlands. Design criteria given here were developed in Europe, where wetland systems have been used more widely. Recent tests of wetlands in tropical climates have yielded good removal with organic loading rates two to three times those of the accepted European loading rates.

- Wetlands should be sized with an area of 5 to 10 m^2 per person served, assuming 100 to 200 L per day per person of wastewater generated. The requirement may be lower if the wetland is used as tertiary, polishing step in the treatment process.

Free Water Surface Wetland

- Free water surface wetlands for domestic wastewater should be sized for a hydraulic loading of 8 to 40 L/ m^2/day.
- The wetland should be sized for a BOD loading of 1 to 20 kilograms per hectare per day, or about 10 metres square / person.
- Appropriate hydraulic detention time ranges from 7 to 40 days. When high strength or higher quality effluent is needed, it is better to use a series of wetlands, each with a detention time of 20 days.

Subsurface Flow Wetland

- Subsurface flow wetlands for domestic wastewater should be sized for a hydraulic loading of 20 to 400 L/m^2/day, or about 5 metres square / person.

PERFORMANCE EFFICIENCY

Wetlands can achieve very high BOD if influent BOD is in particulate or large colloidal states, but 80 to 90 percent removal—for BOD and suspended solids—is more typical. Nitrogen removal depends on the influent nitrogen form and detention time; some submerged flow systems have achieved over 90 percent removal, but more typical systems remove about 30 percent. One-to two-log removals of faecal coliforms have been observed, yet faecal coliform removal is not as reliable in wetlands as in stabilisation ponds.No phosphorus removal is expected after initial startup unless vegetation is harvested (up to 15% removal).

DISADVANTAGES

FWS wetland systems need a large area to operate properly. They are proven and reliable if the organic and hydraulic loading is not too high. When the soluble organic loading rate increases, the BOD and suspended solids removal becomes less reliable. Removal of faecal coliforms also is unreliable, due in part to the use of constructed wetlands by birds and animals; certainly direct reuse without disinfection or filtration is risky. For many receiving waters, wetland effluent requires disinfection and reaeration, as the process is inherently anaerobic. Flies and mosquitos can be a nuisance in FWS wetland areas. This can be partially controlled by planting Talapia, a hardy breed of fish, into open areas of the wetland.

RESIDUALS GENERATED

The BOD and nutrients removed from the waste stream fuel growth of emergent vegetation and biomatter attached to vegetation roots and filtration media (if a subsurface flow system is used). Typical vegetation growth is 56 to 80 kg/hectare/day. Normally, there is no harvesting of SF vegetation. Properly designed and maintained FWS systems require regular harvesting.

OPERATION & MAINTENANCE

The primary maintenance activity is harvesting new FWS vegetation growth. If toxic metals are present in the waste streams, the roots and leaves of the vegetation should be properly disposed of and not ingested by humans or animals. Inlet, outlet, pumping, and other mechanical maintenance may be necessary. Overall, the operational and maintenance requirements are low for wetland processes.

WCR INSTALLATIONS

Wetlands are usually used as a polishing or tertiary final process in the treatment chain in the Caribbean. They are most effective if used in this manner. They are usually overlooked as a secondary process because of land requirements. Wetland treatment is not extensively used in the Caribbean, but it is a promising technology because of the warm, moist, Caribbean climate.

REFERENCES

Boutin, C., 1993; Choate, K.D., 1990; Green, M.B., 1995; Kreissl, J.F.; Kruzic, A., 1994; Mitchell, D.S., 1995; Netter, R., 1993; Perfler, R., 1993; Polprasert, C., 1996; Sweeney, V., 1996; U.S. EPA, 1980; U.S. EPA, 1980; U.S. EPA 1988; U.S. EPA 1992; Urbanc-Bercic.

LAND TREATMENT

DESCRIPTION

Land treatment is the controlled application of wastewater to the land surface for treatment through physical, chemical, and biological means. The three basic types are *slow rate application* (also called *irrigation*), *rapid infiltration,* and *overland flow*.

In the slow rate process, primary or secondary effluent is applied to a vegetated surface and is treated as it flows through the vegetative root zone and the soil. Underdrains may be provided if the effluent is to be reused or disposed of elsewhere. In rapid infiltration, primary or secondary effluent is applied to moderately or highly permeable soils. Treatment is achieved as the wastewater percolates through the soil. Underdrains are not usually provided, and the treated wastewater can serve to recharge the groundwater. Overland flow is the uniform application of primary or secondary effluent at the top of grass-covered slopes. The wastewater flows over the vegetated surface and is treated before it collects in runoff ditches below. This process is most suited to impermeable soils but can work with soils of low or medium permeability as well.

APPLICATIONS

Land treatment processes can use wastewater that has received primary or secondary treatment. The higher the level of pre-treatment the wastewater has received, the less land is required. The slow rate process is most suitable for soils of low to medium permeability. It is a good way to recycle water and nutrients and grow a useful product or crops. Rapid infiltration is appropriate in soils with high permeability and deep groundwater levels. Overland flow is appropriate in impermeable soils on terrain which has a steady, uniform slope; it is very expensive if earthen construction or excavation is needed to create the right slope.

DESIGN CRITERIA

The following table summarises design criteria for the three land treatment processes.

DESIGN CRITERIA FOR LAND TREATMENT PROCESSES			
Feature	Slow Rate	Rapid Infiltration	Overland Flow
Unit hydraulic load (m^3/day/hectare)	14 to 40	165 to 400	90 to 580
Minimum pre-treatment	Primary	Primary	Comminution
Grade of surface (%)	< 4	< 4	2-8
Depth to groundwater (m)	0.6-1	1-3	Not critical
Soil Permeability	Slow to medium	Rapid (sands)	Slow (clays)

PERFORMANCE EFFICIENCY

Typical average and maximum values of pollutant concentrations in effluent from land treatment processes are summarised in the table below.

TYPICAL EFFLUENT POLLUTANT CONCENTRATION FOR LAND TREATMENT PROCESSES

	Slow Rate[a]		Rapid Infiltration[b]		Overland Flow	
	Average	Maximum	Average	Maximum	Average	Maximum
BOD	2	5	5	10	10	15
Suspended Solids (mg/L)	1	5	2	5	10	20
Ammonia Nitrogen (mg/L)	0.5	2	0.5	2	4	8
Total Nitrogen as N (mg/L)	3	8	10-20	20	15-25	10
Total Phosphorus as P (mg/L)	0.1	0.3	<1-3	5	4	6
Faecal Coliform (#/100 mL)	<2	10	10	200	200	2,000

a. Effluent concentrations for slow-rate process based on nitrogen loading below crop uptake levels and percolation through 1.5 m of unsaturated soil
b. Effluent concentrations for rapid-infiltration based on percolation through 4.5 m of unsaturated soil

DISADVANTAGES

Land treatment processes are limited by climate, the slope of the land, and soil conditions. Wastewater application may have to be reduced or even stopped during rainy periods. This would require adequate wastewater storage space during wet periods. Other disadvantages are that land requirements are very high and potential odour and vector problems can occur if inadequate pretreatment is employed.

RESIDUALS GENERATED

The residual associated with land treatment is vegetation growth and the solids generated from pretreatment processes.

OPERATION & MAINTENANCE

Overland flow and slow rate infiltration vegetation growth must be harvested regularly, while rapid infiltration vegetation is harvested periodically. Growth rate depends on the type of vegetation used and the volume and strength of wastewater. If there are no metals or other toxics in the wastewater, harvested vegetation can be fed to cattle and other farm animals. Pumps and distribution pipes need to be serviced and cleaned regularly.

WCR INSTALLATIONS

KCM has no knowledge of specific installations in the WCR.

REFERENCES

Braungart, M., 1997; Kruzic, A., 1994; Goldstein, N. 1981; U.S. E.P.A., 1980; U.S. E.P.A. 1992; U.S. E.P.A. 1984.

FILTRATION

DESCRIPTION

Filters consist of one or more beds of granular material 600 to 900 mm deep. Pre-treated wastewater is applied to the beds and receives treatment as it passes through. The effluent is usually collected through an underdrain and discharged into the subsurface or to surface waters. Most of the treatment occurs through aerobic biological activity in the porous structure of the filter medium and through physical and chemical removal processes. The treatment process is very stable, reliable, and capable of producing a high-quality effluent that is low in BOD, suspended solids, and pathogens.

There are two main types of filters. One type includes backwash filters. When the pore spaces in backwash filters are clogged, the filter can force clean water, usually upwards, through the media to clean it. Backwash filters can backwash continuously, automatically, or intermittently. They are used most often as a post-secondary, or polishing step in conventional, mechanised wastewater treatment facilities. Backwash filters produce excellent effluent quality and are not very land intensive. However, they are hi-tech, expensive, and are not discussed in the remainder of this fact sheet.

The other type of filters are those that do not have backwashing mechanisms and are loaded at far lower rates than backwash filters. When the top layer of these slow sand filters begin to clog, they are simply scraped off and replaced. *Buried sand filters* are constructed below grade; the upstream ends of the underdrains extend above grade to help ventilate or aerate the wastewater. *Open* (or *intermittent*) *sand filters* are constructed at grade, with an exposed surface, which allows easy access for inspection and cleaning. *Recirculating gravel filters* are open filters that recycle 300 to 500 percent of the influent flow. The treated effluent is continuously mixed with the pre-treated influent and applied to the filter. All of these filters nitrify well (convert ammonia into nitrates). Only recirculating filters can denitrify (convert nitrates to nitrogen gas). Nitrification increases the nitrate level in the effluent, which may be an issue if it is to be discharged near a drinking water source. The remainder of this fact sheet only describes the recirculating, open, and buried sand filters.

APPLICATIONS

Sand filters are a reliable and proven method for treating wastewaters from septic tank effluents to secondary treatment effluents. They are most suitable for rural communities, small clusters of homes, individual residences, and businesses, where land is available. They are easy to operate and maintain by local labor, which makes them suitable for rural areas where skilled labour may not be readily available.

DESIGN CRITERIA

- Wastewater requires a minimum of primary treatment (e.g., sedimentation or a septic tank) before application to sand filters. The filter medium will clog quickly if the wastewater is not pre-treated adequately.
- The medium should be 600 to 900 mm deep.
- Smaller filter media provide better contaminant removal but require more frequent cleaning.
- Hydraulic loading and medium size should meet the criteria in the following table.

FILTER TREATMENT HYDRAULIC LOADING AND MEDIUM SIZE			
	Buried	Open (Intermittent)	Recirculating
Hydraulic load per filter area (L/m^2/day)	<40	80 to 160	120 to 200 (forward flow)
Medium diameter (mm)	1.0-1.5	0.75-1.25	1.5-3.0

PERFORMANCE EFFICIENCY

Typical values of pollutant concentrations in sand filter effluent are summarised in the table below. It is assumed that the wastewater has been pre-treated by at least a septic tank.

TYPICAL FILTER EFFLUENT POLLUTANT CONCENTRATION (in mg/L)			
	Buried	Open (Intermittent)	Recirculating
BOD	2-10	2-10	2-10
Suspended Solids	2-10	2-10	2-10
Ammonia nitrogen	<10	<5	<5
Nitrate nitrogen	25-35	25-35	<15

DISADVANTAGES

Passing wastewater through filters requires about 1 metre of hydraulic head. This may necessitate pumping for effluent disposal if the topography of the land is not suitable. Recirculating filters will require pumps in all circumstances. Other disadvantages are that open filters may produce undesirable odours, and that suitable filter media may not be available locally. If filter media are not available locally, other granular materials such as peat derivatives may be suitable.

