Caribbean Regional Fund for Wastewater Management

Assessment of Wastewater Management Technologies in the Wider Caribbean Region

Regional Sectoral Overview of Wastewater Management in the Wider Carubbean Region

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Sustainability Managers

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ASSESSMENT OF WASTEWATER MANAGEMENT TECHNOLOGIES IN THE WIDER CARIBBEAN REGION

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Introduction

The increasing scarcity of water in the world coupled with rapid population growth, particularly in urban areas, is an ever more concerning phenomenon and gives rise to the need for appropriate integrated water resources management practices.

Water supply, sanitation and water management are recognised as global concerns and have become a part of the Millennium Objectives. The Heads of State and Government convened at the United Nations 2000 meeting committed –upon adopting the Millennium Objectives– to reduce by half the proportion of world population without access to drinking water or basic sanitation services, and to do so by the year 2015.

Water is of vital importance to development. The water and sanitation deficit in the Latin American and Caribbean (LAC) region is a major cause for concern. The LAC region possesses 30 percent of the world's water resources; however, large segments of the population live in areas where water –when it exists– is either scarce or polluted. In addition, the distribution of population with respect to these water resources is highly irregular or inequitable. At present, despite the fact that 86 percent of the region's population has access to a source of drinking water, only 49 percent has access to sanitation services (Looker, 1998).

In the LAC region's large urban centres, the lack of appropriate sanitation services has resulted in tremendous health problems for the poorest population. It is estimated that close to 150 of the nearly 510 million inhabitants of the region do not have access to any safe source of water at all, and nearly 250 million do not receive sewerage services (Looker, 1998).

Many Caribbean islands have a low availability of water, and some of the more populated areas are very limited in this resource. For this reason desalinizing plants have played an important role in some countries such as Antigua and Barbuda, the Bahamas and Barbados.

In the cities of the LAC region 13 percent of the population has no access to sanitation services, whereas 7 percent has no access to a source of drinking water. The lack of access to a safe source of water and to sanitation services, together with high population density, generates immense public health problems. In developing nations –where less than 10 percent of wastewater is treated– diarrhoea is one of the primary causes of infant mortality, showing disproportionately high rates in the poor population of these countries. Vector-related disease, such as malaria, also increases in sites containing stagnant wastewater (Looker, 1998).

The disposal of more than 87 percent of municipal wastewater in rivers, lakes, and seas create serious damage to aquatic ecosystems and implies a significant impact to public health; the enormous lack of minimum facilities for the disposal of wastewater contributes significantly to the deterioration of underground water systems, rivers and coastal environments, especially those bodies that have become receptacles for all kinds of waste. A very large proportion of the bodies of water close to cities suffer pollution in varying degrees, sometimes severe. In Mexico, the Advisory Board on Water recognizes that 95% of the country's rivers show some degree of pollution, and has declared the firm intention of treating 50% of Municipal Wastewater by the year 2006.

However, within the WCR, very little investment has been made in sewage treatment facilities in the past; and water supply and treatment often received more priority than wastewater collection and treatment. Currently there is a growing awareness of the impact of sewage contamination on water resources such as rivers and groundwater. Wastewater treatment is now receiving greater attention from development partners in the international community and government regulatory bodies.

It is within this context and against this background that there is a need for a streamlined, integrated approach to wastewater management within the Wider Caribbean Region (WCR). The role of technology in this respect cannot be over-emphasised. According to the World Bank, "The greatest challenge in the water and sanitation sector over the next two decades will be the implementation of low cost sewage treatment that will at the same time permit selective reuse of treated effluents for agricultural and industrial purposes" (Looker, 1998).

One of the failures of conventional treatment technologies currently being used in most WCR is the lack of sustainability. The conventional centralized systems generally use large amounts of scarce water resources to flush domestic wastewater out of residential areas. In turn, the wastewater must be treated and the cost of treatment increases as the flow increases.

Another reason many treatment systems in the region are not successful is that they were copied from treatment systems in developed countries without considering the appropriateness of the technology for the culture, land, and climate. In the end, many of the implemented installations were abandoned due to the high cost of running the system and repairs, and the lack of technical capacity to properly operate and maintain these systems.

According to Looker (1998), the following are the principal challenges facing the sector:

- Meeting the growing demand for municipal wastewater treatment;
- Addressing the public's willingness to pay for water and wastewater services;
- Controlling industrial discharges to sewage-collection systems (that is, indirect discharges);
- Managing sewage sludge;
- Developing viable private-public sector partnerships and feasible privatization schemes, particularly for small- to medium-sized urban centres;
- Ensuring adequate technology transfer and training of municipal authorities;
- Selecting and implementing cost-effective, appropriate technologies from the plethora of options available; and
- Meeting the large financial demand, both in terms of capital costs and for operation and maintenance of water and wastewater systems in the region.

In order to effectively correct these ills, the economic, socio-cultural and environmental setting of countries must first be understood (that is, a Situational Analysis) and the appropriate wastewater solutions placed in context.

This report will look at appropriate wastewater management technologies for the WCR. It has been divided into three sections:

SECTION 1: **Regional Sectoral Overview of Wastewater Management.** This section presents a brief overview of wastewater management in the Wider Caribbean Region (WCR). Special attention is given to the level of regional compliance of existing wastewater systems with Annex III of the Land-Based Sources of Marine Pollution Protocol under the Cartagena Convention and gaps that need to be addressed.

SECTION 2: **Appropriate Treatment Technologies for the Wider Caribbean** – a brief summary of appropriate wastewater management treatment technologies and their extent of use in the WCR are discussed in this section.

SECTION 3: **Barriers to Adopting Alternative Technologies.** This section highlights the main challenges to improving wastewater management in the WCR - the root causes limiting the adoption of appropriate wastewater management interventions in the region and the critical technological barriers to adopting new and innovative wastewater management measures.

SECTION 1: Regional Sectoral Overview of Wastewater Management Technologies in the Wider Caribbean Region

In this section, technologies currently being used in the WCR are discussed within the context of the level of compliance with Annex III of the Protocol on Marine Pollution from Land-Based Sources and Activities (also known as the LBS Protocol) under the Cartagena Convention.

1.1 Overview of Requirements of Annex III LBS Protocol

Annex III of the LBS Protocol sets out specific requirements for signatory countries to the protocol to manage domestic wastewater pollution. This section provides an overview of these requirements and an explanation of their application.

The objective of Annex III is to prevent, reduce and control pollution from domestic wastewater into coastal marine waters of the WCR by managing domestic wastewater discharges. Annex III addresses five domestic wastewater management areas, which are summarized in Table 1.

Table 1: Summary of Domestic Wastewater Management Requirements under Annex III
Discharge of Domestic Wastewater: Regulate domestic wastewater discharges; locate, design, and construct wastewater facilities and outfalls; encourage and promote domestic wastewater reuse and reduction of discharges; promote use of cleaner technologies; and develop plans to implement requirements of Annex III. Compliance should be attained within a 20-year schedule, based on when the respective country signed Annex III.
Effluent Limitations: Ensure that (1) a nation's domestic wastewater management plan is designed to comply with Annex III effluent limitations for Class I and II waters, (2) all discharges take into account impacts associated with total nitrogen and phosphorus requirements, and (3) residual chlorine concentrations and amounts are not toxic to marine organisms.
Industrial Pre-treatment: Develop and implement industrial pre-treatment programmes to manage discharges into new and existing domestic wastewater treatment systems to avert operations damage, population endangerment, sludge contamination, and environmental toxins.
Household Systems: Provide for household system construction, operation, and maintenance of sewage collection in areas without them.
Management, Operations, and Maintenance: Provide for resources, including development of training programmes, development and access to operations manuals, and other technical support for management and system operators to ensure proper system operations.

Discharge of Domestic Wastewater

All discharges of domestic wastewater into the Convention Area are to be regulated. Consequently, Annex III requires that all domestic wastewater discharges impacting the Convention Area, including the marine environment, are to be managed. Annex III is explicit in its requirements to site; design and construct domestic wastewater facilities, household systems, and industrial pre-treatment systems; and encourage and promote pollution prevention practices and use of cleaner technologies.

Effluent Limitations

WCR countries are encouraged to use clean technologies and to site, design and construct wastewater collections and disposal systems which consistently meet the effluent limitations set out in Annex III.

Effluent (discharge) limitations are established in Annex III to regulate discharges into the Convention Area. To comply with the effluent limits, each country must establish a process to classify receiving waters as Class I or II. Application of the domestic wastewater effluent limitations are based on water quality considerations of the receiving water. Table 2 provides the definition of Class I and II waters, as stated in Annex III.

Table 2: Definition of Class I and II Waters

Class I Waters

Waters in the Convention Area that, because of inherent or unique environmental characteristics or fragile biological or ecological characteristics or human use, are particularly sensitive to the impacts of domestic wastewater. Class I waters include, but are not limited to the following:

- Waters containing coral reefs, seagrass beds, or mangroves
- Critical breeding, nursery, or forage areas for aquatic and terrestrial life
- Areas that provide habitat for species protected under the Protocol Concerning Specially Protected Areas and Wildlife to the Convention (the SPAW Protocol).
- Protected areas listed in the SPAW Protocol
- Waters used for recreation

Class II Waters

Waters in the Convention area, other than Class I water, that because of oceanographic, hydrologic, climatic, or other factors, are less sensitive to the impacts of domestic wastewater, and where humans and living resources that are likely to be adversely affected by the discharges are not exposed to such discharges.

<u>Discharges into Class II Waters</u>

Annex III states that "each Contracting Party shall ensure that domestic wastewater that discharges into, or adversely affects, Class II waters is treated by a new or existing domestic wastewater system whose effluent achieves the following effluent limitations based on a monthly average:

Table 3: Effluent limits for Class II

Parameter	Effluent Limit
Total Suspended Solids	150 mg/l*
Biochemical Oxygen Demand (BOD5)	150 mg/l
pH	5-10 pH units
Fats, Oil and Grease	50 mg/l
Floatables	not visible
* Does not include algae from treatment ponds	

Discharges into Class I Waters

Annex III specifies that "each Contracting Party shall ensure that domestic wastewater that discharges into, or adversely affects, Class I waters is treated by a new or existing domestic wastewater system whose effluent achieves the following effluent limitations based on a monthly average:

Table 4: Effluent limits for Class I Waters

Parameter	**Effluent Limit**
Total Suspended Solids (TSS)	30 mg/l*
Biochemical Oxygen Demand (BOD)	30 mg/l
pH	5-10 pH units
Fats, Oil and Grease	15 mg/l
Faecal Coliform (Parties may meet effluent limitations either for faecal coliform or for E. coli (freshwater) and enterococci (saline water).)	Faecal Coliform: 200 mpn/100 ml; or a. *E. coli*: 126 organisms/100ml; b. *Enterococci*: 35 organisms/100 ml
Floatables	not visible
* Does not include algae from treatment ponds	

Annex III of the LBS Protocol further mandates contracting parties to take into account the impact that total nitrogen and phosphorus and their compounds may have on the degradation of the Convention area and, to the extent practicable, take appropriate measures to control or reduce the amount of total nitrogen and phosphorus that is discharged into, or may adversely affect, the Convention area.

Effluent limitations for nutrients, primarily nitrogen and phosphorous are not specifically addressed by Annex III, but reducing these pollutants will benefit the region's water bodies. Because treating nutrients is technically challenging and costly, development of pollution standards (e.g. sewage effluent standards) and promotion best available technologies1 can be important strategies in the control of these pollutants.

1 Article I of the LBS Protocol defines "best available technology" as "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 LBS Protocol.

Industrial Pre-Treatment

A number of industries discharge waste to domestic wastewater systems. In most cases, industrial pollution poses greater risk to public health than pathogenic organisms. Therefore, industrial pre-treatment is vitally important and such programmes must be able to isolate industrial toxins, pathogens, carbon, and nutrients (Rose, 1999) prior to discharge into domestic wastewater systems.

In view of the toxic effects of some industrial waste, Annex III establishes general requirements for pre-treatment for industrial wastewater that is discharged to a domestic wastewater system.

Each country should consider whether separate treatment for these wastes or a higher degree of treatment at the point of origin needs to be enforced. Regulation of domestic wastewater should provide management measures to ensure that industrial discharges do not hinder the operation of new and existing domestic wastewater systems and that toxics are not introduced into the Convention Area that could harm human health and the environment.

Household Systems

On-site household systems are common in small communities and communities where municipal sewerage has not been economically feasible. Household systems may also be appropriate alternatives when rock substrate or topography makes other options impractical. Annex III encourages installation of cost-effective and environmentally acceptable systems that prevent direct or indirect pollution to the Convention Area. Discharges of household systems should also be properly treated to prevent impacts to the Convention Area.

In urban areas, household systems often can be eliminated by sanitary sewer connections, but in rural areas the most economically feasible solution would be individual or combined septic tanks. However, proper maintenance must be applied to extend the life of the septic tanks; otherwise, they will eventually overflow and discharge to the nearest down gradient body of water.

Management, Operations and Maintenance

Annex III requires that domestic wastewater systems are properly maintained, operated, and managed. Management should include a diverse set of measures such as forecasting and allocating the appropriate level of funding for operation and maintenance activities; technology, equipment, and human resources; and other activities such as training for operators, system inspection to evaluate the facilities, associated infrastructure, and management programme’s effectiveness.

1.2 Overview of Current Wastewater Management Practice and Technology Use

This brief assessment of current sewage collection and treatment practices, including the types of technologies in use today, is presented within the context of compliance with Annex III of the LBS Protocol.

Although the goal of contracting countries is to progressively meet the requirements of the LBS Protocol in the development and implementation of sewage systems, it must be acknowledged that many of the existing systems are neither complete nor ideal. However, where they are cost-effective and environmentally acceptable, the region will incrementally make progress towards improving existing water quality.

Summary of Sewage Collection and Treatment Practices and Effects in the WCR

The following table was adopted from UNEP-CEP Technical Report No. 40 entitled "Appropriate Technology for Sewage Pollution Control in the Wider Caribbean Region". It summarises sewage collection and treatment practices and effects in the Wider Caribbean Region.

Table 5: Summary of Sewage Collection and Treatment Practices and Effects in the WCR

Country	Degree of Collection	Degree of Treatment/ Type of Treatment Prevalent	Problems	Monitoring Programmes and Standards
Bahamas	15.6% of population	Deep well injection of raw sewage; 44percent 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; 54percent 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; 46percent 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	STW for Bridgetown, outfall for	Nutrients in coastal	Coastal Zone Management Unit &

Country	Degree of Collection	Degree of Treatment/ Type of Treatment Prevalent	Problems	Monitoring Programmes and Standards
	Bridgetown, South Coast system under construction	South Coast, remainder of island - septic tanks and soakaway pits or suck wells. Few package plants at hotels.	zone impacting coral reefs. High coliform counts in some coastal areas.	Environmental Engineering Unit monitor swimming areas for faecal coliform.
Grenada	1 for city of St. George	Virtually no treatment in some areas; about 60percent 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
Antigua & Barbuda	Mostly for hotels	Numerous hotel package plants; 48percent 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 and European countries.
Dominican Republic	25% of urban population (in 1979)	Sewage discharge into sea		

Country	Degree of Collection	Degree of Treatment/ Type of Treatment Prevalent	Problems	Monitoring Programmes and Standards
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.	
Haiti	None	40% population (mostly urban) uses latrines and septic tanks; 41percent urban + 12percent rural have acceptable disposal means 80-90percent 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; 25percent 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 95percent of coastal population	4 have primary treatment (10percent of coastal population); 2 systems discharge raw sewage (85percent 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; 10percent 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.
Venezuela	65 percent served	3 percent 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.

Source: (UNEP-CEP, 1998)

Discharge of Domestic Wastewater in the Wider Caribbean Region

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 (UNEP-CEP, 2003). In addition, the World Health Organisation (WHO) and UNICEF Joint Monitoring Programme (2000) estimates that 20 percent of the population in the large cities within the LAC region goes without wastewater disposal (Figure 1).

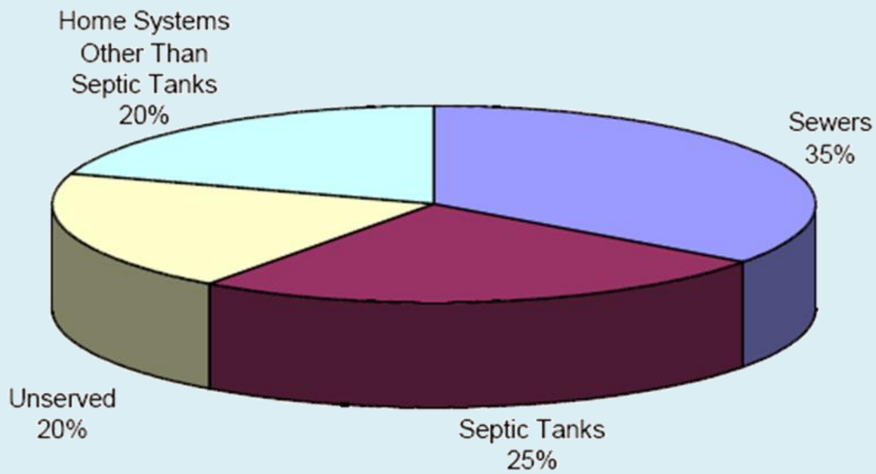

Figure 1: Type of Sanitation Service Provided in Largest Cities in Latin America and the Caribbean (WHO and UNICEF Joint Monitoring Programme, 2000)

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. Instead, residents rely on on-site disposal systems such as pit privies, latrines, or septic tanks. 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. It is generally believed that the absence of large centralised sewer systems has resulted in the proliferation of package sewage treatment plants (CEHI, 1992).

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 (UNEP-CEP, 2003)2:

- 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.

Generally decentralized systems were more cost effective in rural areas where the distance between households were greater and the cost of a centralized system for collection and treatment would be more expensive (within the context of technical and environmental suitability) (UNEP-CEP, 2003).

Sound environmental technologies as well as those that were commonly employed throughout the region, include: conventional sewerage, wastewater collection and transfer, wastewater treatment (on-site; centralized, decentralized); wastewater reuse, wastewater disposal systems; residuals management; “zero” discharge, sludge management.

According to UNEP/GPA (2006), the high costs of building and maintaining traditional sewage treatment plants are frequently the reason for not treating sewage before its disposal. Nevertheless, biological methods of treatment are available for sewage that is not contaminated with industrial waste and which are suitable to the tropical character of the Caribbean region.

Low-cost, low-technology options for the management of domestic sewage are the most appropriate technologies for domestic and industrial sewage pollution control in the WCR (UNEP-CEP, 1998). Some of these are discussed in Section 2.

The reuse of effluent, which is shown to be effective in flow reduction, is applied only to a limited extent in the Caribbean and only where freshwater resources are scarce (CEHI, 1992).

Effluent Limitations

From the table below, it is clear that standards for certain critical parameters vary from country to country across the WCR. The following observations were made:

- Trinidad is the only country which sets separate standards for environmentally sensitive (Class I) and non-sensitive areas (Class II);

2 The percentages do not sum to 100 in the original.

- Cuba, Guadeloupe and Venezuela set lower limits for BOD. At >80 mg/l, the BOD limits for existing plants in Columbia, is well below the guidelines specified in Annex III;
- Only Jamaica and Venezuela have a standard for residual chlorine;
- The pH standard for all countries that specify it, is in line with Annex III; and
- Similarly, the faecal coliform standard applied by most countries complies with Annex III requirements.

Table 6: Effluent Guidelines and Standards for Selected Countries in the Wider Caribbean Region

	BOD_5 mg/l	TSS mg/l	pH	F-Coli #/100 ml	T-Coli #/100 ml	Res. Cl mg/l
Bahamas[2]	<30	<30	6-9	+>85% removal of BOD and TSS		
Barbados	<25	<25				
Cayman Islands	<30	<30	(disposed by deep well injection)			
Columbia[3]	>30%	>30%	6-9			
Colombia[4]	>80%	>80%	6-9			
Cuba	<50	<50	6.5-8.5	<200	<2000	
Guadeloupe[6]	<40	<30				
Honduras	<30	<30	6-9	+>85% removal of BOD and TSS		
Jamaica	<20	<30		<200		<1.5
Panama	>80%	>80%				
Puerto Rico	<30	<30	6-9	+>85% removal of BOD and TSS		
St. Lucia	<25	<30				
Trinidad[7]	<25	<30	6-9	<200		
Trinidad[8]	<125	<175	6-9	<400		
Venezuela	<40	<50	6-9	<200	<1000	<0.5

[2] EPA standards have been adopted in the Bahamas, Honduras and Puerto Rico
[3] Existing treatment plant, in percent removal from influent
[4] New treatment plant, in percent removal from influent
[5] Guidelines-use water quality base approach
[6] Effluents from aerated lagoons
[7] For discharge into inshore seas and environmentally sensitive areas
[8] For discharge into environmentally non-sensitive areas

Source: UNEP-CEP, 2009

Management, Operations and Maintenance

The broad conclusion of the Assessment of Operational Status of Wastewater Treatment Plants in the Caribbean (CEHI, 1992) study was that the performance of the treatment plants was generally poor, and this was accounted for as a result of poor maintenance and management owing to poor financial resources for these activities.

The causes of failure of many wastewater treatment facilities include the use of inappropriate technology, poor operation and maintenance practices, and insufficient funding and skilled personnel3.

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3 Directory of Environmentally Sound Technologies for the Integrated Management of Solid Liquid and Hazardous Waste for SIDS in the Caribbean Region (2004)

Roughly two-thirds of 303 treatment plants in CARICOM countries in 1992 were located in Jamaica and Trinidad and Tobago. A survey collected data on 138 treatment facilities (i.e. 46 percent) revealed that 25 percent were operating in good condition, 36 percent were operating moderately and 22 percent were operating poorly, while 13 percent were not operational (CEHI, 1992).

Of the plants surveyed there was a relationship between the operational responsibility and operational status indicating that 59 percent of the plants were privately owned and operated of which the majority was owned by hotels and resorts. The national water and sewerage utility companies (NWSUs) operated about 25 percent of the wastewater treatment facilities and operated their plants better than the private and Government sector.

Most operators had no formal training (72 percent), but had knowledge of wastewater treatment through on the job training, private studies and experience. A 7 percent higher score for good operating plants with certified operators was observed compared to the plants with non-certified operators and a 6 percent higher score for moderately operational plants (CEHI, 1992).

The lack of test results for operational parameters presented severe constraints for proper operational management and control as well as plant monitoring and inspection. Laboratory testing facilities were generally limited to field tests like residual chlorine. The NWSUs monitored 24 percent of the plants, the governmental departments monitored 23 percent and in 5 percent of the cases samples were sent to private laboratories. Only in 13 cases (9 percent) were analyses performed onsite (CEHI, 1992).

A 1992 report prepared by CEHI (Assessment of Operational Status of Wastewater Treatment Plants in the Caribbean) presented a number of interrelated reasons for the low status of operation of treatment plants included the lack of adequate regulations and approval procedures; inspection procedures and programmes; financial resources allocations; operational skills and process understanding; operation and maintenance manuals; operational support and service contracts; maintenance and absence of preventative maintenance; process monitoring and inadequate laboratory facilities; inappropriate selected technologies; and unavailability of spare parts.

The most common scenario is typified by tourist resorts maintaining their own collection and treatment facilities. These plants do not comply with the criteria for good operation due to:

- Application of technologies that require high levels of skilled human resources and energy input in operation and maintenance;
- Inadequate operating skills and limited understanding of treatment processes and insufficient process monitoring;
- Insufficient time allocation to maintenance;

- Insufficient operational support through operation and maintenance contracts;
- Insufficient funds allocation;
- Inadequate disposal facilities for excess sludge.

SECTION 2: Appropriate Treatment Technologies for the Wider Caribbean Region

2.1 General Selection Criteria and Specifications of Appropriate Technologies for Domestic Wastewater Treatment and Disposal

The first step in the selection of best suited or most appropriate technology for the treatment and disposal of domestic wastewater, is an assessment of needs, which would involve a review of existing systems in use and projections of future needs of the population/ community. This is followed by an evaluation of treatment options, including an evaluation of the potential for flow reduction and determination of a decentralised versus centralised system. The final analysis should bear in mind several factors to arrive at the most appropriate wastewater treatment option.

Existing Systems and Projects of Future Needs

An assessment of existing and future domestic wastewater management systems needs involves several steps (UNEP-CEP, 2003) and consideration of several important factors which bear on the successful outcome of the intervention. The population that needs to be served should be estimated based on projections of existing and future growth.

Communities should be described in terms of projected waste per household, population densities, current costs of domestic wastewater collection, treatment, and disposal, and percentage and types of systems in place such as (1) central sewage systems or (2) septic tanks, cesspools, or other on-site systems for excreta disposal.

The level of treatment and extent of domestic wastewater management systems with any treatment should be assessed. An assessment should be made of industrial dischargers, presence, types, and quantities of dischargers into domestic wastewater treatment systems.

Some additional information needs include a summary of the socio-economic and cultural considerations, the environmental characteristics, such as issues of water availability, siting concerns such as, flood plains, meteorology, geology, climate, and prevalence and profile of human settlements.

This baseline information is then used to project future needs, based on considerations of flow reduction and decentralised vs. centralised system.

Flow Reduction

One of the first considerations in assessing domestic systems is evaluating flow reduction methods. An extensive array of techniques and devices are available to reduce wastewater flows generated by individual water-using activities. Flow reduction has an impact on the volumes of wastewater being produced as well as the characteristics of the wastewater.

The technology design selected should reduce the flow volume or decrease the mass of key pollutants in the influent wastewater. This in turn may impact the type of domestic wastewater system implemented. For example, a semi-rural town may be producing high volumes of wastewater. While a collection and treatment system would be feasible, if flow reduction techniques are implemented, household systems may be a least expensive and environmentally viable option.

Decentralised vs. Centralised

The second consideration in assessing domestic systems is to determine if decentralised or centralised treatment systems are feasible. If there are no existing collection and treatment systems, a cost feasibility needs to be performed to determine if a centralized collection and treatment system is appropriate, or if a decentralized treatment system in appropriate.

Since centralized systems require collection of wastewater and treatment for an entire community at substantial cost, decentralized systems, when properly installed, operated and maintained can achieve significant cost savings while recharging local aquifers and providing water reuse opportunities.

When considering whether decentralized or centralized system is suitable, the following factors need to be considered:

- Capital costs
- Operation and Maintenance costs
- Space available for treated wastewater
- Site Conditions

Cost analysis performed have indicated that decentralised systems are generally a cost-effective means of managing wastewater in rural communities due to the distance between homes and land available.

The selected household system must also be environmentally acceptable. For example, a cesspit is cost-effective, but not as environmentally-acceptable as other alternatives.

In small communities and fringe areas of metropolitan cities, the most cost-effective solution depends on population density, distance to the sewer interceptor, and availability of land. The centralized alternative can be competitive with decentralized options in fringe areas, where the distance to the intercepting sewer is less and the receiving water body can accommodate the additional waste load.

In addition, the cost of failure for centralised systems can be far greater, given that all wastewater is concentrated at a central location. Once the decision has been made to move towards either a centralised or decentralised system, the focus can be turned to managing the necessary domestic wastewater systems.

Analysis

Once existing and potentially viable approaches to addressing domestic wastewater system needs are identified, the final analysis should involve the evaluation and development of recommendations and options based on criteria such as local conditions, effectiveness, availability, cost-effectiveness, environmental acceptability, and stakeholder acceptability.

2.2 Review of Appropriate Wastewater Treatment Technologies and the Extent of Use in the Wider Caribbean Region

There are numerous technologies to deal with the disposal of wastewater throughout the world. Many of these technologies have been used in the Caribbean but, for many reasons have failed because of: inappropriate technology, insufficient operation and maintenance practices, lack of funding and lack of skilled personnel, to name a few. This section will focus on proven sound environmental technologies plus those currently used in the Caribbean, grouped under the following headings.

- Wastewater Collection and Transfer
- Wastewater Treatment (On-site)
- Wastewater Treatment (Centralised and Decentralised)
- Wastewater Reuse
- Wastewater Disposal Systems
- Residuals Management
- "Zero" Discharge

Relatively simple wastewater treatment technologies can be designed to provide low cost sanitation and environmental protection while providing additional benefits from the reuse of water. These include both on-site and off-site treatment systems. Many of these technologies are in use in a number of locations throughout Latin America and the Caribbean.

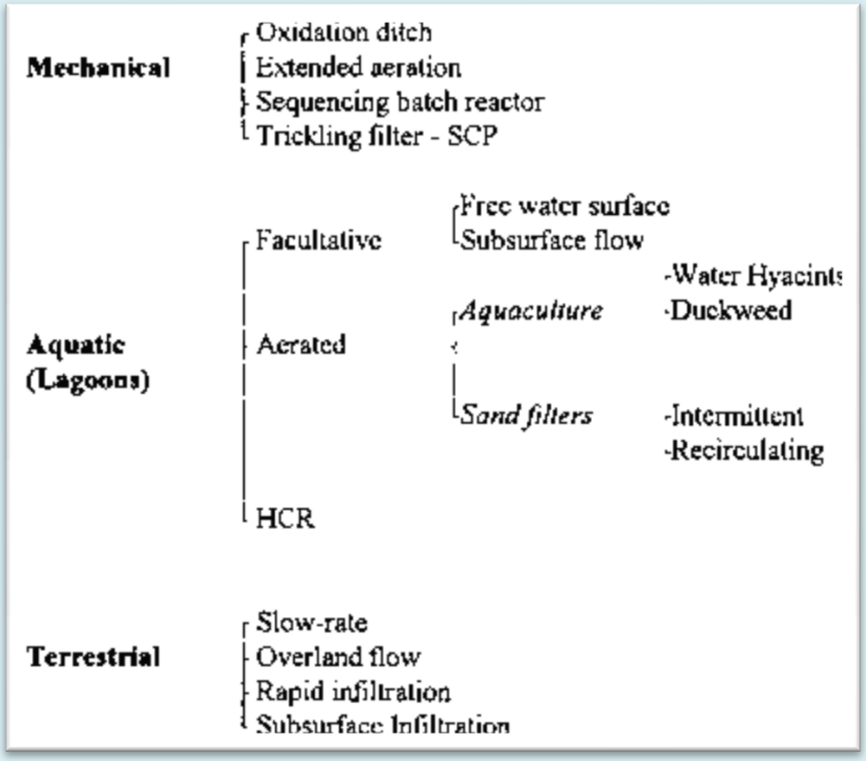
2.2.1 Off-Site Systems

These systems may be classified into three principal types, as shown in Figure 2. **Mechanical treatment systems**, which use natural processes within a constructed environment, tend to be used when suitable lands are unavailable for the implementation of natural system technologies.

Aquatic systems are represented by lagoons; facultative, aerated, and hydrograph controlled release (HCR) lagoons are variations of this technology. Further, the lagoon-based treatment systems can be supplemented by additional pre- or post-treatments using constructed wetlands, aqua-cultural production systems, and/or sand filtration. They are used to treat a variety of wastewaters and function under a wide range of weather conditions.

Terrestrial systems make use of the nutrients contained in wastewaters; plant growth and soil adsorption convert biologically available nutrients into less-available forms of biomass, which is then harvested for a variety of uses, including methane gas production, alcohol production, or cattle feed supplements.

Figure 2: Summary of Wastewater Treatment Technologies



Source: UNEP, 1997

Mechanical Treatment Technologies

Mechanical systems utilize a combination of physical, biological, and chemical processes to achieve the treatment objectives. Using essentially natural processes within an artificial environment, mechanical treatment technologies use a series of tanks, along with pumps, blowers, screens, grinders, and other mechanical components, to treat wastewaters. Flow of wastewater in the system is controlled by various types of instrumentation.