RESIDUALS GENERATED

A small amount of biological matter is produced in the top region of the filter medium which needs to be raked and removed for disposal.

OPERATION & MAINTENANCE

Operation and maintenance requirements are low for non backwashing sand filtration systems. Periodic cleaning (every 6 to 12 months) of the top layer of the filtration medium is required to prevent clogging. Regular maintenance of pumps and wastewater distribution equipment also is required.

WCR INSTALLATIONS

These systems are being studied and applied in parts of Florida, U.S.A.

REFERENCES

Bennani, A.C., 1996; Boutin, C., 1993; Check, G.G., 1994; Evans, B., 1993; Rich, L.G., 1996; U.S. EPA, 1980; U.S. EPA, 1984; U.S. EPA, 1980; U.S. EPA, 1992; Yang, P.Y., 1994.

PRELIMINARY TREATMENT

DESCRIPTION

Preliminary treatment comprises the first unit processes included in most mechanised treatment facilities and some non-mechanised facilities. The most widely used preliminary treatments are *screening* and *grit removal*.

Influent wastewater usually flows through screens that remove floatable material and rags. The separation between bars can vary from 5 mm 50 mm. Where downstream treatment equipment problems are to be avoided, the bar spacing should not exceed 12 mm. Grit removal, when provided, removes inert solids and sands that would damage pumps and other mechanical equipment in downstream processes. There are many different types of grit removal processes, but most include a small chamber through which wastewater flows, large enough to detain the flow so that heavy, inert solids settle to the bottom.

APPLICATIONS

All treatment processes, with the exception of septic tanks and household systems, require some sort of preliminary or screening process to remove large and floatable objects. For mechanically intensive wastewater treatment systems, screening and grit removal are strongly recommended. Grit removal is not necessary in most natural systems, but should be considered in highly mechanised wastewater treatment systems to prolong equipment life. The presence of a significant amount of grit in wastewater quickly wears down pumps and other mechanical equipment.

DESIGN CRITERIA

Screens

- The bar spacing for screens may be from 5 mm to 50 mm, depending on the type of treatment processes downstream. The wider the spacing, the less material retained.
- Typical screenings volumes are 0.037 to 0.22 m^3 per 1,000 m^3 of flow.
- The approach channel to the bar screen should be sized so that the approach velocity is at least 30 to 60 cm per second for average flow conditions.

Grit chamber

- A conventional aerated grit chamber is sized to provide 2 to 5 minutes of wastewater detention time. Other types of grit removal tanks have different criteria. Vortex grit chambers are designed for overflow rates of approximately 66 m/hr at maximum daily flow.
- The volume of grit generated varies with the type of sewage collection system used and its degree of inflow. Grit chambers typically generate from 0.0024 to 0.18 m^3 per 1,000 m^3 of flow.
- Circular designs are used for vortex units; aerated grit chambers are rectangular. Headlosses across the units vary from negligible to 0.6 m.

PERFORMANCE EFFICIENCY

Screens reliably remove all items larger than the bar openings. Most grit chamber designs remove about 95 percent of inert particles larger than 0.21 mm. Some modern designs can remove inert particles even smaller than 0.21 mm.

DISADVANTAGES

Screening and grit removal increase capital and operation and maintenance costs. In most cases though, grit removal is less expensive than the additional maintenance cost for downstream systems that would be incurred if grit and screenings removal is not provided.

RESIDUALS GENERATED

Screenings and grit are collected in these processes. After being washed, drained, and compacted, the residuals are usually disposed in landfills. Typical volumes of residuals are described above in the section on design criteria.

OPERATION & MAINTENANCE

Basic operational requirements for preliminary treatment are residuals removal, washing, and compaction (dewatering). Screenings and grit can be removed mechanically or manually. Grit can be removed manually by shovelling, but this requires a redundant grit chamber so that each chamber can be isolated and drained for shovelling. Usually, grit is removed from the tank bottom with mechanical buckets, inclined screw conveyors, or grit pumps. Grit pumps must be very durable because they pump very abrasive material. For aerated grit chambers, blower operation and maintenance add further costs.

WCR INSTALLATIONS

Screens are used for all types of treatment facilities in the WCR. Grit chambers are used in some larger, conventional treatment facilities. The treatment plant in San Fernando in Trinidad has a grit chamber, as do the Dos Cerritos and Mariposa plants in Venezuela.

REFERENCES

Millette, E.M. 1992; Sweeney, V. 1996; U.S. EPA 1992; Water Environment Federation & American Society of Civil Engineers 1992.

PRIMARY TREATMENT

DESCRIPTION

Primary sedimentation tanks are the most common form of primary treatment. Always placed after a screening or grit removal process, a primary sedimentation tank settles suspended solids from the wastewater flow. As the wastewater flows into a sedimentation tank, the liquid flows very slowly, and the inert and organic solids settle to the bottom. The process theory is the same as for a grit chamber, except that the overflow rate is lower, allowing some of the organic solids, which are less dense than grit, to settle out. The solids that settle on the bottom are scraped to a central point and then drawn out by a sludge pump. Wastewater scum, which is primarily oil and grease, is less dense than the wastewater and floats to the surface. Like the sludge, the scum is also collected by a mechanical arm and periodically drawn off.

Dissolved air flotation (*DAF*) is another type of primary treatment process commonly used for industrial wastewater. A DAF process removes oil and grease in less space than by primary sedimentation. Wastewater and air are pressurised to 3 to 5 atmospheres and released in a tank open to the atmosphere. This releases small bubbles from the solution, which float to the top. The bubbles become enmeshed in the light solids and oils and bring them to the surface. A skimmer then collects solids on the water surface, and the clarified liquid continues to downstream processes. Other types of oil-water separating processes are also widely used in the petroleum industry.

APPLICATIONS

Primary treatment processes often precede secondary, or biological, treatment processes in conventional secondary wastewater treatment facilities. The main purpose of primary treatment is to reduce the loading of BOD and suspended solids to processes downstream. Reducing this load reduces aeration costs for activated sludge plants and the volume of waste-activated sludge generated from secondary treatment. Some treatment facilities can do without primary sedimentation tanks. At such facilities, solids are removed in the downstream processes.

Sedimentation tanks are used as a primary treatment process for most large, conventional domestic sewage treatment facilities and some industrial applications. DAF is used mostly for industrial sewage that contains oil, grease, and other easily floatable solids. Oil refineries, meat packing factories, and dairy processing plants commonly use DAF for primary treatment.

DESIGN CRITERIA

Sedimentation tank

- A surface overflow rate (flow/tank surface area) of 0.8 to 1.5 m/hr for the average design flow is an accepted value in the U.S.
- Sedimentation tanks should be 2 to 5 metres deep.
- Both rectangular and circular tanks are widely used.

Dissolved Air Flotation

- A hydraulic detention time of 20 to 30 minutes is adequate for solids separation.
- Other important design criteria are pressure, recycle ratio, and influent solids concentration and characteristics.

PERFORMANCE EFFICIENCY

A conventional sedimentation tank removes 25 to 40 percent of influent BOD, 40 to 70 percent of total suspended solids, and about 50 percent of the bacterial load. DAF devices can produce an effluent with as little oil as 1 to 20 mg/L.

DISADVANTAGES

DAF treatment processes have more complex operation and energy requirements than plain sedimentation tanks. DAF processes are usually chosen when sedimentation tanks do not provide adequate removal of light solids and oils. For primary sedimentation tanks, the sludge (which is high in organics) should be withdrawn rapidly before denitrification processes generate gaseous nitrogen, which can resuspend some of the solids.

RESIDUALS GENERATED

Solids, scums, and oils are the main residuals collected in primary treatment. The volume generated depends on the volume of wastewater flow, the composition of the wastewater, and the effectiveness of the treatment. For a medium strength wastewater, the amount of sludge generated in a primary sedimentation tank is about 0.10 to 0.17 kg/m^3 of wastewater.

OPERATION & MAINTENANCE

Although primary treatment mechanical processes are relatively simple, routine maintenance is necessary. For conventional sedimentation tanks, the majority of the maintenance is upkeep of pumps, sludge scrapers, scum collectors, and motors. DAF processes require a more intensive maintenance plan for the pressurised pumps, pressure relief valves, and collector systems.

WCR INSTALLATIONS

Sedimentation tanks are used at most conventional, mechanised treatment systems. DAF systems are used mostly in oil refinery and petrochemical waste facilities.

REFERENCES

Bryant, J.S. 1991; Eckenfelder, W.W. 1989; Engelder, C.L. 1993; Millette, E.M. 1992; Rhee, C.H. 1988; Sweeney, V. 1996; Water and Environment Federation & American Society of Civil Engineers 1992.

SECONDARY TREATMENT

DESCRIPTION

In secondary treatment processes, aerobic, anoxic, and anaerobic bacteria feed on organic material in the wastewater, transforming the BOD in the sewage to bacterial mass. Aerobic bacteria, the most commonly used type for secondary treatment, consume organic material only in the presence of oxygen. Anoxic and anaerobic bacteria do not need oxygen, but aerobic processes produce better-quality effluent. For this reason, and because anaerobic and anoxic treatment may produce offensive odours, aerobic processes are by far the most common secondary treatment processes for large treatment facilities, they are the only processes described in this fact sheet.

All aerobic secondary treatment processes have the following in common:

- In the first step, the treatment bacteria are brought into contact with the soluble and suspended organic material in the wastewater. This is accomplished by directing the wastewater to a well-mixed tank containing the treatment organisms (a "suspended growth" system) or passing it over a fixed surface on which the bacteria grow (a "fixed film" system).
- In suspended-growth systems, aerobic bacteria need sufficient oxygen to metabolise the organic material in the wastewater. This is provided by a mechanical aerator, a diffuser, or some other process. Aerators introduce air, or oxygen, into the wastewater.
- The bacteria that metabolise the organic material in the wastewater must subsequently be separated from the wastewater flow. Except for sequencing batch reactors (SBRs), all secondary processes discussed here have a separate secondary sedimentation tank to settle this flocculated cell mass in the same way that primary sedimentation tanks settle suspended organic material. The effluent continues to the discharge or to downstream processes.
- In suspended-growth activated sludge systems, sludge is returned from the sedimentation tank to the aeration tank, which maintains a viable concentration of bacteria to metabolise the incoming organic material. This is called return activated sludge, or RAS. Sludge that is removed and not returned is called wasted activated sludge, or WAS. Sludge return is not necessary for fixed film processes or the SBR process.

Lagoons are natural systems that provide secondary treatment, but they are not addressed here because separate fact sheets have been prepared for them. The secondary treatment processes included here are conventional high-rate processes that require less land than lagoons and wetlands. The following are common high-rate secondary treatment processes:

- Activated sludge
- Oxidation ditch
- Trickling filter
- Sequencing batch reactor (SBR)

In the *activated sludge* process, raw sewage or primary effluent is brought into an aeration basin, where air is bubbled into the wastewater mixture (mixed liquor) and aerobic bacteria metabolise the dissolved and suspended organic material. From the aeration basin, the effluent flows into a secondary sedimentation tank, where the cell mass is settled out. Part of the settled biomass is wasted, and some of it is returned into the aeration basin to maintain a viable biomass concentration. A locally developed variation on the activated sludge process, the modified sequencing batch reactor (MSBR) process, uses a single earthen basin for activated sludge aeration and sedimentation. Separate sedimentation tanks and return activated sludge pumping systems are not required.