Sequencing batch reactors (SBR), oxidation ditches, and extended aeration systems are all variations of the activated-sludge process, which is a suspended-growth system. The trickling filter solids contact process (TF-SCP), in contrast, is an attached-growth system. These treatment systems are effective where land is at a premium.

Mechanized cleaning of screens, DOWASCO Wastewater

Manually cleaned screens/bar rack – St. George's University Grenada – Daniel & Daniel Engineering Inc

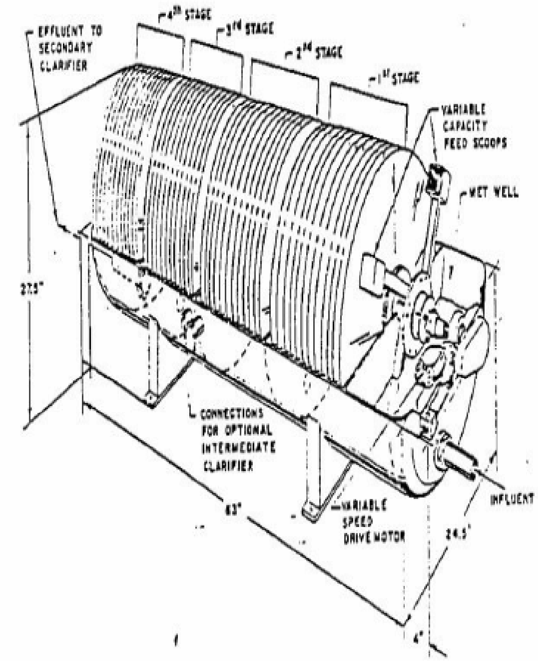
<table>
<tr>
<td>Package Plant
ROTATING BIOLOGICAL CONTACTORS


Figure 9.2. Typical configuration of RBC system (U.S.EPA, 1985)</td>
<td>Technology Description:

A rotating biological contactor consists of closely spaced circular disks of polystyrene or polyvinyl chloride. The disks are submerged in wastewater and rotated slowly through it.

In operation, biological growth becomes attached to the surfaces of the disks and eventually forms a slime layer over the entire wetted surface area of the disks. The rotation of the disks alternately contacts the biomass with the organic material in the wastewater and then with the atmosphere for adsorption of oxygen. The disk rotation affects oxygen transfer and maintains biomass in an aerobic condition. The rotation is also the mechanism for removing excess solids from the disks by shearing forces it creates and maintaining the sloughed solids in suspension so they can be carried from the unit to a clarifier. Rotating biological contactors can be used for secondary treatment, and they can also be operated in seasonal and continuous–nitrification and denitrification modes.

Extent of Use: Not widely used in the Caribbean. Used unsuccessfully in St. Lucia and St. Kitts</td>
</tr>
<tr>
<td colspan="2">Operation and Maintenance: Skilled labour is required</td>
</tr>
<tr>
<td>Advantages:
• High Effluent Quality</td>
<td>Disadvantages /constraints:
• Energy requirement is high
• Highly skilled labour is required for O&M</td>
</tr>
<tr>
<td>Relative Cost:
• High Capital Cost
• High Operation & Maintenance cost</td>
<td>Cultural Acceptability:
• Widely accepted in the Caribbean</td>
</tr>
<tr>
<td>Energy Cost:
• Energy is required on a 24/7 basis for bacterial activity</td>
<td>Pollution Reduction:
• >85 % removal of Organic Matter and Suspended Solids
• high levels of nutrient removal</td>
</tr>
<tr>
<td colspan="2">Suitability:
• Suitable for most situations – Housing Development, Industries, Institutions etc.</td>
</tr>
</table>

<table>
<tr><td colspan="2">Package Plant Types

Plant Type

Sequential Batch Reactors (Source: Cromaglass)


Technology Description:

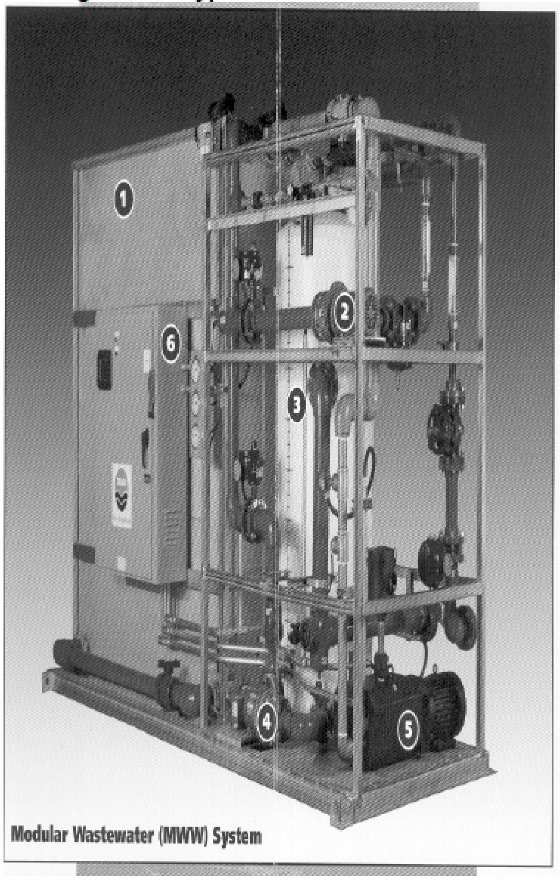
The Cromaglass Systems are essentially Sequencing Batch Reactors where treatment is by timed sequences within a single vessel. The unit consists of 3 sections each performing a different task. In the first section (A) aeration occurs (Solids Retention).</td><td colspan="2">Technology Description continued

This section is separated from the rest of the unit by a non-corrosive screen, which retains inorganic solids. Organic solids are broken up by turbulence created with mixed liquor being forced through the screen by a submersible aeration pump. Section (B) is the continuing Aeration section where air and mixing are provided by pumps. An optional denitrification is performed under anoxic conditions by closing off air-to-air intake pumps, thus stopping aeration but allowing continual mixing. The liquid is then transferred to section (C) the Clarification Section. When the clarification section is overfilled excess is spilled back into the aeration section. After this process, the clarifier is then isolated, solids settle and separate and effluent is pumped out of the Clarifier for discharge. Sludge is removed to a sludge processing unit.

Treatment achieves over 90-95% reduction of BOD and Suspended Solids. The resulting effluent quality has BOD5 – 30mg/L, Total Suspendable Solids 30mg/L.

Extent of Use: Limited use in the Caribbean Region. Growing use in Antigua, St. Kitts, Trinidad & Tobago, Barbados, and St. Lucia</td></tr>
<tr><td colspan="4">Operation and Maintenance:
• High operation and maintenance.
• High technology requiring skilled installation</td></tr>
<tr><td>Advantages:
• Low land space required
• High effluent quality
• Agents available within the region</td><td colspan="3">Disadvantages /constraints:
• High operation and maintenance
• Requires electricity
• High technology requiring skilled operation and maintenance inputs.</td></tr>
<tr><td>Relative Cost:
• High</td><td colspan="3">Cultural Acceptability:
• Is generally accepted within the Caribbean Region</td></tr>
<tr><td colspan="4">Suitability:
• Since only receives liquid waste, not suitable where water scarce or unreliable.
• Where skilled technical backup is available</td></tr>
</table>

Package Plant Type: Membrane Bioreactor



Modular Wastewater (MWW) System

Technology Description:

Membrane Bioreactor Systems utilise filtration technology to replace the traditional secondary clarifier and sand filters in conventional secondary treatment systems. Typically these can be engineered to meet the needs of wastewater treatment and water reuse plants, with average daily flows of less than 100,000 gpd to over 1 mgd.

ZeeMOD™ is constructed around four basic building blocks: the biological treatment reactor, a fine screen trash interceptor, the modular membrane units, and the pre-assembled equipment skid.

Typical Treated Water Results:

BOD	< 5 mg/L
TSS	< 5 mg/L
TN	< 5 mg/L
TP	< 5 mg/L
Turbidity	< 1 NTU

Extent of Use:
Increasing use in the Caribbean region

Operation and Maintenance:

- Moderate operation and maintenance costs
- Requires minimal operator supervision

Advantages:

- Extremely low space requirements
- Consistent high quality effluent
- High tolerance of cyclic and/or shock loadings
- Agents available within the region

Disadvantages /constraints:

- Requires a reliable water supply
- Requires electricity

Relative Cost:

- Moderate

Cultural Acceptability:

- Increasing acceptance within the region.

Suitability:

- Wherever water reuse is desired or where efficient high quality treatment is required.

Aquatic Treatment Technologies

Facultative lagoons are the most common form of aquatic treatment-lagoon technology currently in use. The water layer near the surface is aerobic while the bottom layer, which includes sludge deposits, is anaerobic. The intermediate layer is aerobic near the top and anaerobic near the bottom, and constitutes the facultative zone.
Aerated lagoons are smaller and deeper than facultative lagoons. These systems evolved from stabilization ponds when aeration devices were added to counteract odours arising from septic conditions. The aeration devices can be mechanical or diffused air systems.

The chief disadvantage of lagoons is high effluent solids content, which can exceed 100 mg/l. To counteract this, hydrograph controlled release (HCR) lagoons are a recent innovation. In this system, wastewater is discharged only during periods when the stream flow is adequate to prevent water quality degradation. When stream conditions prohibit discharge, wastewater is accumulated in a storage lagoon. Typical design parameters are summarized in Table x.

Constructed wetlands, aquacultural operations, and sand filters are generally the most successful methods of polishing the treated wastewater effluent from the lagoons. These systems have also been used with more traditional, engineered primary treatment technologies such as Imhoff tanks, septic tanks, and primary clarifiers. Their main advantage is to provide additional treatment beyond secondary treatment where required.

In recent years, constructed wetlands have been utilized in two designs: systems using surface water flows and systems using subsurface flows. Both systems utilize the roots of plants to provide substrate for the growth of attached bacteria which utilize the nutrients present in the effluents and for the transfer of oxygen. Bacteria do the bulk of the work in these systems, although there is some nitrogen uptake by the plants. The surface water system most closely approximates a natural wetland.

Typically, these systems are long, narrow basins, with depths of less than 2 feet, that are planted with aquatic vegetation such as bulrush *(Scirpus* spp.) or cattails *(Typha* spp.). The shallow groundwater systems use a gravel or sand medium, approximately eighteen inches deep, which provides a rooting medium for the aquatic plants and through which the wastewater flows.

Table 7: Typical Design Features Aquatic Treatment Units

Technology	Treatment goal	Detention Time (days)	Depth (feet)	Organic Loading (lb/ac/day)
Oxidation pond	Secondary	10-40	3-4.5	36-110
Facultative pond	Secondary	25-180	4.5-7.5	20-60
Aerated pond	Secondary, polishing	7-20	6-18	45-180

Technology	Treatment goal	Detention Time (days)	Depth (feet)	Organic Loading (lb/ac/day)
Storage pond, HCR pond	Secondary, storage, polishing	100-200	9-15	20-60
Root zone Treatment, Hyacinth pond	Secondary	30-50	<4.5	<45

Source: UNEP-CEP, 1997

Aquaculture systems are distinguished by the type of plants grown in the wastewater holding basins. These plants are commonly water hyacinth *(Eichhornia crassipes)* or duckweed *(Lemna* spp.). These systems are basically shallow ponds covered with floating plants that detain wastewater at least one week. The main purpose of the plants in these systems is to provide a suitable habitat for bacteria which remove the vast majority of dissolved nutrients. The design features of such systems are summarized in Table 8.

Table 8: Typical Design Features for Constructed Wetlands

Design Factor	Surface water flow	Subsurface water flow
Minimum surface area	23-115 ac/mgd	2.3-46 ac/mgd
Maximum water depth	Relatively shallow	Water level below ground surface
Bed depth	Not applicable	12.30m
Minimum hydraulic residence time	7 days	7 days
Maximum hydraulic loading rate	0.2-1.0 gpd/sq ft	0.5-10 gpd/sq ft
Minimum pretreatment	Primary (secondary optional)	Primary
Range of organic loading as BOD	9-18 lb/ac/d	1.8-140 lb/ac/d

Source: UNEP-CEP, 1997

Sand filters have been used for wastewater treatment purposes for at least a century in Latin America and the Caribbean. Two types of sand filters are commonly used: intermittent and re-circulating. They differ mainly in the method of application of the wastewater. Intermittent filters are flooded with wastewater and then allowed to drain completely before the next application of wastewater. In contrast, re-circulating filters use a pump to re-circulate the effluent to the filter in a ratio of 3 to 5 parts filter effluent to 1 part raw wastewater.

Both types of filters use a sand layer, 2 to 3 feet thick, underlain by a collection system of perforated or open joint pipes enclosed within graded gravel. Water is treated biologically by the epiphytic flora associated with the sand and gravel particles, although some physical filtration of suspended solids by the sand grains and some chemical adsorption onto the surface of the sand grains play a role in the treatment process.

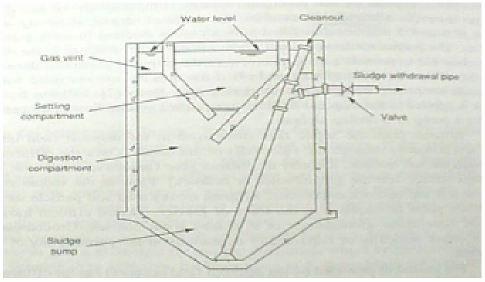
In wetland treatment, natural forces (chemical, physical, and solar) act together to purify the wastewater, thereby achieving wastewater treatment. A series of shallow ponds act as stabilization lagoons, while water hyacinth or duckweed act to accumulate heavy metals, and multiple forms of bacteria, plankton, and algae act to further purify the water. Wetland treatment technology in developing countries offers a comparative advantage over conventional, mechanized treatment systems because the level of self-sufficiency, ecological balance, and economic viability is greater. The system allows for total resource recovery.

Lagoon systems may be considered a low-cost technology if sufficient, non-arable land is available. However, the availability of land is not generally the case in big cities. The demand of flat land is high for the expanding urban developments and agricultural purposes.

The decision to use wetlands must consider the climate. There are disadvantages to the system that in some locations may make it unsustainable. Some mechanical problems may include clogging with sprinkler and drip irrigation systems, particularly with oxidation pond effluent. Biological growth (slime) in the sprinkler head, emitter orifice, or supply line cause plugging, as do heavy concentrations of algae and suspended solids.

<table>
<tr><td>Primary Process

Imhoff Tanks


</td><td colspan="2">Technology Description:

Imhoff tanks are used for domestic or mixed wastewater flows. The Imhoff Tank consists of a two-story tank in which sedimentation is accomplished in the upper compartment and digestion of the settled solids is accomplished in the lower compartment.

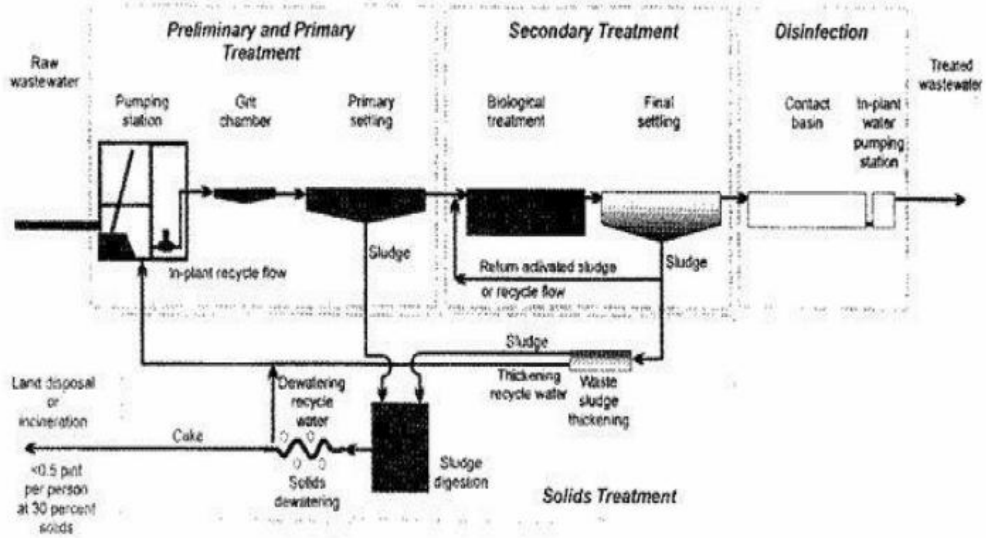
The Imhoff tank is divided into an upper settling compartment in which sedimentation of solids occurs. Sludge then falls through an opening at the bottom into the lower tank where it is digested anaerobically. Methane gas is produced in the process and is prevented from disturbing the settling process by being deflected by baffles into the gas vent channels. Effluent is odourless because the suspended and dissolved solids in the effluent do not come into contact with the active sludge causing it to become foul. When sludge is removed it needs to be further treated in drying beds or other such device, for pathogen control.

The treatment efficiency is equivalent to primary treatment. It can achieve 40% BOD reduction, 65% Suspended solids reduction.

Extent of Use:
• Limited use in the Caribbean Region (for example, Jamaica)</td></tr>
<tr><td colspan="3">Operation and Maintenance:
• Requires removal of scum and sludge at regular intervals.</td></tr>
<tr><td colspan="2">Advantages:
• Improved effluent quality compared to a sedimentation basin
• Can handle variance in organic loading
• Low land space required
• Produces stablised sludge
• No energy required
• Excellent primary treatment</td><td>Disadvantages /constraints:
• Effluent requires tertiary treatment</td></tr>
<tr><td colspan="2">Relative Cost:
• Low capital cost
• Low operation cost</td><td>Cultural Acceptability:
• Is generally accepted within the Caribbean Region</td></tr>
<tr><td colspan="2">Energy Usage:
• Energy generated but not captured</td><td>Pollution Reduction:
• >50% BOD and SS removal</td></tr>
<tr><td colspan="3">Suitability/Appropriateness
• Relatively small scale on site industrial waste and sewage</td></tr>
</table>

Secondary Process

Activated Sludge Treatment
Source: *Water and wastewater Technology* by Mark Hammer,



Daniel & Daniel Engineering compliments US consulting Firm

Technology Description:

The Activated Sludge Process was developed in England in 1914 by Arden and Lockett and was so named because it involved the production of an activated mass of micro-organisms capable of stabilizing a waste aerobically.

Operationally, biological waste treatment with the Activated Sludge Process uses an aeration basin and a secondary clarifier. Organic waste is introduced into a reactor where an aerobic bacterial culture is maintained in suspension. The reactor contents are referred to as the "mixed liquor." In the reactor, the bacterial culture carries out the conversion of organic matter and nutrients utilizing oxygen to produce new bacterial cells. The new bacterial cells are further converted to carbon dioxide, water, ammonia and energy.

The aerobic environment in the reactor is achieved by the use of diffused or mechanical aeration, which also serves to maintain the mixed liquor in a completely mixed regime. After a specific period of time, the mixture of new cells and old cells is passed into a settling tank, where the cells are separated from the treated wastewater. A portion of settled cells is recycled to maintain the desired concentration of organisms in the reactor, and a portion is wasted.

There are various types of activated sludge processes. These are complete mix, conventional, Step aeration, Pure Oxygen, Sequencing batch reactor, Contact Stabilization, Extended Aeration and Oxidation Ditch.

Extent of Use: Widely used in the Caribbean

Operation and Maintenance: Skilled labour is required

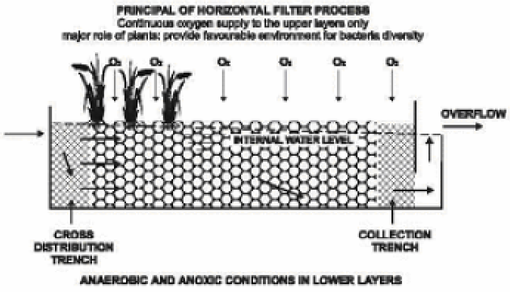
Advantages: • High Effluent Quality	**Disadvantages /constraints:** • Energy requirement is high • Highly skilled labour is required for O&M
Relative Cost: • High Capital Cost • High Operation & Maintenance cost	**Cultural Acceptability:** • Widely accepted in the Caribbean
Energy Cost: • Energy is required continuously for bacterial activity	**Pollution Reduction:** • >80 % removal of Organic Matter and Suspended Solids

Suitability:

- Suitable for most situations – Housing Developments, Industries, Institutions etc.

<table>
<tr>
<td rowspan="2">Tertiary Process

Constructed wetland (Reed bed system/Subsurface flow/Wetlands/Root zone treatment plants/Horizontal Gravel Filter)


</td>
<td>Technology Description:

Wetland systems are suitable for domestic and industrial wastewater that has undergone primary and/or secondary treatment and has a COD content less than 500mg/L. The reed bed system consists of a 1m deep basin sealed with clay or some other form of lining to prevent percolation into groundwater with the basin itself being filled with graded aggregate in which reeds are then planted. Types of reeds utilized in the Caribbean region are bullrush, cattail etc.

Oxygen is transported through the pores of the plant down to the roots whereby the oxygen content increases the biological activity of the soil. When wastewater passes through the root zone and aggregates, organic compounds, nutrients and pathogenic organisms are eliminated.

The effluent quality achieved is up to 85% BOD and COD removal, greater than 95% pathogen removal with significant nutrient content removed</td>
</tr>
<tr>
<td>Extent of Use:
Moderate use within the Caribbean Region (for example, St. Lucia, Grenada, Jamaica). Increasingly being recommended.</td>
</tr>
<tr>
<td colspan="2">Operation and Maintenance:
• Generally low operation and maintenance required, however does need maintaining of reeds or wetland plants to keep weeds out and keep good growth</td>
</tr>
<tr>
<td>Advantages:
• Nutrient and pathogen removal
• Low operation and maintenance requirements
• No energy requirements
• Effluent suitable for discharge in sensitive water bodies or reuse
• Construction material generally available locally
• Aesthetically pleasing
• Provides habitat for birds and aquatic life</td>
<td>Disadvantages /constraints:
• Large land area required
• Manual harvesting of reeds required
• Creates potential environment for insect breeding</td>
</tr>
<tr>
<td>Relative Cost:
• low capital and O&M costs</td>
<td>Cultural Acceptability:
• growing acceptance based on wider exposure within the Caribbean Region</td>
</tr>
<tr>
<td>Energy use:
• None</td>
<td>Pollution reduction:
• 85% BOD and COD removal, greater than 95% pathogen removal with significant nutrient content removed.</td>
</tr>
</table>

Suitability:

- . wide application

Pond Systems:

A. Anaerobic Ponds

Technology Description:

The following set of technology matrices describe a series of ponds: anaerobic, facultative and maturation pond systems. Generally, to achieve effluent quality suitable for discharge into receiving water bodies' ponds are designed in series that is as a system and not singularly.

Anaerobic ponds are biological processes for treating wastewater (see UASB), are generally used as the first in a series of ponds to treat high strength wastewater (50-500kgBOD/ (m3.day)) and are usually highly loaded. Anaerobic stabilisation is the main process, which takes place. Further sedimentation of suspended matter also occurs. Because no aeration is necessary, anaerobic ponds can be as deep as technically feasible. The depth of anaerobic ponds ranges from 2-5 metres, which means a relatively small surface, compared to other pond types. Depending on the soil type, ponds are lined to prevent contamination of groundwater. The pond depth decreases light penetration to the deeper layers reducing the rate of oxygenation.

Effluents from anaerobic systems require further aerobic treatment before discharge to surface water bodies.

Extent of Use:

- Increasing use in the Caribbean Region

Operation and Maintenance:

- Low degree of operation and maintenance required

Advantages: • Low capital cost • Low maintenance and O & M costs • Effective removal of organic load • Simple operation	**Disadvantages /constraints:** • Land space • Odour and insect nuisance • Additional treatment step required
Relative Cost: • Low capital cost compared to conventional anaerobic treatment systems. Low O & M costs	**Cultural Acceptability:** • Is generally accepted within the Caribbean Region
Energy Usage: None required if gravity fed	**Pollution Reduction:** 70-80% BOD Removal

Suitability

- Pre-treatment of high strength industrial or municipal wastewater
- When land available and relatively inexpensive

Pond Systems:

B. Facultative Ponds (Oxidation/Waste Stabilisation Ponds)

Technology Description:

These systems require much greater areas of land than the more compact and conventional trickling filters and Aerobic Stabilisation Ponds. Facultative ponds offer an option for considerably lower capital cost and relatively low operating and maintenance cost for effective treatment of wastewater. These ponds are predominantly used in municipal treatment systems or are often used as the second in a series of ponds. Facultative ponds treat waste in the range of 50-150kg BOD/ (ha.day).

The pond depth is in the range of 1-2.5 meters with detention times rating from 20-60 days. Depending on the soil type, ponds are lined to prevent contamination of groundwater.

A biological process for treating wastewater, the ponds are called facultative because of their combined aerobic and anaerobic action. The oxygen supplied for the aerobic process is obtained either mechanically through aerators (high rate aerobic ponds) or through algal growth. Influent waste organic matter is broken down by aerobic heterotrophic bacteria. The resulting degradation products are used by algae, which also use light as a source of energy to synthesize algal cells by photosynthesis releasing oxygen to satisfy the demand of the aerobic biodegradation process. Near to the bottom of the pond, suspended matter settles and anaerobic conditions exist.

Unless the algae are harvested, total carbon in the effluent will be similar to influent. Often such discharges are used for irrigation or in constructed wetlands.

Extent of Use:

Increasing use in the Caribbean Region.

Operation and Maintenance:

- Relatively high degree of operation and maintenance required if algae harvested or mechanical aerator used for supplying oxygen

Advantages: • Low capital cost • Effective removal of organic load • Simple operation	**Disadvantages /constraints:** • Land space • Insect nuisance • Harvesting algal biomass
Relative Cost: • Low capital cost compared to conventional aerobic treatment systems.	**Cultural Acceptability:** • Is generally accepted within the Caribbean Region
Energy Usage: Relatively high if mechanical aerators are used	**Pollution Reduction:** 70-95 % BOD Removal

Suitability

- Municipal wastewater
- Land available and relatively inexpensive
- Effluent discharge for irrigation or in constructed wetland

Pond Systems:

C. Maturation Ponds

Technology Description:

Maturation Ponds are low loaded lagoons (50-150kg BOD/ (ha.day) in which the effluent from facultative ponds are polished. Kjeldahl nitrogen is oxidized and pathogens die off to a great extent due to long retention times.

Extent of Use:

- Increasing use in the Caribbean Region

Operation and Maintenance:

- Low degree of operation and maintenance required

Advantages:	**Disadvantages /constraints:**
• Low capital cost • Low maintenance and O & M costs • Removal of nitrogen and bacteria • Simple operation	• Land space • Harvesting algae
Relative Cost: • Low capital cost compared to conventional aerobic treatment systems. Low O & M costs	**Cultural Acceptability:** • Is generally accepted within the Caribbean Region
Energy Usage: None required if gravity fed	**Pollution Reduction:** Significant removal of microbes and nitrogen

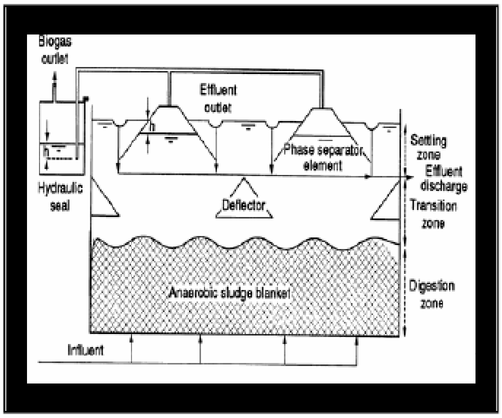
Suitability

- Polishing of industrial/municipal wastewater
- Land available and relatively inexpensive

Facultative and maturation ponds in series for treatment of municipal wastewater in a city in Jamaica.
(Photograph provided by UCYConcepts@aol.com)

Aerobic Lagoons, St. Lucia (Courtesy CEHI)

UASB



Technology Description:

The Upflow Anaerobic Sludge Blanket Reactor is a high rate anaerobic treatment system (which can facilitate high loading and short retention time). It is utilized on both a small and large scale

Technology Description continued

The UASB process is characterized by an active sludge blanket/bed at the bottom of the reactor that degrades the incoming wastewater. The bacteria may spontaneously agglomerate to form granules. These granules have good settling properties and are not susceptible to being washed from the system under normal conditions. Retention of active sludge, either granular or flocculent within the UASB reactor enables good treatment at a high organic loading rate.

The maintenance of high sludge concentration in the reactor is one of the most important conditions of a UASB process. The higher the concentration of viable sludge, the higher will be the conversion.

Source: SRC www.jawmanins.com

Extent of Use: In Jamaica for agro-industrial wastewater and centralised sewerage systems

Operation and Maintenance:

- Medium to high degree of operation and maintenance required
- Highly skilled personnel required
- In start up period, monitoring and control critical
- Gas must be scrubbed before use

Advantages:

- Low production of stabilised sludge
- High treatment efficiency
- No energy required for treatment
- Relatively low capital and operating costs
- Energy recovery

Disadvantages /constraints:

- Start up time not immediate (3-6 months)

Relative Cost:

- Low capital cost (US$ 250-500/cubic meter)
- Low operation cost

Cultural Acceptability:

- Limited acceptance within the Caribbean Region (due in part to lack of exposure)

Energy Usage:

- Generated energy 0.35 m3 methane/kg COD removed

Pollution Reduction:

- > 85% BOD and SS removal

Suitability/Appropriateness

- High strength organic waste, Utilized on small and large scale

UASB, Scientific Research Council, Food Technology Institute, Kingston, Jamaica

Terrestrial Treatment Technologies

Terrestrial treatment systems include slow-rate overland flow, slow-rate subsurface infiltration, and rapid infiltration methods. In addition to wastewater treatment and low maintenance costs, these systems may yield additional benefits by providing water for groundwater recharge, reforestation, agriculture, and/or livestock pasturage. They depend upon physical, chemical, and biological reactions on and within the soil. Slow-rate overland flow systems require vegetation, both to take up nutrients and other contaminants and to slow the passage of the effluent across the land surface to ensure maximum contact times between the effluents and the plants/soils. Slow-rate subsurface infiltration systems and rapid infiltration systems are "zero discharge" systems that rarely discharge effluents directly to streams or other surface waters. Each system has different constraints regarding soil permeability.

Although slow-rate overland flow systems are the most costly of the natural systems to implement, their advantage is their positive impact on sustainable development practices. In addition to treating wastewater, they provide an economic return from the reuse of water and nutrients to produce marketable crops or other agriculture products and/or water and fodder for livestock.

The water may also be used to support reforestation projects in water-poor areas. In slow-rate systems, either primary or secondary wastewater is applied at a controlled rate, either by sprinklers or by flooding of furrows, to a vegetated land surface of moderate to low permeability. The wastewater is treated as it passes through the soil by filtration, adsorption, ion exchange, precipitation, microbial action, and plant uptake. Vegetation is a critical component of the process and serves to extract nutrients, reduce erosion, and maintain soil permeability.

Overland flow systems are a land application treatment method in which treated effluents are eventually discharged to surface water. The main benefits of these systems are their low maintenance and low technical manpower requirements. Wastewater is applied intermittently across the tops of terraces constructed on soils of very low permeability and allowed to sheet-flow across the vegetated surface to the runoff collection channel.