The *oxidation ditch* process is an activated sludge process in which wastewater flows into a ring-shaped channel instead of a rectangular aeration basin. Oxygen is not evenly mixed throughout the oxidation ditch as it is in a conventional activated sludge process. This provides zones of varying reaction, allowing more operational control of the process. Cell mass is settled out in a secondary sedimentation tank and recycled back into the oxidation ditch.

In a *trickling filter* process, primary effluent is evenly distributed over a circular bed of fist-sized stones 900 to 1800 mm deep. Bacteria, fungi, and algae grow on the rock surface. As wastewater flows between the rocks, aerobic bacteria metabolise the organic material in the wastewater. As the biomass grows, the influent wastewater flow sloughs off the excess, which settles out in a secondary sedimentation tank. There is no recycling of sludge for a trickling filter, but there is usually a high effluent recycle ratio—300 to 500 percent of the influent flow is recycled from after the filter or sedimentation tank back to the filter.

In the *SBR* process, all steps of the treatment process take place in a single complete-mix tank, to which influent is directed intermittently. The treatment process consists of discrete, timed processes: fill, mix/aerate, settle, withdraw effluent, and withdraw sludge. Some SBR manufacturers combine these processes and develop proprietary timing cycles, but all SBRs use a combination of the above five elements. Historically, SBRs were only used for small treatment facilities. In recent years, there has been a resurgence of interest in the SBR process because it entirely eliminates the need for secondary sedimentation and RAS pumps.

APPLICATIONS

These secondary treatment processes are usually most appropriate for large, high population density communities because of their high cost and the high level of skill required for operation and maintenance. Although these processes produce good-quality effluent for large flows if operated and maintained properly, they produce very poor effluent quality if operated improperly. Oxidation ditches have the highest land requirements of the processes described in this fact sheet, and SBRs have the lowest. Both are appropriate for medium-sized communities due to their high reliability. Trickling filters have a high capital cost, but low operational costs compared to an activated sludge plant because no aeration is needed.

DESIGN CRITERIA

Activated Sludge

- The mixed liquor suspended solids concentration (MLSS) ranges from 1,500 to 3,000 mg/L.
- The hydraulic detention time is from 6 to 24 hours.
- The solids residence time is from 3 to 20 days.

Oxidation Ditch

- The hydraulic detention time is 24 hours or more.
- The solids residence time ranges from 10 to 30 days.
- Flow channels are from 2 to 4 m deep.
- Channel velocities should be from 24 to 36 cm/second.

Trickling Filter

- The hydraulic loading rate has a very wide range. The most commonly used trickling filters use a loading rate per filter surface area of 1 to 9.2 m/day.
- The organic loading rate is 175 to 1,000 kg BOD/day/1,000 $m^{3.}$
- Unless the filter medium used is lightweight plastic, the filter depth is 1 to 3 m. For plastic media, depth can be as high as 12 metres.

Sequencing Batch Reactor

- The hydraulic detention time ranges from 24 to 40 hours for most applications.
- The solids retention time ranges from 5 to 40 days.

PERFORMANCE EFFICIENCY

Typical values of pollutant concentrations in secondary treatment effluent are summarised in the table below.

TYPICAL SECONDARY TREATMENT EFFLUENT CONCENTRATIONS (mg/L)			
	BOD	Suspended Solids	Ammonia-Nitrogen
Activated sludge	4-40	5-50	5-15
Oxidation ditch	3-30	4-32	1-5
Trickling filter	9-58	9-100	5-15
SBR	5-30	6-25	1-10

DISADVANTAGES

Secondary processes generally require a high degree of skilled labour for operation and maintenance. They are mechanically intensive, and produce poor effluent quality if key equipment is not working properly. These processes also generate a higher volume of sludge than natural processes used for wastewater treatment. Sludge treatment and disposal is a significant cost associated with secondary treatment processes. Flies can be a serious nuisance with trickling filters, as they live and breed within the filter medium.

RESIDUALS GENERATED

Secondary treatment can generate 0.10 to 0.15 kg of sludge per day per cubic metre of wastewater. Trickling filters generate a comparable quantity of sludge. The sludge generated is generally high in volatile solids and it can become septic quickly, producing offensive odours if not treated or disposed immediately.

OPERATION & MAINTENANCE

Operation and maintenance requirements are extremely high for secondary treatment processes. Except for the SBR process, all require flow and/or sludge recycling. While the capital or energy cost may not be excessive, pump maintenance is crucial for proper operation. Except for the trickling filter, all processes require aeration. Aeration is usually provided with a blower. The energy needed to run a blower or aerator makes it the single most costly operational element in a wastewater treatment process. A standby generator must be provided for pump and blower operation in case of electricity supply failure; if outages are longer than a few hours, then standby power for aerator equipment is prudent. Another operational consideration is the amount of sludge to be generated. As the sludge volume increases, it is more cost effective to perform sludge treatment before final disposal. This introduces further equipment and operation and maintenance costs.

WCR INSTALLATIONS

Extended aeration activated sludge is used at the Dos Cerritos, Venezuela plant. Modified sequencing batch reactors (MSBRs) are used in Juangriego, Venezuela. Trickling filters are in use in Arima, Trinidad and San Fernando, Trinidad. Small package activated sludge plants are used throughout the WCR.

REFERENCES

Millette, E.M. 1992; Sweeney, V. 1996; U.S. Department of Commerce, 1991; U.S. EPA 1980; Water Environment Federation & American Society of civil Engineer 1992.

NUTRIENT REMOVAL

DESCRIPTION

Secondary treatment processes remove BOD and suspended solids from the wastewater stream. Partial removal of nitrogen and phosphorus ocurs in secondary treatment by incorporation into waste sludge. Specialised processes are needed, however, to remove higher amounts of nitrogen and phosphorus. Physical processes for nitrogen removal include breakpoint chlorination and demineralization by reverse osmosis or other means. Chemical removal of phosphorus is typically achieved by precipitation with metal salts. A wide variety of biological processes using anoxic and anaerobic zones can be used for removal of both nitrogen and phosporus. In this fact sheet three typical nutrient removal processes are discussed :

- The A^2/O process for biological phosphorus and nitrogen removal
- The MLE process for biological nitrogen removal
- Chemical precipitation for phosphorus removal

The A^2/O Process. Many treatment systems remove BOD, suspended solids, and nutrients through microbiological activity. A typical biological nutrient removal (BNR) process is the A^2/O (anaerobic, anoxic, and oxic) process. An oxic, or aerated, zone has "free oxygen" (O_2) available for microbiological respiration; an anoxic zone has nitrate; and an anaerobic zone has neither.

The A^2/O process generally uses the same mechanical equipment as the conventional activated sludge process, with additional reactor zones provided before the secondary sedimentation tank instead of just one. These zones may be separate tanks or separated areas of a single tank. Raw sewage or effluent from primary treatment flows first to the anaerobic zone, then to the anoxic zone, and finally to the oxic zone before discharge to a secondary sedimentation tank, where the cells settle out.

In the oxic zone, the solids residence time should be long enough to allow nitrification, the biological conversion of ammonia to nitrates. Effluent from the oxic zone is recycled to the anoxic zone, where facultative bacteria denitrify the recycled stream (convert the nitrates to nitrogen gas, which harmlessly diffuses into the atmosphere). Sludge from the secondary sedimentation tank is recycled to the anaerobic zone. The anaerobic zone stimulates the microbiological organisms, causing what has been called "luxury uptake" of phosphorus when the cells arrive in the oxic zone. If phosphorus removal is not necessary, the anaerobic zone is not needed, and nitrogen removal can be achieved with two reactors using the Modified Ludzak Ettinger (MLE) process.

The MLE Process. The Modified Ludzak-Ettinger (MLE) Process is a two-stage process for removal of nitrogen biologically. In the MLE process nitrified mixed liquor is recirculated to an anoxic tank in which raw sewage or primary treatment effluent is mixed with return sludge and internal recirculation mixed liquor. It is the simplest form of biological nitrogen removal system. Recirculation rates are typically in the range of 200 to 400 percent of clarified effluent.

Chemical Precipitation. Metal salts are frequently used for precipitation of phosphorus from wastewater. Alum, ferric chloride, and lime can be used to cause precipitation of soluble phosphorus as metal phospates and hydroxides. The chemicals can be added to primary eflfuent, activated sludge mixed liquour, or to secondary effluent to effect removal of soluble phosphorus.

Most other biological nutrient removal processes are variations of these processes. Other biological processes that can remove nitrogen are upflow granular filters and some sand filters. Many of the biological nutrient removal processes are patented, which increases the cost of construction. Some nutrient removal is effected in processes such as wetlands and oxidation ponds. For discussion of nutrient removal features of these low-technology processes see the references cited for the fact sheets for these processes.

APPLICATIONS

Most receiving water standards in the WCR do not specify allowable nitrogen or phosphorus concentrations. Consequently, nutrient removal is rarely practised in the region. However, most of the coastal waters in the WCR are nutrient poor. This means that any amount of nutrients discharged into enclosed water bodies such as estuaries or bays may cause eutrophication problems. Many nutrient removal processes are expensive and complex and suitable only for dense population centres. However, they should be considered whenever wastewater effluent is discharged to receiving water other than open ocean. High ammonia-nitrogen concentrations are toxic to fish and animals, and high nitrate concentrations in drinking water are toxic to humans and can quickly kill infants.

DESIGN CRITERIA

Key design criteria for the MLE and A^2/O processes are summarised in the following table. Additional design criteria include such factors as dissolved oxygen concentrations and temperature. Theoretical precipitant doses for phosphorus removal are indicated in the next table. In actual practice dose rates required for complete removal of soluble phosphorus are 50 to 100% more than the theoretical requirement.

DESIGN CRITERIA FOR BIOLOGICAL NUTRIENT REMOVAL PROCESSES		
	MLE process	A^2/O process
Cell detention time (days)	6 to 10	4 to 27
Hydraulic detention (hours)		
anaerobic	N/A	0.5 to 1.5
anoxic	3 to 5	0.5 to 1.0
oxic	3 to 8	3.5 to 6.0
Return activated sludge (% of influent)	20 to 100	20 to 50
Internal recycle (% of influent)	200 to 400	100 to 300

THEORETICAL CHEMICAL REQUIREMENT FOR PHOSPHORUS PRECIPITATION	
Precipitant	Precipitant Ratio To P
Alum	9.6 : 1
Ferric Chloride	5.2 : 1
Calcium Oxide	2.71 : 1

PERFORMANCE EFFICIENCY

Typical effluent concentrations from the A^2/O process range from 0.2 to 5 mg/L of total phosphorus and 5 to 10 mg/L of total nitrogen. Average concentrations are about 1 mg/L for total phosphorus and 8 mg/L for total nitrogen. Variations on this process can achieve higher removals. Comparable effluent nitrogen concentrations can be achieved with the MLE process. Upflow and fluidised bed filters (also known as denitrification filters) can remove 80 to 95 percent of influent nutrients. Recirculating sand filters can remove 40-75% of the influent nitrogen. Conventional activated sludge treatment processes produce effluent with 10 to 15 mg/L of total nitrogen and 2 to 6 mg/L of total phosphorus depending on the influent concentrations. Chemical precipitation can remove soluble phosphorus to low concentrations (less than 0.1 mg/L.) For complete removal of phosphorus, inorganic phosphorus included in effluent suspended solids must be removed, typically by filtration.