Treatment, including nitrogen removal, is achieved primarily through sedimentation, filtration, and biochemical activity as the wastewater flows across the vegetated surface of the terraced slope. Loading rates and application cycles are designed to maintain active microorganism growth in the soil. The rate and length of application are controlled to minimize the occurrence of severe anaerobic conditions, and a rest period between applications is needed. The rest period should be long enough to prevent surface ponding, yet short enough to keep the microorganisms active. Site constraints relating to land application technologies are shown in Table x.

Table 9: Site Constraints for Land Application Technologies

Feature	Slow Rate	Rapid Infiltration	Subsurface Infiltration	Overland Flow
Soil texture	Sandy loam to clay loam	Sand and sandy loam	Sand to clayey loam	Silty loam and clayey loam
Depth to groundwater	3 ft	3 ft	3 ft	Not critical
Vegetation	Required	Optional	Not applicable	Required
Climatic restrictions	Growing season	None	None	Growing season
Slope	<20percent, cultivated land < 40percent, uncultivated land	Not critical	Not applicable	2percent-8percent finished slopes

Source: UNEP-CEP, 1997

In rapid infiltration systems, most of the applied wastewater percolates through the soil, and the treated effluent drains naturally to surface waters or recharges the groundwater. Their cost and manpower requirements are low. Wastewater is applied to soils that are moderately or highly permeable by spreading in basins or by sprinkling. Vegetation is not necessary, but it does not cause a problem if present. The major treatment goal is to convert ammonia nitrogen in the water to nitrate nitrogen before discharging to the receiving water.

Subsurface infiltration systems are designed for municipalities of less than 2,500 people. They are usually designed for individual homes (septic tanks), but they can be designed for clusters of homes. Although they do require specific site conditions, they can be low-cost methods of wastewater disposal.

Extent of Use of Off-Site Treatment Systems

These treatment technologies are widely used in Latin America and the Caribbean. Combinations of some of them with wastewater reuse technologies have been tested in several countries. Colombia has extensively tested aerobic and anaerobic mechanical treatment systems.

Chile, Colombia, and Barbados have used activated sludge plants, while Brazil has utilized vertical reactor plants. Argentina, Bolivia, Colombia, Guatemala, Brazil, Chile, Curaçao, Mexico, Jamaica, and Saint Lucia have successfully experimented with different kinds of terrestrial and aquatic treatment systems for the treatment of wastewaters. Curaçao, Mexico, and Jamaica have used stabilization or facultative lagoons and oxidation ponds; their experience has been that aquatic treatment technologies require extensive land areas and relatively long retention times, on the order of 7 to 10 days, to adequately treat wastewater.

An emerging technology, being tested in a number of different countries, is a hybrid aquatic-terrestrial treatment system that uses wastewaters for hydroponic cultivation. However, most of the applications of this hybrid technology to date have been limited to the experimental treatment of small volumes of wastewater.

Operation and Maintenance of Off-Site Treatment Systems

Operation and maintenance requirements vary depending on the particular technology used. In mechanical activated-sludge plants, maintenance requirements consist of periodically activating the sludge pumps, inspecting the system to ensure that are no blockages or leakages in the system, and checking BOD and suspended solids concentrations in the plant effluent to ensure efficient operation.

In the case of aquatic treatment systems using anaerobic reactors and facultative lagoons for primary wastewater treatment, the following operational guidelines should be followed:

- Periodically clean the sand removal system (usually every 5 days in dry weather, and every 2 to 3 days in wet weather).
- Daily remove any oily material that accumulates in the anaerobic reactor.
- Daily remove accumulated algae in the facultative lagoons.
- Open the sludge valves to send the sludge to the drying beds.
- Establish an exotic aquatic plant removal program (aquatic plant growth can hamper the treatment capacity of the lagoons).
- Properly dispose of the materials removed, including dried sludge.

A preventive maintenance programme should also be established to increase the efficiency of the treatment systems and prolong their lifespan.

When using terrestrial treatment systems or hybrid hydroponic cultivation systems for wastewater treatment, it is advisable to have two parallel systems, and to alternate applications of wastewater to these systems every 12 hours in order to facilitate aeration and to avoid damage to the system. Care is required to avoid hydraulic overload in these systems, as the irrigated plant communities could be damaged and the degree of treatment provided negated. Periodic removal of sediments accumulated in the soil is also required to improve the soil-plant interaction and to avoid soil compaction/subsidence.

Level of Involvement in Off-Site Treatment Systems

Government involvement is essential in the implementation of most of the wastewater treatment technologies. The private sector, particularly the tourism industry, has successfully installed "packaged" or small-scale, self-contained sewage treatment plants at individual sites. In some cases, the installation of these plants has been combined with the reuse of the effluent for watering golf courses, lawns, and similar areas.

The selection and construction of the appropriate wastewater treatment technology is generally initiated and financed, at least partially, by the government, with the subsequent operation and maintenance of the facility being a responsibility of the local community. Nevertheless, despite the large number of well-known and well-tested methods for wastewater treatment, there still exist a significant number of local communities in Latin America which discharge wastewater directly into lakes, rivers, estuaries, and oceans without treatment. As a result, surface water degradation, which also affects the availability of freshwater resources, is more widespread than is desirable within this region.

Effectiveness of the Technology for Off-Site Treatment Systems

Natural treatment systems are capable of producing an effluent quality equal to that of mechanical treatment systems. All can meet the limits generally established for secondary treatment, defined as biological oxygen demand (BOD) and total suspended solids (TSS) concentrations of less than 30 mg/l. All except the lagoon systems can also produce effluents that meet the criteria generally categorized as advanced treatment, defined as BOD and TSS concentrations of less than 20 mg/l. The results of a project conducted in Bogota, Colombia, to compare the performance of different sewage treatment processes are summarized in Table 10.

Table 10: Comparative Performance of Sewage Treatment Systems

Process	Oxygen Supply	Reactor Volume	Retention Time	Removal Efficiency
Activated sludge	Pressurized air	10 m^3	4-6 hr	90% - 95 % organic matter 90% - 95% suspended solids
Biologic rotary discs	Air	1 m^3	1-3 hr	90% - 95 % organic matter
Ascendant flow	Anaerobic	2 m^3	24 hr	50% - 60% organic matter 57% suspended solids
Anaerobic filtration	Anaerobic	2 m^3	36 hr	40% - 50% organic matter 52% suspended solids

Septic tank	Anaerobic	2 m^3	36 hr	25% organic matter
Hydroponic cultivation	Aerobic/anaerobic	6 m^3	12 hr	65% - 75% organic matter

Source: UNEP-CEP, 1997

Suitability of Off-Site Treatment Systems

Mechanical systems are more suitable for places where land availability is a concern, such as hotels and residential areas. Mechanical plants are the least land intensive of the wastewater treatment methods based on natural processes.

Lagoon and oxidation pond technologies are suitable where there is plenty of land available. Slow-rate systems require as much as 760 acres. Hybrid hydroponic cultivation techniques, using aquatic and terrestrial plants for the treatment for wastewater, also require relatively large amounts of land, and are best suited to regions where suitable aquatic plants can grow naturally.

Advantages of Off-Site Treatment Systems

Table x below summarizes the advantages of the various wastewater treatment technologies. In general, the advantages of using natural biological processes relate to their "low-tech/no-tech" nature, which means that these systems are relatively easy to construct and operate, and to their low cost, which makes them attractive to communities with limited budgets.

However, their simplicity and low cost may be deceptive in that the systems require frequent inspections and constant maintenance to ensure smooth operation. Concerns include hydraulic overloading, excessive plant growth, and loss of exotic plants to natural watercourses. For this reason, and also because of the land requirements for biologically based technologies, many communities prefer mechanically-based technologies, which tend to require less land and permit better control of the operation. However, these systems generally have a high cost and require more skilled personnel to operate them.

Disadvantages of Off-Site Treatment Systems

Table 12 also summarizes the disadvantages of the various wastewater treatment technologies. These generally relate to the cost of construction and ease of operation. Mechanical systems can be costly to build and operate as they require specialized personnel. Nevertheless, they do offer a more controlled environment which produces a more consistent quality of effluent. Natural biological systems, on the other hand, are more land-intensive, require less-skilled operators, and can produce effluents of variable quality depending on time of year, type of plants, and volume of wastewater loading. Generally, the complexity and cost of wastewater treatment technologies increase with the quality of the effluent produced.

Table 11: Treatment/ Disposal of Household Liquid Effluent

	Advantages	Disadvantages
Land Treatment		
• Irrigation	Effluent quality excellent	Large land requirement Limited by soil type, depth, topography, climate, etc. Sprinkler clogging, odors
• Rapid Infiltration	Simple operation Least land-intensive	Limited by soil type, depths, hydraulic capacity
• Overland Flow	Soil clogging not a problem Depth to groundwater not critical	Limited by soil type, crop water tolerances, climate slope Vegetation required Potential odor, vector problems
• Wetland Application	Good for small flows Low cost, simple	Large area required Potential for mosquito breeding
Discharge to Surface Water		
• Lagoons	Simple operation Low cost High reliability Long service life	Large land requirements
• Attached Growth or Suspended Growth	Process more controllable than lagooning, land treatment Performance well documented for wastewater treatment Small land requirement	Higher capital and operating costs than lagooning, land treatment
Discharge to Treatment Plant	Construction and maintenance of liquid stream facility not required	May have adverse impact on treatment plant if liquid stream high-strength.

Table 12: Treatment/ Disposal of Septage from Household Systems

	Advantages	Disadvantages
• Spreading	Soil conditioning, fertilization Dewatering not needed Inexpensive liquid transfer	Septage should be stabilized Large area required
• Trench Fill	Suitable for unstabilized septage Low initial costs	Daily soil cover required for vector control Large land area
• Area Fill Mound	Suitable in shallow-water table areas or where excavation not possible	Stabilized septage required High manpower and equipment Leachate must be controlled
• Incineration	Stabilization not required Small land required	High Costs Air pollution control devices required Dewatering required

Cultural Acceptability of Off-Site Treatment Systems

Governments and the private sector in many countries of the Wider Caribbean fail to fully recognize the necessity of wastewater treatment and the importance of water quality in improving the quality of life of existing and future generations. The contamination of natural resources is a major impediment to achieving key developmental objectives for healthy population, environmental sustainability and economic growth and development.

While some of the systems described in this report have earned cultural acceptability within the region, there are some systems which have not yet been successfully introduced to the region but are well-known in other parts of the world.

Further Development of the Technologies for Off-Site Treatment Systems

The cost-effectiveness of all wastewater treatment technologies needs to be improved. New designs of mechanical systems which address this concern are being introduced by the treatment plant manufacturing industry. The use of vertical reactors with an activated-sludge system, being tested in Brazil in order to acquire data for future improvement of this technology, is one example of the innovation going on in the industry.

Similar product development is occurring in the use of aquatic and terrestrial plants and hybrid hydroponic systems, as a means of wastewater treatment; however, these technologies are still in an experimental phase and will require more testing and research prior to being accepted as standard treatment technologies. In addition, education to create an awareness of the need for wastewater treatment remains a critical need at all levels of the wastewater sector.

Table 13: Advantages and Disadvantages of Conventional and Non-conventional Wastewater Treatment Technologies

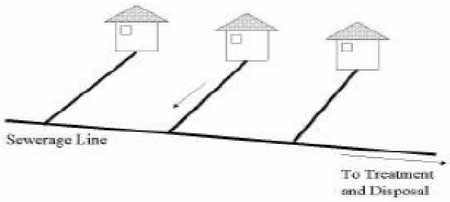
Treatment Type	Advantages	Disadvantages
	Aquatic Systems	
Stabilization lagoons	Low capital cost Low operation and maintenance costs Low technical manpower requirement	Requires a large area of land May produce undesirable odors
Aerated lagoons	Requires relatively little land area Produces few undesirable odors	Requires mechanical devices to aerate the basins Produces effluents with a high suspended solids concentration
	Terrestrial Systems	
Septic tanks	Can be used by individual households Easy to operate and maintain Can be built in rural areas	Provides a low treatment efficiency Must be pumped occasionally Requires a landfill for periodic disposal of sludge and septage
Constructed wetlands	Removes up to 70 percent of solids and bacteria	Remains largely experimental Requires periodic removal of excess plant

	Minimal capital cost Low operation and maintenance requirements and costs	material Best used in areas where suitable native plants are available
Mechanical Systems		
Filtration systems	Minimal land requirements; can be used for household-scale treatment Relatively low cost Easy to operate	Requires mechanical devices
Vertical biological reactors	Highly efficient treatment method Requires little land area Applicable to small communities for local-scale treatment and to big cities for regional-scale treatment	High cost Complex technology Requires technically skilled manpower for operation and maintenance Needs spare-parts-availability Has a high energy requirement
Activated sludge	Highly efficient treatment method Requires little land area Applicable to small communities for local-scale treatment and to big cities for regional-scale treatment	High cost Requires sludge disposal area (sludge is usually land-spread) Requires technically skilled manpower for operation and maintenance

Additional Examples of Off-Site Sewerage

<table>
<tr>
<td rowspan="2">Collection and Transfer Systems:

Conventional Sewerage


</td>
<td>Technology Description:

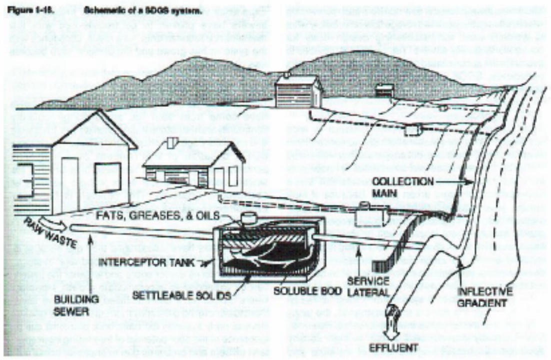
Domestic sewage is collected by an underground pipe system to treatment facilities.

Conventional sewerage consists of individual connections (households, commercial enterprises etc.) to a piped reticulation system. The reticulation systems normally include a series of pump stations to convey the sewage through the system, especially on atoll and coastal communities due to flat topography and high groundwater levels. Manholes and other access chambers are required to maintain and clean reticulation systems. Grinder pumps may be installed at individual properties under circumstances where the sewage has to be lifted from the property to the main sewer line.

Systems are normally based on conservative design criteria resulting in high capital construction and operational costs.</td>
</tr>
<tr>
<td>Extent of Use:
• Major population centres in the Caribbean Region.</td>
</tr>
<tr>
<td colspan="2">Operation and Maintenance:
• High degree of operation and maintenance if pumping is required
• Skilled personnel required</td>
</tr>
<tr>
<td>Advantages:
• minimal intervention by users
• low to moderate O&M costs
• promotes good hygiene practices.</td>
<td>Disadvantages /constraints:
• high capital costs
• technology requiring skilled engineers, contractors and operators.
• ample and reliable piped water supply required
• adequate treatment and/or disposal required for a large point source discharge.</td>
</tr>
<tr>
<td>Relative Cost:
• high capital costs</td>
<td>Cultural Acceptability:
• is generally accepted within the Caribbean Region</td>
</tr>
<tr>
<td>Energy use:
• low to moderate</td>
<td>Pollution reduction:
• none</td>
</tr>
<tr>
<td colspan="2">Suitability
• High population density</td>
</tr>
</table>

Collection and Transfer Systems:

Small bore (Settled) Sewerage



Source: Daniel and Daniel Engineering Inc.

Technology Description:

Similar to "conventional sewerage" systems where domestic sewage is collected by an underground pipe system and conveyed to treatment facilities. However before the sewage enters the reticulation system, it enters a septic tank, where most settleable solids are removed, thus only the liquid effluent is reticulated. Periodic removal (3-5 years), treatment and disposal of septage are required. Good practices suggest inspection every two years.

The resulting effluent is of "better" quality than if the septic tanks were not in place. However the septic tanks will require maintenance and cleaning.

In principle, the design of the "settled" system is the same as "conventional" systems, however with solids removed from the system, pipelines may be smaller.

Extent of Use:

- Increasing use in the Caribbean Region (for example, Grenada)

Operation and Maintenance:

- high degree of operation and maintenance if pumping is required
- skilled personnel required
- maintenance and cleaning of septic tanks required

Advantages:

- promotes good hygiene practices.
- minimal intervention by users
- low capital costs
- moderate O&M costs
- promotes good hygiene practices.

Disadvantages /constraints:

- relies on maintenance of individual septic tanks
- technology requiring skilled engineers, contractors and operators
- ample and reliable piped water supply required
- adequate treatment and/or disposal required for a large point source discharge.

Relative Cost:

- lower capital costs than conventional sewerage

Cultural Acceptability:

- growing acceptance within the Caribbean Region

Energy use:

- low to moderate

Pollution reduction:

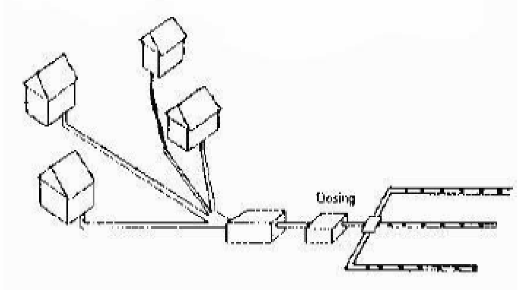
- 30-40% reduction in BOD and suspended solids

Suitability:

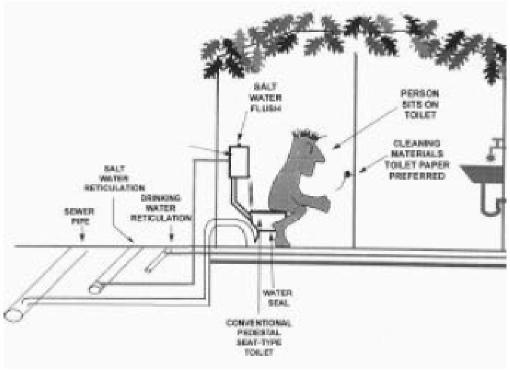
- Small communities (for example, housing schemes and villas)

<table>
<tr>
<td rowspan="2">Collection and Transfer Systems:

Cluster Systems


</td>
<td colspan="2">Technology Description:

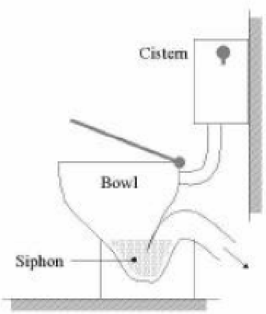
A cluster system refers to a common collection and disposal system grouping several houses or commercial properties. A cluster system is used to collect sewage from areas with significantly varying housing densities. For example, if there are several villages along a stretch of coastline but very little housing in between the villages, rather than sewer the entire coastline, it may be more economical to develop a cluster system for each village.</td>
</tr>
<tr>
<td colspan="2">Extent of Use:
• Used in the Caribbean</td>
</tr>
<tr>
<td colspan="3">Operation and Maintenance:
• Relatively low especially if gravity sewers are used.</td>
</tr>
<tr>
<td>Advantages:
• Less costly than conventional sewerage</td>
<td colspan="2">Disadvantages /constraints:
• More than one collection, treatment and disposal system</td>
</tr>
<tr>
<td>Relative Cost:
• moderate</td>
<td colspan="2">Cultural Acceptability:
• Accepted within the Caribbean Region</td>
</tr>
<tr>
<td colspan="3">Suitability:
• Suitable for areas requiring sewers but with widely varying housing densities.</td>
</tr>
</table>

Collection and Transfer Systems: **Dual Distribution (Reticulation) Systems** Source: ADB 	**Technology Description:** Dual distribution systems involve the use of water from two different sources and reticulated in two separated distribution networks. Potable water is distributed in one system for most domestic and commercial uses while a second system reticulates non-potable water (i.e. salt, brackish, rain water or treated wastewater) for flushing toilets and other non-potable uses. Using this technology conserves limited freshwater resources. This type of technology would generally be used near the coast where seawater or brackish water is abundant. Saltwater systems require special consideration for the selection of materials due to corrosive nature of seawater. Pipes need to be colour-coded or have other identification to distinguish from potable supply reticulation pipes and to avoid possible cross connections. **Extent of Use:** In the Caribbean, U.S. Virgin Islands, Turks and Caicos, Cayman Islands and the Bahamas use these systems.

Operation and Maintenance:
- high degree of operation and maintenance
- potential corrosion problems exist that may compound maintenance requirements.

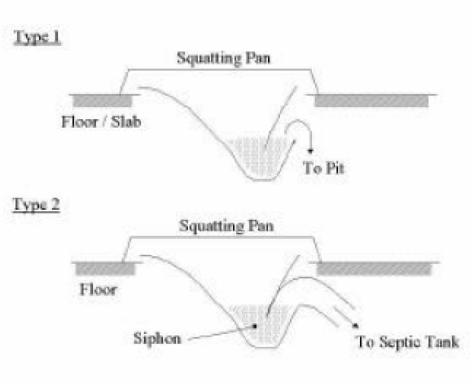
Advantages:	**Disadvantages /constraints:**
• use of lesser quality waters for non-potable purposes reduces the use of limited freshwater resources.	• high capital costs • technology requiring skilled expertise such as engineers, technicians, contractors and operators. • Risk of polluting groundwater through leaks • Risk of cross connections
Relative Cost: • High due to the duplication of distributions networks and the need to use corrosion resistant materials if seawater is used.	**Cultural Acceptability:** • Growing acceptance in water-scarce islands of the Caribbean.
Energy use: • moderate to high	**Pollution reduction:** • water conservation will result in pollution reduction over the life-cycle of the system

Suitability:
- In water-stressed areas

Collection and Transfer Systems: **Cistern-Flush Toilet** Source: T. Loetscher (1998) 	**Technology Description:** The toilet bowl consists of a siphon, which provides a water seal against bad odours from the effluent pipe. Excreta are flushed away with water stored in the cistern (depending on the type between five to twenty litres per flush). Dual flush toilets are available to reduce water used to flush urine. Cistern-flush toilets provide the highest level of convenience and have a very clean and hygienic appearance. The cistern-flush toilet itself has no treatment effects. Cistern-flush toilets use large amounts of water. Installing them results in a water use of around 15 litres per flush. Increasingly, low flush toilets are being used with reduced water consumption to approx. 10 litres per flush. Cistern-flush toilets are more prone to malfunctioning and leakage than pour-flush toilets. **Extent of Use:** • extensively throughout the Caribbean
Operation and Maintenance: • subject to malfunction of flushing system.	
Advantages: • easy to use and clean • hygienic	**Disadvantages /constraints:** • high water use
Relative Cost: • higher than pit latrines and pour flush	**Cultural Acceptability:** • No cultural problems
Energy use: • **NA**	**Pollution reduction:** **NA**
Suitability: • Very suitable if reliable water supply exists and if the user can afford it.	

<table>
<tr>
<td rowspan="2">Collection and Transfer Systems:

Pour-Flush Toilet Source: T. Loetscher (1998)


</td>
<td>Technology Description:

The toilet pan consists of a siphon, which provides a water seal against bad odours from the effluent pipe. Excreta are flushed away with water, which is poured manually into the pan by using a scoop. The amount of water required to flush this type of toilet is between two and three litres. Pour-flush toilets provide a high level of convenience and have a very clean and hygienic appearance. The pour-flush toilet itself has no treatment effects.

The pour flush toilet can also be constructed with a riser to sit on instead of the squat type as shown.</td>
</tr>
<tr>
<td>Extent of Use:
• Limited use in the Caribbean region</td>
</tr>
<tr>
<td colspan="2">Operation and Maintenance:
• Easy to operate and maintain</td>
</tr>
<tr>
<td>Advantages:
• Easy to use and clean
• Hygienic if riser is used
• Uses less water then cistern-flush toilets</td>
<td>Disadvantages /constraints:
• Requires storage and handling of water</td>
</tr>
<tr>
<td>Relative Cost:
• Lower than cistern flush</td>
<td>Cultural Acceptability:
• Not widely accepted</td>
</tr>
<tr>
<td>Energy use:
NA</td>
<td>Pollution control:
NA</td>
</tr>
<tr>
<td colspan="2">Suitability:
• Very suitable in areas with limited piped water supply</td>
</tr>
</table>

<table>
<tr>
<td>On-Site Wastewater Treatment

Ecological Sanitation

Double Vault urine diverting dry eco-toilet</td>
<td>Technology Description:

Ecological sanitation systems are designed around true containment and provide two ways to render human excreta innocuous: dehydration and decomposition. The preferred method will depend on climate, groundwater tables, amount of space and intended purpose for the sanitized excreta. Dehydration is the chemical process of destroying pathogens by eliminating moisture from the immediate (containing) environment. Some drying materials, like wood ash, lime and soil are added to cover the fresh deposit. Ash and lime increase pH, which acts as an additional toxic factor to pathogens if the pH can be raised to over 9.5. The less moisture the better, and in most climates it is better to divert the urine and treat it separately

Urine is never mixed in this toilet but continuously diverted into a separate container and later used in diluted form as plant fertiliser

Extent of Use:
• Not widely used in the Caribbean</td>
</tr>
<tr>
<td colspan="2">Operation and Maintenance:
• . Requires care in operation; easy to maintain</td>
</tr>
<tr>
<td>Advantages:
• Systems do not require water for flushing, reduces domestic water consumption.
• Reduces the quantity and strength of wastewater to be disposed of on-site.
• Suited for new construction at remote sites where conventional on-site systems are not feasible.
• Self-contained systems eliminate the need for transportation of wastes for treatment/disposal.
• Diverts nutrient- and pathogen-containing effluent from soil, surface water, and groundwater.</td>
<td>Disadvantages /constraints:
• Maintenance of these toilet systems requires more responsibility by users than conventional wastewater systems.
• Removing the finished end-product is an unpleasant job if the toilet system is not properly installed or maintained and may produce odours.
• Smaller units may have limited capacity for accepting peak loads.
• Using an inadequately treated end product as a soil amendment may have possible health consequences.</td>
</tr>
<tr>
<td>Relative Cost:
• Low</td>
<td>Cultural Acceptability:
• . NA</td>
</tr>
<tr>
<td>Energy use:
Low</td>
<td>Pollution reduction:
Waterless system greatly reduces pollution</td>
</tr>
<tr>
<td colspan="2">Suitability :
• Well suited to the region especially in areas where water is not readily available</td>
</tr>
</table>

2.2.2 On-site Wastewater Treatment Systems

One approach to sustainability is through decentralization of the wastewater management system. This system consists of several smaller units serving individual houses, clusters of houses or small communities. Decentralized systems are more flexible and can adapt easily to the local conditions of the urban area as well as grow with the community as its population increases (Schertenlieb, 2000). This approach leads to opportunities for treatment and reuse of water, nutrients, and byproducts of the technology (i.e. energy, sludge, and mineralized nutrients) in the direct location of the settlement.

On-site treatment relies on decomposition of the organic wastes in human excreta by bacteria. This can take place in a simple pit in the ground or in specially designed tanks to promote the bacterial decomposition of the wastes. Unless re-use of the wastewater is specifically intended, the overflow from the pit or tank is allowed to soak into the ground. Further bacteriological decomposition and soil filtration, absorption and purification processes take place in the soil. The potential for groundwater pollution, however, exists with on-site treatment and disposal systems, because not all pollutants (e.g. nitrate) are removed by these processes.

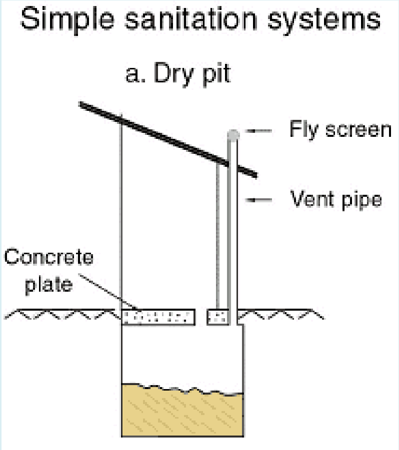
Pit latrine, pour flush latrine, composting toilet, septic tank, evapo-transpiration bed, tile field, soakway pit and two improved on-site treatment units are described below because they represent major types of on-site treatment systems.

Pit Latrine

A pit latrine collects excreta in a pit dug in the ground beneath the toilet structure. If the soil is loose the pit needs to be lined with, for example, loose bricks to prevent the wall from collapsing. During storage in the pit decomposition of the organic substances takes place under anaerobic conditions. The anaerobic decomposition releases gases (carbon dioxide, methane and sulphuric gases) and reduces the volume of sludge.

Seepage of water into the surrounding soil takes place through the sides and bottom of the pit. During seepage further decomposition of organic matter by soil bacteria takes place reducing the BOD of the water. There will also be die-off of bacteria and viruses during storage and as the water percolates through the soil. Bacteria under these conditions do not generally remove nutrients, so pollution of groundwater will occur.

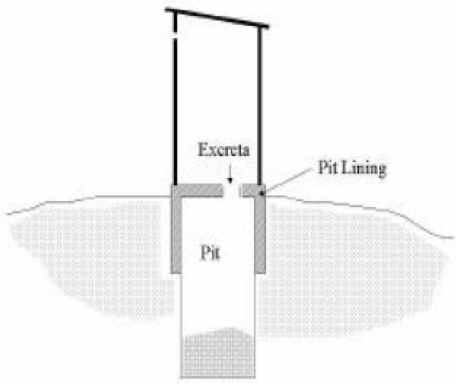
Figure 3: Ventilated Pit Latrine



Modified designs of the pit latrine which are more sanitary and environmentally-acceptable are discussed in the following pages.

<table>
<tr>
<td rowspan="2">On-Site Wastewater Treatment

Pit Latrine

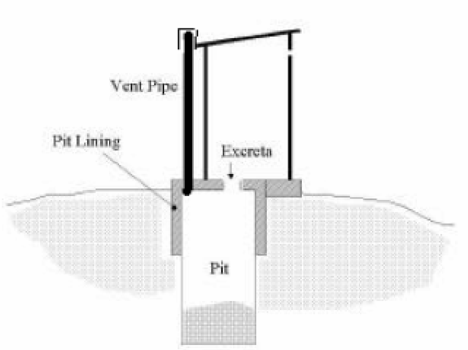

</td>
<td>Technology Description:

The pit latrine is designed for the on-site disposal of human excreta. It consists of a concrete squatting plate or riser, which is placed over an earthen pit. Its design life is between 15 - 30 years. If less than 10 years, a double vault composting (DVC) latrine should be considered instead. The pit diameter is between 1 - 1.5 m. The depth of the pit is at least 2 m, but usually more than 3 m. The top 0.5 m of the pit always requires lining. In loose soil, the entire pit should be lined in order to prevent collapse. One unit can serve one or several households.

If constructed properly, they provide good health benefits. All types of anal cleansing materials may be used. Since ventilation of pit latrines is simple, odours and insect nuisance may occur. Excreta can be seen through the hole in the squatting plate.</td>
</tr>
<tr>
<td>Extent of Use:
used throughout the Caribbean Region especially in rural areas</td>
</tr>
<tr>
<td colspan="2">Operation and Maintenance:
easy to operate and maintain</td>
</tr>
<tr>
<td>Advantages:
low cost
encourages public involvement in construction (potential for self help is high)
pit latrines do not need water for flushing
simple to construct
limited land area required
can be used in areas with low permeability soils</td>
<td>Disadvantages /constraints:
since pit latrines involve soil absorption, there is a danger of groundwater contamination
odours and insect nuisance may occur
usually removed from main dwelling</td>
</tr>
<tr>
<td>Relative Cost:
lowest cost for on-site technologies</td>
<td>Cultural Acceptability:
culturally accepted in much of the Caribbean</td>
</tr>
<tr>
<td>Energy use:
NA</td>
<td>Pollution reduction:
NA</td>
</tr>
<tr>
<td colspan="2">Suitability :
suitable low cost waste disposal method</td>
</tr>
</table>

<table>
<tr>
<td>On-Site Wastewater Treatment

VIP Latrine



VIP latrine, showing black pipe & screen (modified by CEHI)</td>
<td>Technology Description:

The ventilated improved pit (VIP) latrine is designed for the on-site disposal of human excreta. With the exception of some enhancements in design (e.g. a dark, vent pipe, to encourage upflow of air and improve ventilation; screening the top of the ventilation pipe will assist in reducing flies as well) its construction is similar to that of the pit latrine.