DISADVANTAGES

Nutrient removal processes are more complex and expensive than secondary treatment. The extra tanks and recycle lines add a high capital cost and increase the operation and maintenance cost. Also, it is crucial that the solids produced in the process be treated or disposed of correctly. Through solubilisation, aerobic and anaerobic solids digestion processes can produce liquid side streams very high in nitrogen and phosphorus. If these side streams are returned to the main plant flow, the effluent quality will degrade. Another disadvantage is the variability of phosphorus removal in biological systems. Chemical removal of phosphorus requires a continuing expense for chemical precipitant and additional costs for disposal of the resulting sludge.

RESIDUALS GENERATED

The volume of sludge generated in biological nitrogen and phosphorus removal processes is the same as or less than that for conventional activated sludge plants. Chemical precipitation can increase sludge loads substantially.

OPERATION & MAINTENANCE

Operations and maintenance costs increase when nutrient removal is included in treatment. Capital costs include the construction of additional tanks, pipes, and recirculation pumps. Ongoing costs include maintenance of the aeration systems, pipes, and pumps. Processes are complex and require skilled labour for efficient operation. Chemical costs for chemical precipitation of phosphorus can substantially increase plant operational expenses.

WCR INSTALLATIONS

The Mariposa treatment plant in Venezuela has been designed for partial BNR.

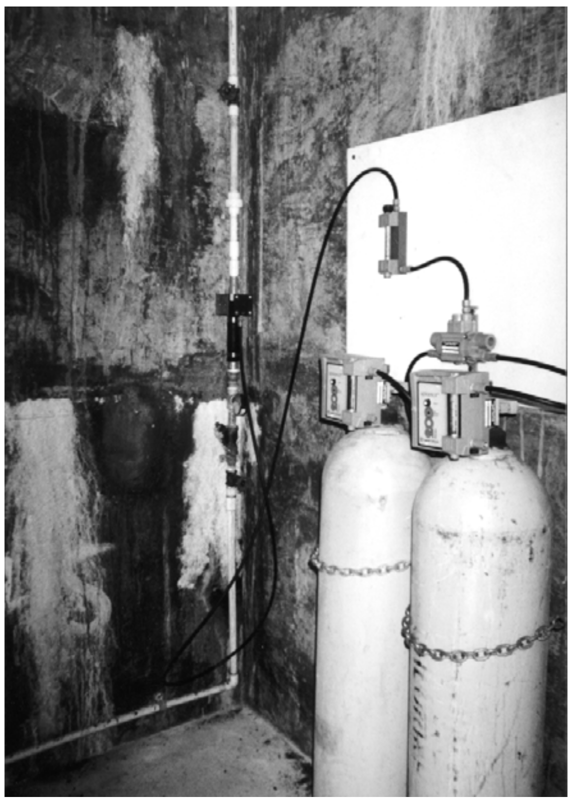
REFERENCES

Boutin, C. et al 1993; Check, G.G. et al 1994; Rich, L.G. 1996; U.S. EPA February 1980; U.S. EPA October 1980; Water Environment Federation & American Society of Civil Engineers 1992.

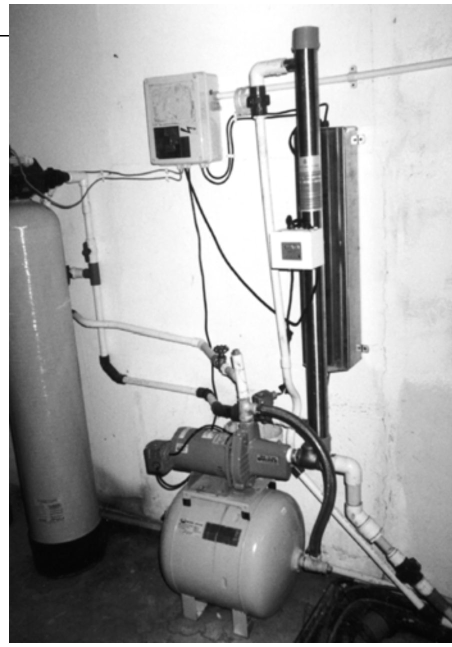
DISINFECTION

DESCRIPTION

Disinfection removes pathogens from treated wastewater effluent. Pathogens are bacteria and viruses that are harmful to human health and kill many individuals when present in drinking water. Common disinfection processes include *chlorination, ultraviolet radiation, ozonation,* and *pond disinfection*.



Chlorine and ozone are strong oxidising agents. They oxidise organic and inorganic matter and quickly kill all the pathogens they contact. Chlorine can be added to wastewater in a liquid, gas, or tablet form. Ozone is added as a gas only.



Ultraviolet (UV) radiation sterilises pathogens by restructuring their DNA or genes to prevent reproduction. UV radiation is applied to the wastewater through low-pressure mercury lamps that emit 85 percent of their energy in the wavelength range most harmful to pathogens. Typically, wastewater flows through channels or pipes with submerged UV lamps.

Pond disinfection is the natural process of pathogen removal in successive stabilisation ponds. Visible light and ultraviolet radiation from the sun, sedimentation, and natural die-off are the mechanisms for pathogen removal in ponds.

APPLICATIONS

Wastewater effluent discharged below ground generally experiences adequate pathogen and bacteria removal as it travels through the soil. Wastewater discharged to surface waters will not be naturally disinfected as quickly. Since human contact with waters high in pathogen concentration increases the risk of infection, disinfection should be considered for all surface water discharges.

Chlorination is appropriate for most wastewater, and is the most popular disinfection process in the world. Ultraviolet radiation performs well, but performs less well with effluents high in turbidity or suspended solids. Sand filtration prior to UV radiation is common. Ozonation disinfects more powerfully than chlorine, and with no harmful by-products. It is usually used to disinfect highly treated secondary or filtered effluent. Ozone must be generated on-site, which can be costly and requires a reliable power supply. Pond disinfection is a simple-technology, maintenance-free process that requires a large land area.

DESIGN CRITERIA

- Chlorination, UV radiation, and ozonation all require a specified contact time between the wastewater and the disinfectant. To ensure an adequate contact time between the wastewater and the disinfectant, the disinfection chambers should be designed to minimise hydraulic short-circuiting (fast, direct flow between the chamber's inlet and outlet).

Chlorination

- For a contact time of 1 hour, the typical chlorine dosage is 10 to 25 mg/L for septic tank effluent, 2 to 5 mg/L for secondary treatment effluent, and 2 to 10 mg/L for rapid sand filter effluent.
- An alternate dosage guideline is to produce a chlorine residual of 0.5 mg/L in the wastewater after 15 minutes of contact time.
- Violent initial mixing should be provided.

Ultraviolet Radiation

- Ultraviolet radiation supplies a great amount of energy, thus contact times between the wastewater and UV lamp are typically very short. A contact time of 1 minute or less is common. This disinfection process is preferred over chlorine and ozone where dechlorination is required before discharge.

Ozonation

- The hydraulic detention times in an ozone contactor chamber range from 30 seconds to 15 minutes depending on the type of contactor used.
- The EPA recommended ozone dosage is 5 to 15 mg/L for disinfection of wastewater effluent.

- This is the most expensive disinfection choice.

Pond Disinfection

- Pond disinfection should be used as a polishing process, after most of the BOD has been removed.
- Disinfection ponds should be shallow to maintain aerobic conditions. Most disinfection ponds are 300 to 1000 mm deep.
- Several small ponds in series provide better coliform and pathogen removal than a large pond with the same total area.
- Algae will be generated where detention times exceed 2-3 days.
- The efficiency of this process relies heavily on the presence of sunny conditions.

PERFORMANCE EFFICIENCY

The contact time and recommended dosages provided produce a final effluent with a maximum of 200 faecal coliforms/100 mL.

DISADVANTAGES

Chlorination produces many undesirable organic compounds that are toxic to humans and aquatic life. Sometimes dechlorination is necessary to lower the residual chlorine concentration in the effluent. Chlorine gas is a hazardous element, and safety features must be employed where it will be stored. Ozonation is a very expensive disinfection process that currently is not in wide use for wastewater disinfection, so limited design data and experience are available on the process. Ozonation, and to a lesser extent, ultraviolet radiation should only be used for high-quality effluent. Otherwise, slime and scaling accumulate on the lamps, greatly decreasing the radiation transmittance and thus the disinfection power, or excessive ozone demands result. Slime accumulation and mineral scaling may necessitate frequent cleanings of UV lamps. Pond disinfection requires a great deal of space.

RESIDUALS GENERATED

Chlorination is the only disinfection process discussed here that can produce harmful organic by-products. For this reason, it is desirable to remove as much of the organic material as possible in previous treatment processes before adding chlorine.

OPERATION & MAINTENANCE

Disinfection processes require effluent monitoring to verify pathogen removal. Chlorination processes require a feeder mechanism to introduce the liquid, gas, or tablet form of the chlorine.

Typical maintenance includes replacing chemicals, adjusting feeds rates, and maintaining the mechanical components. Most chlorine systems are designed for minimum maintenance. Ultraviolet radiation requires little maintenance other than regular cleaning and replacement of the lamps. Ozone generating and feeder equipment uses a large amount of electricity and is complicated. The EPA estimates that 8 to 10 kW-hours are used for each pound of ozone generated.

WCR INSTALLATIONS

Most large treatment facilities and some smaller aerated package plants in the WCR use chlorine to disinfect the effluent. Ultraviolet radiation has found some uses, but is not widely practised. Pond disinfection has been successfully used in Venezuela.

REFERENCES

Andrews, R.N. et al. 1993; Arthur, J.P. 1983; Curtis, T.P. et al. 1992; Ghrabi, A. et al. 1993; Giroult, E. 1995; Kalbermatten, J.M. 1982; Millette, E.M. 1992; Mills, S.W. et al. 1992; Oragui, J. et al. 1995; Ruiz, C.S. et al. 1995; Sweeney, V. 1996; U.S. EPA February 1980; U.S. EPA October 1980; U.S. EPA 1992; Water Environment Federation & American Society of Civil Engineers 1992.

EFFLUENT DISPOSAL

DESCRIPTION

Wastewater effluent can be disposed of on the *land surface*, in the *subsurface*, or into *surface waters*, including freshwater and marine waters.

There is some overlap in what is considered land surface and subsurface disposal; for this fact sheet, land surface disposal refers to an evaporation pond. Effluent flows into the pond, and most of it evaporates. Subsurface disposal is the application of effluent to the land surface, a subsurface absorption bed, or any other mechanism that eventually leads the effluent to the groundwater. Most subsurface systems are soil absorption systems. Surface water disposal in the WCR is generally effluent discharge to estuaries, bays, and the open ocean through a simple outfall pipe. Outfall pipes can be as short as several metres and as long as several kilometres.

APPLICATIONS

Land surface disposal is most appropriate in dry or arid climates. An evaporation pond may work in the most arid parts of the WCR, but most areas of the region receive too much rainfall for evaporation ponds to be effective. Subsurface disposal systems are commonly used for on-site treatment systems, especially septic tanks. They also can be used with high-density treatment systems, provided the soil is permeable enough and there is no significant risk of groundwater contamination. Because soil treatment systems are very effective in removing BOD, suspended solids, and pathogens, primary treatment is the only treatment required prior to subsurface disposal. A secondary function of subsurface disposal (provided there is adequate distance between the discharge point and the water table) is groundwater recharge. Surface water disposal is the most common method of wastewater disposal in urban, high-density areas. This is particularly true for most of the large coastal urban centres in the WCR.