VIP latrines do not need water for flushing. They rely on soil absorption and are simple to construct. If constructed properly, they provide good health benefits.

All types of anal cleansing materials may be used.

A VIP latrine can be upgraded to a latrine with vault or a pour-flush latrine.

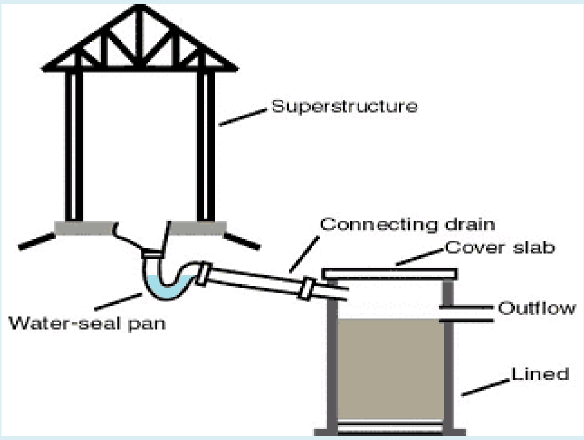
Extent of Use:
Being actively promoted as an improvement on the pit latrine with increasing use in the Caribbean</td>
</tr>
<tr>
<td colspan="2">Operation and Maintenance:
• easy to operate and maintain</td>
</tr>
<tr>
<td>Advantages:
• low cost
• encourages public involvement in construction (potential for self help is high)
• pit latrines do not need water for flushing
• simple to construct
• limited land area required
• can be used in areas with low permeability soils
• the ventilation of VIP latrines is good, odours and insect nuisance normally do not occur.</td>
<td>Disadvantages /constraints:
• since pit latrines involve soil absorption, there is a danger of groundwater contamination
• odours and insect nuisance may occur
• There is a danger of groundwater contamination.
• Usually removed from dwelling</td>
</tr>
<tr>
<td>Relative Cost:
• slightly higher than pit latrines</td>
<td>Cultural Acceptability:
• culturally accepted in much of the Caribbean but being phased out in some islands (for example in Barbados)</td>
</tr>
<tr>
<td>Energy use: NA</td>
<td>Pollution reduction: NA</td>
</tr>
<tr>
<td colspan="2">Suitability:
• suitable low cost waste disposal method however not suitable for flood prone areas</td>
</tr>
</table>

Pour Flush Latrine

A pour flush toilet has a water seal. The problems associated with odour and insects are avoided by having the water seal. Excreta deposited in the latrine pan is flushed by pouring 2 - 3 litres of water into it. The mixture is directed into a pit in the same way as for a pit latrine. The processes of biodegradation of the organic wastes in the pit are exactly the same. More water percolates through the soil surrounding the pit, and the potential for groundwater pollution is higher. A pour flush toilet with a pit is therefore not suitable when groundwater table is close to the surface.

Sludge has to be regularly emptied from the pit. The use of two adjoining pits alternately enables the sludge in a full pit to undergo further decomposition while the other pit is being used, and enables manual sludge emptying after further sludge decomposition.

Figure 4: Pour Flush Latrine

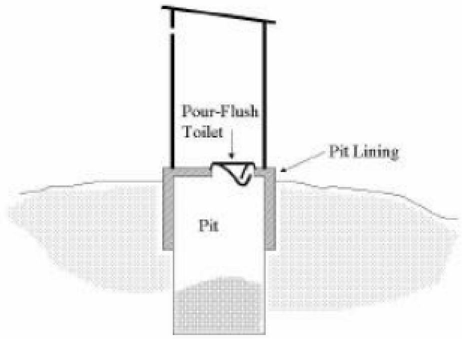


With the use of the pit latrine, composting toilet and pour flush latrine, greywater (sullage) has to be separately treated. Greywater can be reused directly or after treatment.

On-Site Wastewater Treatment

Pour-Flush Latrine

Source: T. Loetscher (1998)



Technology Description:

The pour-flush latrine is designed for the on-site disposal of human excreta. Its construction is similar to that of the pit latrine, except that it uses a pour-flush pan instead of a squatting plate with a hole in it. One unit can serve one or several households.

If constructed properly, they provide good health benefits.

The water seal in the pour-flush pan forms an effective barrier against odours and insect nuisance, and prevents excreta from being seen once flushed.

Extent of Use:

- not commonly used throughout the Region

Operation and Maintenance:

- easy to operate and maintain

Advantages:

- pour-flush latrines need small amounts of water for flushing.
- they are simple to construct, thus the potential for self help is high

Disadvantages /constraints (as other pit latrine technologies):

- since pit latrines involve soil absorption, there is a danger of groundwater contamination.

Relative Cost:

- low

Cultural Acceptability:

- cultural accepted

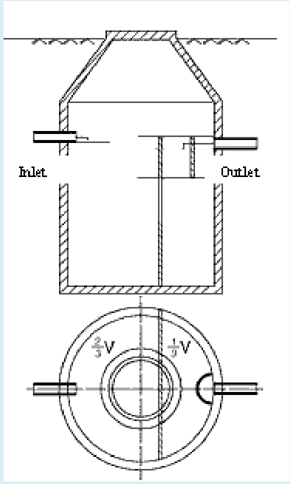
Suitability:

- suitable for household use, however contamination of groundwater may be an issue.

Septic Tank

A septic tank is a watertight tank, usually located just below ground, and receives both blackwater and greywater. It can be used with pour flush toilets or cistern flush toilets. It functions as a storage tank for settled solids and floating materials (e.g. oils and grease). The storage time of the wastewater in the tank is usually between 2 and 4 days. About 50% removal of BOD and Suspended Solids (SS) is usually achieved in a properly operated septic tank due to the settling of the solids during wastewater storage.

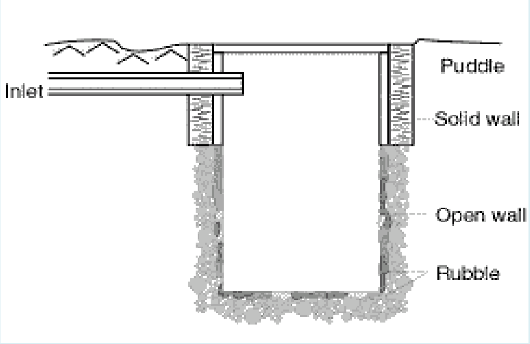
Figure 5: Septic Tank



A septic tank can be constructed of bricks and mortar and rendered, or of concrete. Its shape can be rectangular or cylindrical. A septic tank can be partitioned into two chambers to reduce flow short-circuiting and improve solids removal.

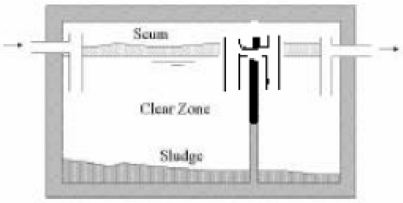
The overflow from a septic tank is directed to a leach (absorption) pit or trench. A leach pit is similar to the pit of a pit latrine or pour flush latrine. The pit must be sized to allow percolation of the volume of wastewater generated. A pit works well in soils with high permeability. In soils with lower permeability a trench can provide the larger surface area of percolation. The trench is usually filled with gravel and a distribution pipe for the wastewater is placed in this gravel layer. Soil is then placed above this gravel layer to the ground surface.

Figure 6: Leach (Absorption) Pit

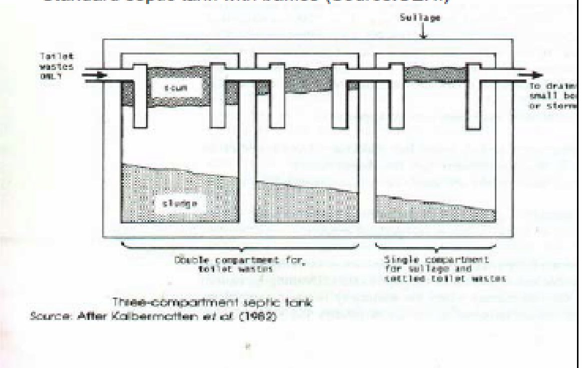


On-Site Wastewater Treatment

Septic Tank



Standard septic tank with baffles (Source:CEHI)



Three chamber septic tank
Source: Kalbermatten et al. (1982

Technology Description:
The septic tank is designed for the on-site treatment of domestic sewage. The tank is usually located underground and usually consists of two compartments allowing for one to three days of hydraulic retention. The first compartment is approximately twice as large as the second one. Baffles should be placed diagonally, to maximise the transit time of sewage between entry and exit from each chamber. Septic tanks can be constructed with only one compartment. However, this will result in significantly reduced treatment effects and cost savings are minimal.

There are two main treatment effects:
1) Contaminants are removed from the sewage by either settling of heavy particles or by flotation of materials less dense than water (e.g. oils and fats). The sludge layer at the bottom of the tank is a result of the settling process. The scum layer is formed through the flotation process.
2) Bacteria digest organic matter in the sludge and the scum layer. The digestion process is important because it prevents the excessive accumulation of sludge.

Septic tanks can reduce the BOD of raw sewage by up to 40% and the suspended solids content by 30-40%. Their effluent is thus more readily absorbed into the ground than raw sewage. Therefore, smaller soil absorption facilities (e.g. seepage pit or drain field) are required.

The effluent of septic tanks is still heavily contaminated with pathogens, organic matter and nutrients that require further treatment. Effluent quality can be further improved by installing a solids filter on the septic tank outlet. This prevents the carry over of solids into the absorption field.

Since they can only accept liquid waste, they must be connected to a flush toilet. Thus they are not suitable where water supply is scarce or unreliable.

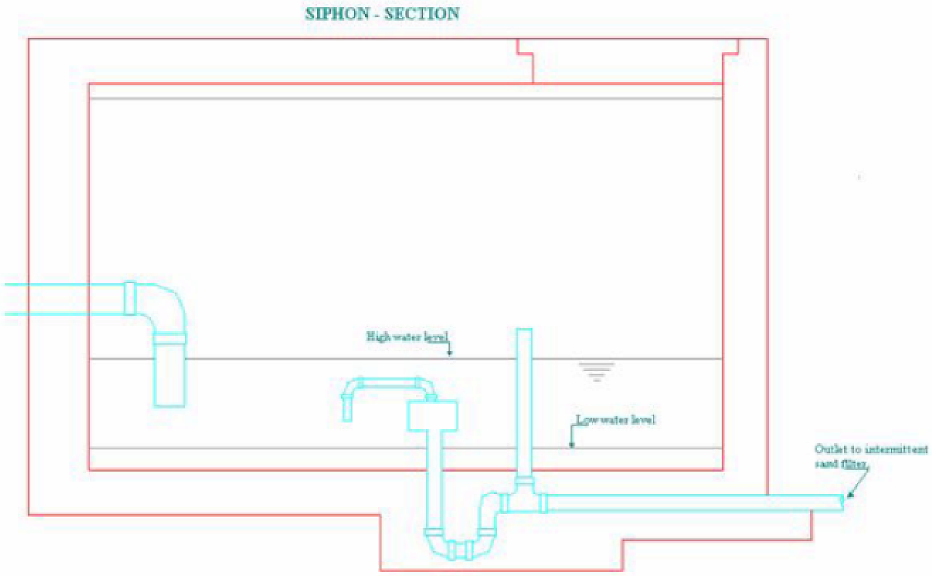
Extent of Use; extensively used in the Caribbean

Operation and Maintenance:

• septic tanks require routine checks for sludge and scum levels every two years. Properly designed and constructed septic tanks require desludging every three to five years. (Note: During the desludging process, some sludge should be left to restart the biological process. Tanks should be refilled.)	
Advantages: • greywater can be treated together with toilet waste • easy to construct • use of a variety of construction materials (in some cases prefabricated)	**Disadvantages /constraints:** • construction of septic tanks requires skilled labour • effluent requires further treatment
Relative Cost: • higher than the cost of a pit latrine but relatively low as a percentage of total building construction costs	**Cultural Acceptability:** • culturally accepted
Energy use: NA	**Pollution reduction:** • 30-40% reduction in BOD and suspended solids
Suitability: • Suitable for most applications.	

Dosing Devise (end of septic tanks)

Sewage siphon



(Source: Daniel and Daniel Engineering Inc.)

The purpose of a siphon is to secure an intermittent discharge to a sand or other filter, after effluent leaves a septic tank, thus allowing a considerable period of time for one sewage dose to work off in the filters before another flush is received. It also provides distribution over a larger area and in a more even manner than if the sewage was allowed to dribble with an uncontrolled flow.

The siphon action is rather simple and requires two conditions for its operation:

-All air must be evacuated from the piping

-The discharge end must be lower than the liquid level in the tank from which the liquid is to be -removed

The essential principle of operation is that a column of air is trapped between two columns of water, and when the water in the tank rises to a predetermined height (called the discharge line), the pressure forces out the confined air, upsetting the balance and causing a rush of water through to the pipes leading to the distribution field. The entire operation is fully automatic and occurs as a function of the water level in the tank.

Manufacturers of sewage siphons usually furnish full information for their setting and other details. If properly installed and maintained, sewage siphons require very little attention and will flush without failure for many years. However, they are susceptible to stoppage if rags, newspaper, and similar solids get into the sewage. If sludge is allowed to build up, it will prevent proper operation until the sludge is removed.

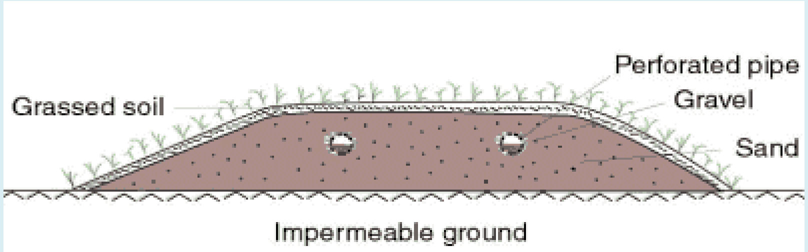
Evapo-transpiration Bed

A leach pit or trench does not work when the soil permeability is too low (e.g. clayey soil or hard rock). In regions where annual evaporation is high, trees and shrubs can be used to help pump the water into the atmosphere by evapo-transpiration. An evapo-transpiration bed can be designed similar to a leach trench, but a suite of suitable local vegetation species tolerant of high nutrients and water are planted above and surrounding the trench (Fig.x). The trench should be sized to store water during the rainy season or low evaporation periods.

A leach pit or drain does not work either when the groundwater table is close to ground surface. In this case off-site disposal is necessary using a settled sewerage system. If the groundwater table is not too close, an inverted leach drain can be used.

The organic solids in a septic tank undergo anaerobic bacterial decomposition just as in the pit of a pit latrine. The sludge needs emptying, and the period between emptying is usually designed to be between 3 to 5 years. The sludge has to be further treated before reuse or disposal.

Figure 7: Evapo-transpiration Bed



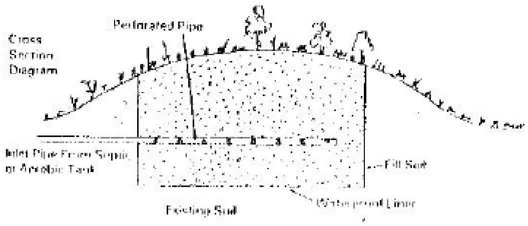
The septic tank overflow undergoes further bacterial decomposition as it percolates through a leach pit or trench. Soil bacteria, usually under aerobic conditions undertake the decomposition. The BOD of the wastewater can reach a low figure (<20 mg/L) if the distance between the bottom of the pit or trench to the groundwater table is greater than 2 m. Nutrients are not significantly removed by the bacteria and usually pollute the groundwater. Pathogenic bacteria are removed by die-off or filtration by the soil, but viruses may travel further in the soil or groundwater.