DESIGN CRITERIA

Evaporation ponds

- Evaporation plus percolation must be greater than or equal to the influent wastewater flow plus precipitation.

Subsurface disposal

- The volume of wastewater effluent that can be discharged into a subsurface area depends on the soil permeability and the depth of the water table.
- Some design criteria are given in Fact Sheet #1.

Surface disposal (outfall)

- Marine outfalls dilute wastewater effluent with seawater as it flows out of the diffusers. The dilution level depends on such factors as the receiving water current velocity, the velocity and volume of discharge, the depth of the receiving water, and density differences between the effluent and receiving water. The U.S. EPA has produced computer programs to calculate this dilution; these programs are available to the general public.
- The level of treatment needed prior to surface water disposal depends on the receiving water requirements:

  – In open ocean situations with a properly designed outfall, wastewater may be disposed of with only preliminary or primary treatment because dilution will lower the pathogen concentration below World Health Organisation (WHO) standards.

  – In sensitive areas such as estuaries or coral reefs, the diluting capacity of the ocean must lower pollutant concentrations enough to prevent harm to the sensitive area; this may require advanced treatment or nutrient removal.

  – The outfall must be very long (1 to 5 km), and preferably in deep water so that strong currents dilute and move the wastes farther offshore. Ocean currents must be analysed in great detail to ensure that the wastes are not drawn back to land or other sensitive areas. If a short outfall is used, treatment with disinfection prior to disposal is adequate to maintain pathogen concentrations below WHO standards.

PERFORMANCE EFFICIENCY

N/A

DISADVANTAGES

N/A

RESIDUALS GENERATED

N/A

OPERATION & MAINTENANCE

Operation and maintenance requirements for effluent disposal systems depend on the quality of the effluent and the type of discharge. The only maintenance required for all effluent disposal systems is ensuring that the discharge orifice is not clogged with debris and performing any mechanical maintenance of pumps. The better the effluent quality, the fewer problems will develop with clogging in the distribution system. If the discharge can be achieved with gravity flow, very little operation or maintenance is required.

WCR INSTALLATIONS

In the Caribbean, the majority of wastewater effluent is disposed of through rivr or ocean outfalls. Unfortunately, in most cases there is little or no wastewater treatment before disposal. Subsurface disposal is practised throughout the WCR wherever septic tanks are used. In Barbados, effluent from septic tanks is discharged into 6 metre deep wells excavated into the thick coral limestone rock formation overlaying the ground water aquifers. The coral rock layer varies from 200-300 feet thick and acts as a natural filter for the purification of effluents. This is not allowed in Zone (I) water protection areas, however, where potable water is abstracted from the aquifer. Zone (I) areas are sized to allow an average travel time of 300 days through the rock to the aquifer source. Jamaica also practices subsurface effluent disposal. In Venezuela, most wastewater effluent is disposed to rivers with a short reach to the Caribbean Sea.

REFERENCES

Archer, A.B. 1990; Bartone, C.R. et al. 1984; Compton, A.W. 1973; Faruqui, N. 1993; Ruiz, C.S. et al. 1995; UNEP 1994; U.S. EPA February 1980; U.S. EPA October 1980; U.S. EPA 1992.

OIL-WATER SEPARATION

DESCRIPTION

Oil-water separation processes are physical processes to remove floating oils, some emulsified oils, and oils attached to suspended solids. Oil-water separation processes are usually the first treatment processes performed on oily wastewater because floating oils can inhibit biological activity necessary for secondary treatment and will coat filters, screens, and pumps. The two main types of oil-water separation processes are *dissolved air flotation* (DAF) and *gravity separation oil skimming*. This fact sheet addresses oil skimming; DAF is described in *Fact Sheet #10 – Primary Treatment*.

The oil skimming process uses a gravity-based separating tank where oils float to the surface because they are less dense than wastewater, as long as no other objects interfere. In a typical oil-skimming process, the oily wastewater flows into a basin, and oils that collect on the water surface are skimmed off with a belt-type mechanism or a suction pipe.

Sometimes, the skimmed product is placed in a secondary reservoir, where further separation occurs, with the oil passing over a weir and the skimmed water being removed from below. This allows almost complete separation.

APPLICATIONS

Gravity separators with skimmers provide inexpensive and effective oil-water separation for any type of oily wastewater, such as wastewater produced by oil refineries, petrochemical plants, food processing plants, slaughterhouses, and many other industries.

DESIGN CRITERIA

- The tank should provide enough detention time to allow the oil and water to separate.
- Turbulence should be minimised because it encourages the oil to emulsify (break into small droplets), which decreases skimming efficiency

PERFORMANCE EFFICIENCY

The key design parameter for gravity separators is hydraulic detention time, which is calculated as the volume of the tank divided by the flow rate through it. The appropriate detention time for optimal performance depends on the density of the oil in the process flow. In general, the longer the detention time, the higher the removal percentage, as shown in the following table. However, excessive detention times in oil-water separators should be avoided as this may cause some oil droplets to hydrate or emulsify, which makes them difficult to remove.

EFFECT OF DETENTION TIME ON OIL REMOVAL BY GRAVITY SEPARATION WITH SKIMMING	
Detention Time (minutes)	Oil Removal (%)
10	30
20	50
40	65
80	70
160	75

DISADVANTAGES

Very low oil concentrations are difficult to achieve using only gravity separators with skimmers. Other processes such as sand filters and reverse osmosis membranes are needed to achieve very high oil removals. Usually, a gravity separator with skimmers will not produce effluent clean enough to be re-used as cooling water. However, in most cases, it will bring oil concentrations low enough so that the effluent can safely be discharged to a public sewer.

RESIDUALS GENERATED

The volume of collected oil will depend on the process flow, and the percentage of oil removed. Often the oil can be re-used or recycled.

OPERATION & MAINTENANCE

There are no maintenance requirements other than regular lubrication and cleaning of the mechanical parts.

WCR INSTALLATIONS

KCM has no knowledge of installations in the WCR.

REFERENCES

Benedek, A. 1992; Beychok, M.R. 1967; Borup, M.B. et al. 1987; Bryant, J.S. et al. 1991; Chigusa, K. et al. 1996; Copeland, E.C. et al. 1991; Engelder, C.L. et al. 1993; Galil, N. 1990; Hobson, T. 1996; Jones, H.R. 1973; Mitchell, D.B. et al. 1994; Park, T.J. et al. 1996; Rhee, C.H. 1988; Viraraghavan, T. et al. 1994; Wong, J.M. 1995.

COAGULATION/PRECIPITATION

DESCRIPTION

Coagulation is a chemical/physical process that removes colloids (particles with diameters from 0.1 to 1.0 nanometers) and other suspended matter that does not settle out with conventional physical processes. Compounds called coagulants are added to the wastewater, and electrical forces encourage the coagulants and colloids to flocculate, or join together and become larger, heavier suspended matter. The flocculated particles then quickly settle, or precipitate, and are removed from the wastewater.

Precipitation is the addition of a lime or caustic to a waste stream so that metals removal can be enhanced. The idea is to add enough lime or caustic so that the pH of the wastewater solution is at the metal's minimum solubility, thus encouraging the metal to precipitate (form as a solid) as a hydroxide or other complex. As precipitates, metals are removed by settling or by filtration.

APPLICATIONS

Coagulation has many applications for wastewater treatment, particularly for industrial wastewater. Coagulation removes very fine suspended matter, including colloids, metallic ions, iron, phosphates, suspended organic material, and fine oil droplets. It is also used for pH control. Paperboard industries, oil refineries, and rubber, paint, and textile and some food processing factories use coagulation as a wastewater treatment process. Precipitation is used to remove metals from waste streams.

DESIGN CRITERIA

Appropriate design criteria for coagulation/precipitation are determined by what is to be removed. Different coagulants are needed for different pollutants. The following table provides typical doses for common coagulants.

COAGULANT DOSAGE FOR SPECIFIC POLLUTANTS

Coagulant	Dosage (mg/L)	Pollutant Removed
Lime	150 to 500	Colloids, heavy metals, phosphorus
Alum	75 to 250	Colloids, phosphorus, and emulsified oils (with a mix of coagulants)
Ferrous Sulphates	70 to 200	Metals, phosphorus
Cationic Polymers	2 to 5	Enhances performance of above coagulants

The following precipitation processes are most suitable for removing the associated metals:

- Sulphide precipitation to remove arsenic

- Sulphate precipitation to remove barium

- Alum precipitation to remove mercury.

PERFORMANCE EFFICIENCY

The following table summarises performance efficiency for common coagulants and wastewater sources.

COAGULANT PERFORMANCE EFFICIENCY		
Wastewater Source	Coagulant and Dosage	Removal Efficiency
Synthetic rubber plant	Alum—100 mg/L	80% COD; 80% BOD
Vegetable processing plant	Lime—0.5 kg/kg BOD	35% to 70% BOD
Laundry	$Fe_2(SO_4)_2$—0.25 kg/m^3	90% BOD
Wool scouring plant	$CaCl_2$—1 to 3 kg/kg BOD	75% to 80%

The following table summarises precipitation performance efficiency for some metal contaminants.

PRECIPITATION PERFORMANCE EFFICIENCY	
Metal	Expected Soluble Concentration in Effluent after Precipitation
Arsenic	0.005 to 0.05 mg/L
Barium	0.5 mg/L
Mercury	0.0005 to 0.02 mg/L
Lead	0.05 to 0.10 mg/L
Copper	0.05 to 0.10 mg/L
Zinc	0.05 to 1.0 mg/L

DISADVANTAGES

Although most coagulants are inexpensive, the cost can be high for an ongoing supply of them, particularly in some parts of the WCR. Another disadvantage is the volume of sludge generated, which includes the solids removed from the waste stream as well as the coagulants that are added. If any metals or toxics are coagulated or precipitated, then the sludge must be disposed of carefully and cannot be reused.

RESIDUALS GENERATED

A high volume of sludge is generated. The amount depends on the amount of coagulant added, the amount of precipitate formed, and the amount of solids removed.

OPERATION & MAINTENANCE

Operation and maintenance for coagulation and precipitation processes are several times that required for ordinary sedimentation tanks, plus the additional cost of the additives.

WCR INSTALLATIONS

KCM has no knowledge of installations in the WCR.

REFERENCES

Eckenfelder, W.W. 1989; Water Environment Federation & American Society of Civil Engineers 1992.

AIR STRIPPING

DESCRIPTION

Air stripping processes remove volatile organic or chemical materials. The volatile constituents come into contact with air that is bubbled through the wastewater flow. They then diffuse into a gaseous state and are removed from the wastewater as the air bubbles out. This happens naturally in aerated biological processes and is engineered to occur at a faster rate in packed tower air strippers. Air that has passed through the process flow (or exhaust air) is passed through a gas scrubber if the constituent concentration is too high to allow direct emission to the atmosphere. Otherwise, it is vented to the atmosphere.

APPLICATIONS

Air stripping's primary use is to remove volatile organic compounds (VOCs) such as those generated by petrochemical industries. It can also be used for ammonia removal.

DESIGN CRITERIA

Detailed design criteria can be found in textbooks on petrochemical wastewater treatment. The following are general design criteria that will improve VOC removal through air stripping:

- The removal rate increases as the air flow increases.
- The removal rate increases as the air and water temperature increases.
- The removal rate increases as the air-water interface area increases.
- Compounds with a higher "Henry's constant" (a constant describing a gas's solubility in water) are removed more quickly than those with a low Henry's constant.

PERFORMANCE EFFICIENCY

The performance efficiency depends on the constituent solubility, the packing tower dimensions, and the temperature.

DISADVANTAGES

If the constituent concentrations in the exhaust gas are high, or if the exhaust gas is odorous or hazardous, it should be sent to a gas scrubber. This increases the cost of the operation considerably. Another disadvantage is that additional pumps or blowers may be required to operate an air stripper.

RESIDUALS GENERATED

Air stripping generates a gas containing VOCs. The volume of the exhaust gas is the amount of gas that travels through the stripping columns. The concentration depends on operating conditions.

OPERATION & MAINTENANCE

Operation and maintenance requirements for air stripping are standard maintenance of the pumps that send air and water flow through the packing columns and any additional maintenance associated with a gas scrubber, if one is used. The only maintenance required for the actual column is an occasional cleaning of the filter medium.

WCR INSTALLATIONS

KCM has no knowledge of specific installations in the WCR.

REFERENCES

Eckenfelder, W.W. 1989; U.S. EPA 1980; Water Environment Federation & American Society of Civil Engineers 1992.

BIOLOGICAL TREATMENT OF INDUSTRIAL WASTE

DESCRIPTION

Biological treatment processes use micro-organisms to remove suspended and soluble BOD and COD (chemical oxygen demand) from wastewater. Some of these micro-organisms operate under *aerobic* conditions (free oxygen is present) and others operate under *anaerobic* conditions (free oxygen is not present).

Aerobic treatment processes are the same as those described in *Fact Sheet #5 – Lagoons and Stabilisation Ponds*, and *Fact Sheet #11 – Secondary Treatment*. Lagoons, activated sludge, rotating biological contactors, and trickling filters are processes that can treat industrial wastewaters aerobically. This fact sheet references Fact Sheets #5 and #11 for some information.

The following anaerobic treatment processes are widely used to treat industrial wastewaters:

- The *anaerobic filter* can be operated in an upflow or downflow mode, where upflow or downflow describes the direction of process flow through the filter. The anaerobic organisms grow on the filter medium and degrade the organic material in the wastewater as it flows through. The physical filtration helps eliminate or minimise the need for solids removal downstream.
- The *fluidised bed reactor* is a filter operated in an upflow mode. The filter medium is sand, and the flow velocity through the filter must be high enough to expand the space between the sand particles, filling the entire reactor.
- *Upflow anaerobic sludge blanket* (UASB) reactors have gained much popularity in the last decade, particularly in Latin America. Wastewater flows into the bottom of the reactor then upward through a blanket of biologically formed granules, which provide treatment as the wastewater flows through. The UASB process requires a relatively low hydraulic detention time compared to the other anaerobic processes.

APPLICATIONS

Aerobic treatment processes are used for secondary treatment of domestic wastewaters. They are also used for BOD and COD removal from industrial wastewaters. However, in industrial applications, aerobic processes may serve as polishing processes and follow anaerobic processes. Industrial wastewaters sometimes have extremely high BOD concentrations, which would be very costly to treat aerobically.

Anaerobic treatment processes are well suited for treatment of industrial wastewaters with very high BOD and COD loadings. Anaerobic processes typically require longer detention times, but have many advantages over aerobic treatment processes in industrial applications:

- Industrial wastewaters can have COD values as high as 100,000 mg/L. Aerobic treatment processes would require a very large aeration capacity to treat this level. (Anaerobic processes are not aerated.)
- Anaerobic processes produce one-fourth to one-third as much sludge as aerobic processes.
- Anaerobic processes generate a significant amount of methane gas. In medium to large reactors, it is economically feasible to capture and reuse the methane to generate energy.

DESIGN CRITERIA

Aerobic Processes

Design criteria for aerobic processes can be found in *Fact Sheet #5 – Lagoons and Stabilisation Ponds*, and *Fact Sheet #11 – Secondary Treatment*.

Anaerobic Processes

Design criteria for the anaerobic processes are summarised in the following table.

DESIGN CRITERIA FOR ANAEROBIC BIOLOGICAL TREATMENT PROCESSES		
	Loading (kg/m^3/day)	Hydraulic Detention Time (days)
Anaerobic filter	0.5-3.5	1-2
Fluidised reactor	3-5	
UASB	10-90	0.2-1

PERFORMANCE EFFICIENCY

Performance efficiency for aerobic processes can be found in *Fact Sheet #5 – Lagoons and Stabilisation Ponds*, and *Fact Sheet #11 – Secondary Treatment*.

The performance efficiency of anaerobic processes ranges from 40 to 90 percent. Typical efficiencies are in the 60 to 80 percent range.

DISADVANTAGES

The disadvantages of aerobic processes can be found in *Fact Sheet #5 – Lagoons and Stabilisation Ponds*, and *Fact Sheet #11 – Secondary Treatment*.

Anaerobic processes do not achieve high quality effluent unless an aerobic treatment process follows as a polishing step. Anaerobic systems also require large land areas and have long start-up times; it is 2 to 3 months before an anaerobic process operates efficiently. This is a problem for seasonal industries, such as some food processing plants and dairy farms.

RESIDUALS GENERATED

Both aerobic and anaerobic systems produce sludge. The volume generated depends on the wastewater composition and the degree of treatment. A good rule of thumb for sludge production is that aerobic processes produce about 0.6 to 1.2 kg of sludge per kg of BOD removed; anaerobic processes produce about one-fourth to one-third as much. Anaerobic processes also produce about 5.6 cubic feet of methane per pound of COD removed.

OPERATION & MAINTENANCE

The operation and maintenance requirements for anaerobic processes are very similar to those for secondary treatment processes. Routine maintenance for piping and pumps is necessary. A key difference is that anaerobic processes are not aerated, which is the primary expense for aerated treatment processes. The level of operator skill necessary to operate most anaerobic processes is not as high as for a typical activated sludge plant. However, it is still a skilled position.

WCR INSTALLATIONS

KCM has no knowledge of specific installations in the WCR.

REFERENCES

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SUSPENDED SOLIDS REMOVAL

DESCRIPTION

The primary suspended solids removal processes are coagulation, sedimentation, and physical filtration. These processes are applicable for suspended solids removal from any wastewater. Information on the suspended solids removal processes are included in *Fact Sheet #8 – Sand Filtration*, *Fact Sheet #10 – Primary Treatment*, and *Fact Sheet #20 – Coagulation/Precipitation*.

ACTIVATED CARBON ADSORPTION

DESCRIPTION

Adsorption is a physical and chemical process in which solute molecules (molecules or compounds present in a solution) collect onto a solid surface, also known as the adsorbent. The precipitate formed from certain coagulants, such as aluminium hydroxide and ferric hydroxide, adsorbs some colour-causing molecules and trihalomethane precursors. However, activated carbon is the most common adsorbent. Activated carbons are made from a combination of wood, lignins, coal, lignite, and petroleum residues.

Activated carbon is used in two ways. One is to pass the waste stream through a column filled with porous activated carbon media known as *granular activated carbon (GAC)*. As the waste stream flows through the column, pollutants adsorb onto the carbon surface. When activated carbon has reached its adsorption capacity, there is no net change in the wastewater's pollutant concentration as it flows through the activated carbon media. This is known as "breakthrough."

The other method is to add *powdered activated carbon (PACT)* to an activated sludge treatment process. The PACT adsorbs pollutants, then settles out from the flow in a secondary clarifier.

APPLICATIONS

Activated carbon processes are an excellent way to remove non-biodegradable organic materials, colour, taste, odour, and refractory organic material from waste streams. Activated carbon processes are sometimes, though infrequently, used in domestic wastewater treatment. Activated carbon is commonly used to treat wastes from food processing industries, textile factories, petrochemical industries, oil refineries, and metal processing or plating industries. For GAC processes, most of the suspended solids and biodegradable organic material should have been previously removed so that the carbon's adsorption capacity is not wasted on constituents that can be removed by other processes.

DESIGN CRITERIA

Two factors make it difficult to provide design criteria for activated carbon processes:

- There is a wide range of activated carbon quality. Each type of activated carbon has a different adsorption capacity.
- The chemicals to be adsorbed, or the adsorbate, each have different affinities for the activated carbon. This needs to be determined through pilot testing.

The dosage of PACT required to achieve 90 percent removal of total organic carbon (TOC) in activated sludge tanks ranges from 20 to 1,000 mg/L.

The following table summarises typical design criteria for GAC column adsorption systems.

TYPICAL DESIGN CRITERIA FOR GAC ADSORPTION SYSTEMS		
	Median	Range
Empty Bed Contact Time (minutes)[a]	10	3 to 34
Depth of Filter (meters)	1.0	0.2 to 8
Hydraulic Loading (meters/hour)	6	1.9 to 20

a. Empty bed contact time is the hydraulic detention time inside an empty filter.

PERFORMANCE EFFICIENCY

Carbon adsorption processes can achieve removals up to 99 percent; typical removal efficiencies are from 90 to 95 percent.

DISADVANTAGES

When the activated carbon reaches its adsorption capacity, it must be regenerated or replaced. This is the most expensive aspect of activated carbon adsorption processes. GAC columns are economical if they are used continuously. However, if they are only used a few months out of the year, it makes sense to use PACT processes because there is no capital for setting up a PACT process if an activated sludge process is in place. PACT processes are not as economical if they are used continuously because of the excess sludge build-up. Also, because the spent carbon is mixed into the sludge, regenerating the carbon is a more difficult.

RESIDUALS GENERATED

GAC columns generate activated carbon with an exhausted adsorption capacity. PACT processes generate exhausted activated carbon also. However, in PACT processes, the exhausted carbon is mixed with the biological solids from the activated sludge process.

OPERATION & MAINTENANCE

In addition to routine mechanical maintenance of pumps, piping, and activated sludge processes (for PACT), adsorption systems require fresh carbon regularly. If little carbon is exhausted, it may be economical to replace the exhausted carbon with fresh carbon; if a significant amount is exhausted, regenerating it on-site is more economical. Regeneration for exhausted activated carbon from columns is usually accomplished in hearth furnaces at temperatures of 650 to 1,000ºC. Regenerating exhausted carbon from PACT processes is a more involved process known as wet-air oxidation. It requires temperatures near 450ºC at a pressure of 40 atmospheres.

WCR INSTALLATIONS

KCM has no knowledge of specific installations in the WCR.

REFERENCES

American Water Works Association 1990; Eckenfelder, W.W. 1989; Weber, W.J. Jr., 1972.

DEMINERALISATION

DESCRIPTION

Demineralisation processes remove dissolved, or ionic, constituents from waste streams. Two important demineralisation processes are *ion exchange* and *membrane separation*.

Ion exchange processes remove ions from waste streams as they are passed through a synthetic, porous resin. A cationic resin will exchange a positive ion, such as a sodium or hydrogen ion, for a positive ion in the waste stream. Anionic resins exchange negative ions in the waste stream with hydroxide ions. The waste stream is passed through the resin until all the available exchange sites are exhausted (a point called "breakthrough"). When the resins are exhausted, cationic resins are regenerated by submersing them in an acid solution, and anionic resins are regenerated by submersing them in a caustic solution. After regeneration, the resin is rinsed with water, and is ready for use.

Membrane separation processes act like a filter. Semi-permeable membranes allow water or solvents to pass through, while keeping ions, metals, or other molecules too large to pass through the membrane pores on the upstream side. A pressure differential is generated between the upstream and downstream end of the membrane, which forces the waste stream through the membrane. The concentrated solution collecting on the upstream side of the membrane is disposed of and can be as high as 100,000 mg/L. The most common membrane material is cellulose acetate. A common membrane process is called reverse osmosis (RO).

APPLICATIONS

Ion exchange processes can be used to remove any ionic constituent from a waste stream. Their most common application in wastewater treatment is for metal processing and plating industry's waste streams. In the plating industry, an advantage to ion exchange processes is the recovery of chromium from the waste stream.

Membrane separation processes can be used as a final step in treating waste streams with undesirable ions, colloids, and oily emulsions. To minimise clogging the membrane, or fouling, pre-treatment processes should remove suspended matter, bacteria, and any precipitable ions. This will also prolong the membrane life.

DESIGN CRITERIA

Ion exchange

- The minimum bed depth should be 600 to 750 mm.

- The treatment flow rate can be 16 to 40 m^3/hour per cubic metre of resin.
- The regenerant flow rate is typically 8 to 16 m^3/hour per cubic metre of resin.
- Rinse water volumes are 4 to 14 m^3 per cubic metre of resin.

Membrane separation

Typical design criteria for membrane separation are summarised in the following table.

TYPICAL DESIGN CRITERIA FOR MEMBRANE SEPARATION PROCESSES		
	Range	Typical
Gage pressure on upstream end (atmospheres)	20 to 70	40
Packing density (square metre of membrane per cubic metre)	150 to 1,500	
Flux (m^3/m^2/day)	0.4 to 3.2	0.5 to 1.4
Feed water velocity (cm/second)	1.2 to 75	

PERFORMANCE EFFICIENCY

Ion exchange removal efficiencies range from 85 to 99.99 percent. Typical removal efficiencies are from 95 to 99.99 percent.

Typical performance efficiencies for membrane separation are summarised in the following table.

TYPICAL PERFORMANCE EFFICIENCIES FOR MEMBRANE SEPARATION PROCESSES		
	Range	Typical
Recovery of feed flow (%)	75-95	80
Rejection of solute (%)	85-99.5	95
Membrane life (years)		2

DISADVANTAGES

The spent regenerant from ion exchange processes must be disposed of safely. This can be a large expense if a large flow is treated. Other disadvantages are that effluent quality is highly variable, this process is not feasible with wastewater of high dissolved solids concentrations, and when the resin becomes exhausted, breakthrough occurs rapidly.

Membrane separation processes provide very good removal, but operation costs are very high. Pressure differences across membranes are nearly 40 times atmospheric pressure. Also, membranes have a history of problems with fouling. Membranes should be used only for waste streams of already very high quality.

RESIDUALS GENERATED

Ion exchange processes produce exhausted regenerating solutions, which contain the ions removed from the waste stream.

Membrane separation processes generate very concentrated brine streams with concentrations up to 100,000 mg/L of dissolved solids.

OPERATION & MAINTENANCE

Ion exchange processes require that the operators have a good understanding of the process. Membrane separation processes require frequent cleaning and backwashing. Also, operational costs are very high for membrane processes. Maintaining a pressure difference across the membrane of 40 atmospheres is expensive.

WCR INSTALLATIONS

KCM has no knowledge of specific installations in the WCR.

REFERENCES

American Water Works Association 1990; Eckenfelder, W.W. 1989; Weber, W.J. Jr., 1972.

CHEMICAL OXIDATION

DESCRIPTION

Chemical oxidation is a process to transform reduced inorganic and organic contaminants that are resistant to conventional biological treatment into non-hazardous or less toxic substances that are more stable, less mobile, or inert. Chemical oxidation can convert inorganic compounds to a stable oxidation state that permits precipitation or discharge to a municipal sewer system or receiving water with substantially reduced impact. Chemical oxidation of organic compounds converts organic compounds into carbon dioxide, water, and oxides of nitrogen, or to simpler organic products that are amenable to conventional biological treatment

APPLICATIONS

Chemical oxidation has been used to oxidise organic constituents including: halogenated volatiles (TCE, DCE, PCE, TCA, MeCL), halogenated semi-volatiles, non-halogenated volatiles (alcohols, ketones, aldehydes, acetates, hydrazine, nitrated esters), non-halogenated semi-volatiles (phenol, quaternary amines), PCBs, pesticides, dioxins/furans, and organic cyanides. Chemical oxidation also is effective for inorganics (volatile metals, non-volatile metals, inorganic cyanides and sulphides). Chemical oxidation has been used to destroy metal complexes to allow chemical precipitation of toxic metals. Alkaline chlorination is frequently the most appropriate technology for cyanide destruction. Chemical oxidation technology has been used to treat industrial wastewater generated by the petrochemical industry, chemical formulators, paint and ink formulation industry, textile dying and finishing, metal plating and finishing, and the agricultural chemicals industry.

DESIGN CRITERIA

The oxidising agents most commonly used for chemical oxidation are: ozone, hydrogen peroxide, sodium hypochlorite, chlorine, and chlorine dioxide. Ultra-violet (UV) light and ferrous and ferric sulphates have been used as catalysts to enhance the rate and effectiveness of chemical oxidation processes. Catalysed oxidation reactions are often 10 to 1,000 times faster and more effective. Selection of the oxidant, dosage and pH, the need for reaction catalyst, and the reaction time all depend on the matrix, the concentration, the specific contaminant, and the concentration and type of interfering contaminants. Specific design criteria are usually developed from bench and pilot tests.

Oxidant dosage rates are generally in the range of 1 to 3 times the stoichiometric requirements. Reaction times are generally in the range of 30 to 120 minutes.

The half life of ozone is 20-30 minutes at 20ºC, therefore it must be produced on-site.

PERFORMANCE EFFICIENCY

Performance and efficiency depend on the contaminant involved, the specific oxidation system used and the presence of interfering or competing substances.

DISADVANTAGES

The cost of the oxidising chemicals is the major disadvantage of this technology. The formation of toxic or potentially hazardous intermediate compounds because of incomplete oxidation is occasionally a consideration (e.g. trihalomethanes, epoxides and nitrosoamines). The formation of toxic or hazardous by-products is most often associated with halogen-based oxidants.

The oxidation process is relatively non-selective; consequently all organic and reduced inorganic substances in the water can interfere with the oxidation of the target contaminant(s). This interference can normally be overcome by increasing the dosage of oxidant chemicals, but this increases the operational costs.

Oil and grease should be minimised to optimise the efficiency of the process.

The half life of ozone is 20 to 30 minutes at 20ºC, therefore it must be produced on-site. Although this eliminates the storage and handling problems associated with other oxidants, ozone based systems generally have a higher capital cost compared to those using peroxide or chlorine, due to the expense of the ozone generator and the off-gas recovery/treatment system.

Fenton's catalysed oxidation (ozone or hydrogen peroxide catalysed by ferrous or ferric ion) processes produce ferric oxide sludge that generally must be removed from the wastewater following the oxidation reaction.

Oxidation systems employing UV light to catalyse the oxidation reaction have higher electrical costs, and UV lamps are subject to scaling or coating, which reduces the effectiveness of the catalyst. UV-catalysed reactions do not perform well in turbid wastewater.

This technology is not well suited for waste loads with large variations in character and concentration in a continuous treatment system application unless flows are equalised to minimise the variations in wastewater entering the reactor.

On-line process monitoring systems are often necessary to monitor pH, flow rate, temperature, contaminant of concern, and residual oxidant concentration.

RESIDUALS GENERATED

Metal oxides may be formed as a by-product of the oxidation reaction. Sedimentation or filtration may be required prior to reuse or disposal of the water. Chemical oxidation employing ferric or ferrous catalysts can generate significant quantities of sludge depending on the quantity of catalyst used. Other residuals formed can include partially oxidised products if the oxidation is incomplete, which may require supplemental treatment (biological, activated carbon adsorption, etc.).

OPERATION & MAINTENANCE

Incomplete oxidation may be caused by an insufficient quantity of the oxidation chemicals, inhibition of oxidation reactions by a pH that is too low or too high, the strength of the oxidising chemicals, the presence of interfering compounds that consume chemicals, or inadequate mixing or contact time between the oxidant and the target contaminant.

WCR INSTALLATIONS

KCM has no knowledge of specific installations in the WCR.

REFERENCES

Patterson 1985; EPA 1991b.

SLUDGE THICKENING

DESCRIPTION

Sludge thickening includes processes for removing water from sewage treatment plant sludge to reduce the cost of subsequent treatment processes or sludge disposal as a concentrated liquid. Typical sludge thickening processes include the following:

- Gravity thickening
- Lagoon thickening
- Gravity belt thickening
- Centrifuge thickening.

Gravity thickening feeds liquid sludge to a concrete or steel tank. Tanks are usually cylindrical in shape and fed radially. Effluent from the tank is discharged over a fixed weir for return to the beginning of the liquid treatment process. Thickened sludge is pumped out of the bottom of the tank for transfer to a subsequent process such as digestion or to a vehicle for disposal as a liquid sludge. Gravity thickening is often more successful with primary sedimentation sludge or combined primary and secondary sedimentation sludge than with secondary sedimentation sludge alone.

Lagoon thickening is gravity thickening in an earthen basin. Sludge is wasted from the liquid stream in dilute form and pumped or drained by gravity to an earthen basin. Supernatant (top water) is withdrawn via weirs or gates and returned to the liquid process. Thickened sludge is withdrawn from the bottom of the lagoons by gravity or dredge pump.

Gravity belt thickening (GBT) is a relatively new technology that uses the gravity zone of a belt filter press for sludge thickening. High process loading rates can be applied, with application of polymers for sludge conditioning. Sludge concentrations are typically higher than those achievable with gravity thickening. GBTs are relatively low-power machines.

Centrifuge thickening is the sludge thickening process with the highest thickening capability in a given process footprint. In this process, sludge is pumped to a solid bowl centrifuge rotating at up to 3,000 revolutions per minute to produce acceleration of up to 2,000 times the normal gravitational acceleration.

The dissolved air flotation (DAF) process has been used in the past for sludge thickening, but today it has been almost entirely replaced by GBT and centrifuge thickening for applications where a compact thickening process is required.

APPLICATIONS

Lagoon thickening is appropriate for many applications in low to medium population density communities in the Caribbean region because of its simplicity and economy. Gravity thickening uses less land area than lagoon thickening, but requires more operator attention and equipment maintenance. GBT and centrifuge thickening are appropriate for high population density communities and industrial use.

DESIGN CRITERIA

Typical design criteria for sludge thickening are summarised in the following table.

TYPICAL DESIGN CRITERIA FOR SLUDGE THICKENING PROCESSES

	Design Criterion	Typical Value for Primary Sludge	Typical Value for Secondary Sludge
Gravity Thickening	Loading Rate, $kg/m^2/hr$	4 to 6	0.5 to 1.5
Lagoon Thickening	Detention Time, days	2 to 10	2 to 10
GBT	Loading Rate, kg/m/hr	500 to 1,000	300 to 600
Centrifuge Thickening	Residence Time, minutes	Proprietary	Proprietary

PERFORMANCE EFFICIENCY

Typical performance efficiencies for sludge thickening are summarised in the following table.

TYPICAL PERFORMANCE EFFICIENCY FOR SLUDGE THICKENING PROCESSES

	Typical Solids Concentration After Thickening for Primary Sludge	Typical Solids Concentration After Thickening for Secondary Sludge
Gravity Thickening	4 to 8%	1.5 to 3%
Lagoon Thickening	2 to 4%	1.5 to 3%
GBT	6 to 8%	4 to 6%
Centrifuge Thickening	6 to 8%	4 to 6%

DISADVANTAGES

Lagoon thickening requires a larger land area than gravity thickening or mechanical thickening processes such as GBT and centrifuge thickening. Gravity thickening has higher maintenance and operating requirements than lagoon thickening. GBT thickening requires higher operator attention and regular maintenance by qualified technicians. Centrifuge thickening has high power requirements. Maintenance work for restoration of scroll and bowl coatings or tiles can require highly skilled maintenance workers and expensive shipment from outside the country for replacement materials.

RESIDUALS GENERATED

All thickening processes produce effluent flows that must be returned to the plant or otherwise disposed of.

OPERATION & MAINTENANCE

Regular operation and maintenance of lagoon thickeners includes management of sludge pumping and periodic dike maintenance. Gravity thickening, GBT, and centrifuge operation require close operator attention for control of loading rate. These equipment-intensive thickening processes will require regular equipment maintenance and may require periodic import of maintenance parts from outside the Caribbean region.

WCR INSTALLATIONS

All the installations visited by the KCM team in the Caribbean region used either no thickening or lagoon thickening of sludges.

REFERENCES

U.S. EPA, 1979.

SLUDGE STABILISATION

DESCRIPTION

Sludge stabilisation are processes performed on thickened waste solids from biological processes. The purpose of stabilisation is to reduce the volatile solids and pathogen content in the sludge so they can be safely disposed or used for land application. Stabilisation processes also reduce the volume of the solids. Typical sludge stabilisation processes include :

- Aerobic Digestion
- Air Drying
- Anaerobic Digestion
- Composting
- Lime Stabilisation

Aerobic digestion is the biochemical oxidation of wastewater sludge in aerobic conditions in open or closed tanks. Aerobic digesters are operated in batch mode or continuous feed mode. In either case, there may be a solids settling step, where the aerated solids are allowed to settle to the bottom. The stabilised sludge is drawn off the bottom or from the mixed tank.

Air drying beds are shallow paved, or earthen basins where thickened waste sludge is allowed to naturally dry.

Anaerobic digestion is the biochemical oxidation of wastewater sludge in the absence of free oxygen in closed tanks. During the process, methane is released as the organic material is degraded.

Composting is a process where aerobic organisms degrade and disinfect already thickened sludge. The sludge is mixed with bulking material, such as wood chips, to provide the necessary porosity for adequate aeration. The sludge is then laid over a network of porous piping and aerated. The stabilised sludge can then be used as fertiliser.

Lime stabilisation is the addition of alkaline compounds to raise the pH of the sludge mixture. Holding the sludge mixture at a high pH for an extended period of time will remove pathogens.

APPLICATIONS

For high density areas, digestion and lime stabilisation are appropriate because of their relatively low land requirements compared to the two other processes. They also require a high degree of operator attention and equipment. Composting is not very intensive, but piping and compost handling equipment are needed. Air drying is the simplest stabilisation process. It only requires land space, a sunny climate without extended periods of rainy weather, and equipment to apply and remove the sludge from the drying beds.

DESIGN CRITERIA

The design criteria for these processes identify the temperature and residence time needed in that process for a significant reduction of pathogens.

SLUDGE STABILISATION DESIGN CRITERIA		
	Minimum Temperature (ºC)	Residence Time (days)
Aerobic	20	40
Digestion	15	60
Air Drying	0	90
Anaerobic	35-55	15
Digestion	20	60
Composting	40	5

Lime stabilisation requires that sufficient lime is added to the sludge to raise the pH of the mixture to 12 after two hours of contact.

PERFORMANCE EFFICIENCY

The above design criteria are rules of thumb for achieving the sewage sludge criteria in the U.S. EPA's Sludge Disposal Regulations. The goal of the regulations is to achieve a minimum of 38 percent of volatile solids reduction.

DISADVANTAGES

The disadvantages to digestion processes are that the equipment, operation and maintenance costs can be very high. Also, trained operators are needed for proper operation. Composting and air drying can be low-tech processes but they require large land areas and large amounts of organic materials such as wood chips or waste plant material as a bulking agent. Air drying is easiest to operate, however, it may not be suited to rainy areas in the Caribbean.

RESIDUALS GENERATED

All stabilisation processes produce a sludge that can be disposed of by land application. Anaerobic digestion produces a useful by product, methane gas, which can be used as a fuel source.

OPERATION & MAINTENANCE

Regular operation of digesters includes management of sludge pumping, mixing, and controls. Equipment intensive processes will require regular equipment maintenance and may require periodic import of maintenance parts from outside the Caribbean region.

WCR INSTALLATIONS

The Arima and San Fernando plants in Trinidad have anaerobic digesters. The small package plant in Charleyville, Trinidad has air drying beds. All the facilities in Venezuela included in the site visit for this study use sludge lagoons for stabilisation and drying.

REFERENCES

U.S. EPA, 1979.

SLUDGE DEWATERING

DESCRIPTION

Sludge dewatering includes processes for removal of water from sewage treatment plant sludge to reduce the cost of subsequent treatment processes or prior to sludge disposal as a concentrated liquid. Dewatering processes are similar to thickening processes, but higher solids concentrations are achieved. Typical sludge thickening processes include:

- Belt filter press dewatering
- Centrifuge dewatering
- Screw press dewatering
- Plate and frame dewatering

Belt filter presses dewater sludge by one or two belts that apply pressure to the sludge and squeeze out the liquids. Belt filter presses can achieve very high solids concentrations with minimal power requirements.

Centrifuge dewatering is the sludge dewatering process with the highest loading rate in terms of dewatering capability in a given process footprint. In this process, sludge is pumped to a solid bowl rotating at up to 3,000 revolutions per minute to produce equivalent gravitational acceleration of up to 2,000 times the normal.

Screw press dewatering is a new process that can produce very high sludge concentrations. Sludge is pumped inside a perforated cylinder surrounding a rotating screw. The screw forces the sludge toward the end of the container and progressively dewaters it by the pressure of the screw against the sludge.

Plate and frame presses are an old, high maintenance, and high cost dewatering processes. They achieve high sludge cake solids concentrations at the expense of high chemical and power costs.

APPLICATIONS

Belt filter press, centrifuge, and screw pump dewatering are appropriate for high population density communities and industrial use.

DESIGN CRITERIA

Typical design criteria for sludge dewatering processes are presented in the following table.

DESIGN CRITERIA FOR SLUDGE DEWATERING PROCESSES			
	Design Criteria	Typical Value for Primary Sludge	Typical Value for Secondary Sludge
Belt Filter Press	Loading Rate, kg/m/hr	900 to 1,500	500 to 1,000
Centrifuge	Residence Time	Proprietary	Proprietary
Screw Press	Loading Rate	Proprietary	Proprietary

PERFORMANCE EFFICIENCY

Typical performance efficiencies for sludge dewatering processes are in the following table.

PERFORMANCE EFFICIENCIES FOR SLUDGE DEWATERING PROCESSES		
	Typical Value for Primary Sludge	Typical Value for Secondary Sludge
Belt Filter Press	25 to 35 %	15 to 22%
Centrifuge	25 to 30%	12 to 15%
Screw Press	25 to 31%	10 to 20%

DISADVANTAGES

Belt filter presses are very sensitive to incoming feed sludge characteristics. They also require operator attention and regular maintenance by qualified technicians. Centrifuge dewatering has high power requirements. Maintenance work for restoration of scroll and bowl wear-resistant coatings or tiles can require highly skilled maintenance workers and/or expensive shipment from outside of the country for replacement materials. Screw presses are a new technology, so design criteria are not well established.

RESIDUALS GENERATED

All dewatering processes produce effluent flows that must be returned to the plant or otherwise disposed of.

OPERATION & MAINTENANCE

Belt filter press, centrifuge, and screw pump operation requires close operator attention for control of loading rate. Equipment for these intensive dewatering processes requires regular maintenance and may require periodic import of maintenance parts from outside the Caribbean region.

WCR INSTALLATIONS

None of the installations visited by the KCM team in the Caribbean region used dewatering processes.

REFERENCES

U.S. EPA, 1979.

COLD DIGESTION / DRYING LAGOONS

DESCRIPTION

Cold digestion/drying (CDD) lagoons for sludge treatment are a low-technology alternative for solids management that incorporate all of the functions of thickening, stabilisation, dewatering, and storage in a series of earthen basins. These lagoons receive waste activated sludge or a combination of primary and secondary sludge. Overflow from the lagoons is from the opposite end of the lagoon from the feed. The overflow or supernatant is returned to the plant inlet.

Digestion and stabilisation takes place in the lagoon at ambient temperatures. Two lagoons are needed. One lagoon is used for fill while the other is used for maturation. At the end of the one-year filling period the fill lagoon is isolated and allowed to dry for a period up to one year and sludge fill is directed to the alternate basin. Rooted aquatic plants such as *scirpus* grow on the surface during the maturation period and assist in sludge drying by evapotranspiration. When these plants change colour to brown from green due to desiccation, the sludge may be removed.

APPLICATIONS

Cold digestion / drying lagoons may be used in tropical climates when conditions of rainfall and evaporation permit. Evaporation should exceed rainfall by at least 500 mm for best results. Sludge from conventional activated sludge plants, extended aeration plants may be conveniently processes in CDD lagoons. Primary sludges should not be applied where odours could not be tolerated.

DESIGN CRITERIA

Design criteria are as follows :

- Depth of sludge and water should not exceed 0.7 m
- Area should be 1 square meter per 5 to 20 persons served, depending on climatic conditions.
- Two or more lagoons should be built
- Side slopes should be lined with concrete.
- Access should be provided for sludge removal equipment in the form of an earthen ramp into the interior of the lagoon.

PERFORMANCE EFFICIENCY

Solids concentrations in the dried sludge may be as great as 25-30% for cake 300 mm deep.

DISADVANTAGES

A larger land area is required than for mechanical thickening, digestion, and dewatering. Limited to use in hot climates with a prolonged dry season.

RESIDUALS GENERATED

Excess supernatant water needs to be pumped back to the plant inlet. Dried sludge requires disposal or beneficial use.

OPERATION & MAINTENANCE

CDD lagoons require little operation or maintenance during filling. Sludge is lifted by means of wheeled mini-loaders or agricultural tractors with large wheels depending on the characteristics of the lagoon floor (normally unlined.)

WCR INSTALLATIONS

CDD lagoons have been in use at the Juangriego, Dos Cerritos, and Cruz del Postel plants on Margarita Island in Venezuela since 1989.

REFERENCES

Lansdell 1996.

APPENDIX E.
EXPERTS MEETING INVITEES AND PARTICIPANTS

Appropriate Technology for Sewage Pollution Control
in the Wider Caribbean Region
March 1998

APPENDIX E.

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