Percolation of septic tank overflow is much slower compared to rainwater percolation. This is because a layer of bacterial slime grows on the surfaces of the soil particles, restricting flow. Two leach pits or trenches used alternately, say every 6 months, are better than a single leach pit or trench of the same total area for percolation, because as one is used the other will recover its percolation rate.

EVAPO-TRANSPIRATION BEDS

Evapotranspiration Bed
(Used with Septic or Aerobic Tank)

sand bed is lined with plastic or other waterproof material. Bed could be mound or level. Liquid evaporates because liner prevents it from filtering through natural soil. Plants speed evaporation by drawing moisture from soil & breathing it into the air. Used where conventional absorption field not possible.



Technology Description:

The Evapo-transpiration Bed is a subsurface flow system designed with slopes of 1 % or slightly higher. The basin is excavated, lined (to reduce/prevent infiltration into the ground water) and packed with a porous medium (usually gravel). A layer of soil then covers the Evapo-transpiration Bed.

The main objective of the system is to treat the effluent leaving a secondary or advanced primary system by removing the remaining organic matter, nutrients and faecal coliform.

Treatment of the water in the Evapo-transpiration Bed takes place through the porous medium, the gravel. The vegetation plays a role by transferring oxygen through its roots to the bottom of the basin and providing a surface, in addition to the gravel, for attachment of the bacteria that performs most of the water treatment.

A properly sized Evapo-transpiration Bed would not have any effluent leaving the system as most water would either be evaporated or taken up by the roots of the plants, which would loose water through the leaves by transpiration.

Extent of Use:
Widely used in the Caribbean

Operation and Maintenance: No maintenance of system is required. System can be designed in a manner to prevent the outflow of effluent if effluent is not needed.

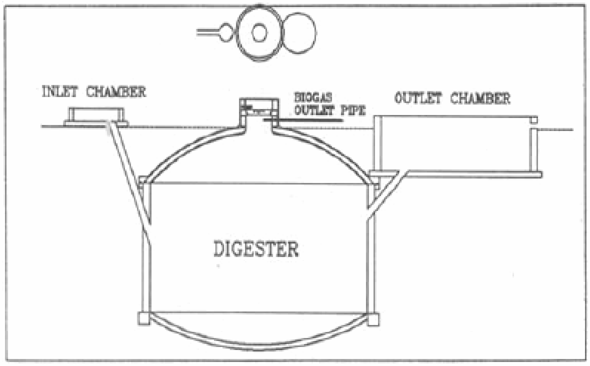
Advantages:	**Disadvantages /constraints:**
• High Effluent Quality • Land area is re-created as a green area	• Large land requirement
Relative Cost: • Low cost	**Cultural Acceptability:** • Widely accepted in the Caribbean
Energy Cost: • No energy required	**Pollution Reduction:** • 99 % Faecal Coliform • Polishing of organic matter and nutrients

Suitability:
- Suitable for most situations where land is available – Housing Development, Institutions etc.

Biodigester Units

Biodigester

(Biogas – Biofertilizer Plant)



Source: Scientific Research Council, Jamaica (1995)

Technology Description:

The biodigester system is a concrete tank used for the degradation of organic waste such as animal waste, sewage, green plants and plant waste and agro-industrial waste and wastewater to produce biogas and biofertilizer.

Technology Description continued

The technology does not work well with human excreta alone (see BST). The system utilizes the anaerobic technology (i.e. in the absence of air). When the organic material listed above is placed into the system it remains in the system for about thirty days (the retention time) during which bacteria break it down and produce biofertilizer (digested slurry) and biogas.

The gas is then collected in the dome of the digester and carried through PVC pipelines to different sources of use as stoves, refrigerators, and diesel engines, after scrubbing. The digested slurry is stored in the outlet chamber where it is then be trenched/piped to the field or dried and carried to the point of use.

The daily yield of biofertilizer corresponds to the amount of the daily input of fresh material while the daily quantity of gas corresponds to half the digester size.

Source: SRC www.jawmanins.com

Extent of Use:
Widely used in the Caribbean (e.g. Jamaica, Guyana, Barbados, Trinidad and Tobago, Grenada)

Operation and Maintenance:

- Low degree of operation and maintenance required (if gravity fed)
- Relatively low skilled personnel required
- Gas must be scrubbed before use

Advantages:

- Prevents pollution of groundwater
- Low potential for malodours
- Sludge can be used as bio-fertilizer
- Effluent utilised as liquid fertiliser
- Improve farm sanitation (fly/insect nuisance significantly reduced)

Disadvantages /constraints:

- skilled labour is required for the construction of a watertight tank

Relative Cost:

- Low capital cost (US$ 100/cubic meter)
- Low operation cost

Cultural Acceptability:

- Is generally accepted within the Caribbean

Energy Usage:

- Generated energy 0.5 m^3 methane/m^3 biodigester volume

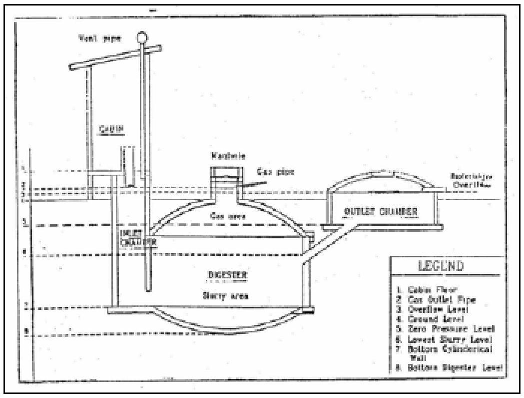
Pollution Reduction:

- 80% BOD and SS removal

Suitability/Appropriateness

- Farms, agro-industrial applications

Sanitary Bio-latrine Unit Source: Scientific Research Council, Jamaica (1995)



Source : SRC www.jawmanins.com

Technology Description:

The Bio-latrine Units are installations where the Biodigester plants have been built to collect the waste from a VIP latrine. From the cabin the faeces go directly into the inlet chamber and into the digester under gravity. The design and development of the SBU incorporates concepts from both VIP latrines and the agricultural biogas plant.

Within 120 days the bacteria degrades the excreta. The result of this process is biogas, a renewable source of energy. The digested process matter is then discharged automatically to the outlet chamber where it over flows to a tertiary treatment system.

The number of cabins and the size of the digester are determine by the number of persons using the system daily

Extent of Use:

- In Jamaica, in camping sites, inner city and rural communities

Operation and Maintenance:

- Low degree of operation and maintenance required
- Relatively low skilled personnel required
- Gas scrubbed before use

Advantages:

- No handling of human excreta
- Fly/insect nuisance significantly reduced
- Prevents underground water pollution
- No malodour
- Aesthetically improvement over VIP latrine
- Promotes good hygiene practices.

Disadvantages /constraints:

- Effluent requires tertiary treatment

Relative Cost:

- Higher capital costs than VIP latrines (US$ 100/cubic metres)
- Low operation cost

Cultural Acceptability:

- Is generally accepted within Jamaica

Energy Usage:

- Generate energy 1 m3/m3 sewage

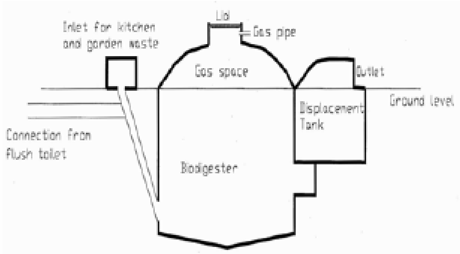
Pollution Reduction:

- > 75% BOD and SS removal

Suitability/Appropriateness

- Single households, institutions, small communities

<table>
<tr>
<td colspan="2">Biodigester Septic Tank (BST) Source: Scientific Research Council, Jamaica (1995)


</td>
<td>Technology Description:

The BST is an on-site sanitation unit, which provides for the disposal of toilet (black) wastewater as well as of kitchen and bathroom (grey) water.

The BST totally relies on the bioorganic breakdown of the organic waste. The biochemical process occurs under airless conditions and produces biogas and the liquid effluent.

The sizing of the system is determined by number of persons, wastewater generation rate and retention time (6 days).

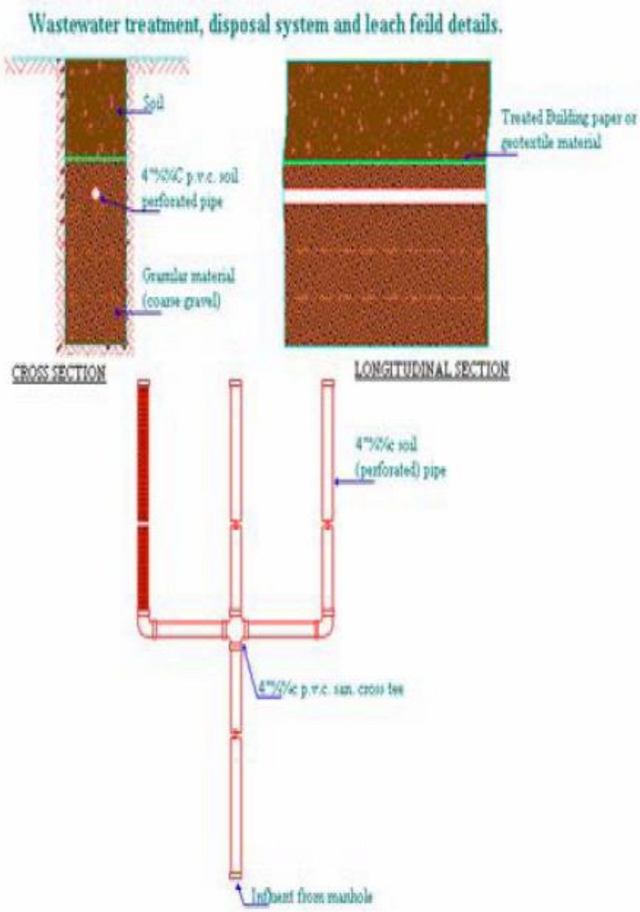
Source: SRC www.jawmanins.com

Extent of Use:
In Jamaica, in single households, apartment and townhouse complexes</td>
</tr>
<tr>
<td colspan="3">Operation and Maintenance:
• Low degree of operation and maintenance required
• Relatively low skilled personnel required
• Gas scrubbed before use</td>
</tr>
<tr>
<td>Advantages:
• No handling of human excreta
• Fly/insect nuisance significantly reduced
• Prevents underground water pollution
• No malodours
• Little or no sludge produced
• Improvement over traditional septic tank (solids treated)</td>
<td colspan="2">Disadvantages /constraints:
• Effluent requires tertiary treatment</td>
</tr>
<tr>
<td>Relative Cost:
• Higher capital costs than traditional septic tanks (US$ 100/cubic metre)
• Low operation cost</td>
<td colspan="2">Cultural Acceptability:
• Is generally accepted within Jamaica</td>
</tr>
<tr>
<td>Energy Usage:
• Generates energy 1 m^3/m^3 sewage</td>
<td colspan="2">Pollution Reduction:
• > 80% BOD and SS removal</td>
</tr>
<tr>
<td colspan="3">Suitability/Appropriateness
• Single households, apartment and townhouse complexes, institutions, small communities</td>
</tr>
</table>

Tile Field

Combined On-Site Wastewater Treatment and Disposal

Drain Field (French drain or tile field) Source: Daniel & Daniel Engineering, Inc



Technology Description

The septic tank is necessary pre-treatment, and is discussed earlier. The drain field is designed for the on-site disposal of sewage. It is an area of land consisting of one or several long trenches, into which sewage is discharged through underground perforated pipes which are surrounded by granular media. Alternatives to perforated pipes that may provide increased infiltration capacity are under development. The sewage percolates into the granular bed after which it is decomposed by bacteria in the soil. A geomembrane is placed above the granular bed that prevents silt from clogging the bed. Usually, one drain field receives the effluent from one septic tank.

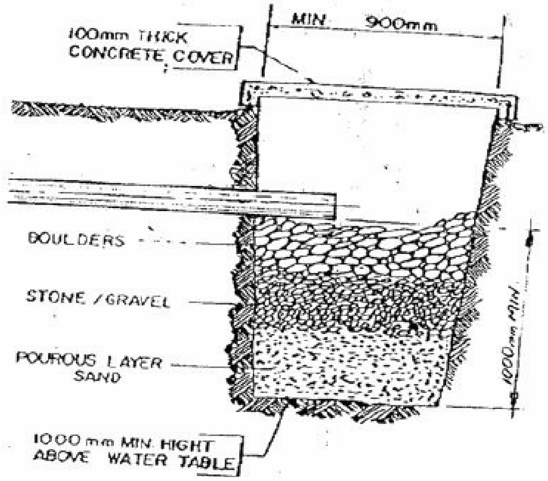
Tile fields should be sized to accept grey water. To prevent run-on, the tile field is usually slightly raised. The life of a drainage field can be extended by placing a solids filter on the outlet of the septic tank to prevent solids entering and blinding the drainage field.

<table>
<tr><td colspan="2">Extent of Use:
Low usage because of land availability and seepage pits are easier and cheaper to construct</td></tr>
<tr><td colspan="2">Operation and Maintenance:
• if constructed properly, no maintenance is required
• O & M reduced if septic tank or other system using trenches are maintained properly
• area should be grassed and heavy traffic avoided</td></tr>
<tr><td>Advantages:
• the construction of drain fields is simple
• better disposal method than seepage pits
• improved effluent quality</td><td>Disadvantages /constraints:
• large space requirements.
• since drain fields are based on soil absorption, there is a danger of groundwater contamination</td></tr>
<tr><td>Relative Cost:
• low to moderate as compared to sea outfall</td><td>Cultural Acceptability:
• culturally accepted</td></tr>
<tr><td>Energy use:
NA</td><td>Pollution reduction:
Further polishing of effluent achieved</td></tr>
<tr><td colspan="2">Suitability:
• very suitable to dispose of septic tank effluent where enough space is available, and where the soil has medium absorption capacity (not too slow, and not too fast resulting in ground water contamination)</td></tr>
</table>

Soakaway Pit

<table>
<tr>
<td colspan="2">Combined On-Site Wastewater Treatment and Disposal

Seepage Pit (Soakaway)



SOAKAWAY PIT
SECTIONAL ELEVATION</td>
<td colspan="2">Technology Description:

The seepage pit is designed for the on-site disposal of sewage effluent. It consists of an underground pit, the walls of which are usually stone packed. Through the voids in the packing material, effluent percolates into the soil, where microorganisms decompose the effluent.

Usually, one seepage pit receives the effluent from one septic tank.

The soakaway should be sized to accept greywater.

Percolation tests should be conducted for appropriate sizing of the pit.

Extent of Use:
Soakaway pits are extensively used in the Caribbean</td>
</tr>
<tr>
<td colspan="4">Operation and Maintenance:
• minimal maintenance is required.
• O & M reduced if septic tank or other system using trenches are maintained properly</td>
</tr>
<tr>
<td colspan="2">Advantages:
• the construction of a seepage pit is simple</td>
<td colspan="2">Disadvantages /constraints:
• there is a danger of groundwater contamination</td>
</tr>
<tr>
<td colspan="2">Relative Cost:
• low compared to tile field</td>
<td colspan="2">Cultural Acceptability:
• culturally accepted</td>
</tr>
<tr>
<td colspan="2">Energy use:
NA</td>
<td colspan="2">Pollution reduction:
Further polishing achieved</td>
</tr>
<tr>
<td colspan="4">Suitability:
• suitable to dispose of septic tank effluent where groundwater table is not high.</td>
</tr>
</table>

Mound Systems

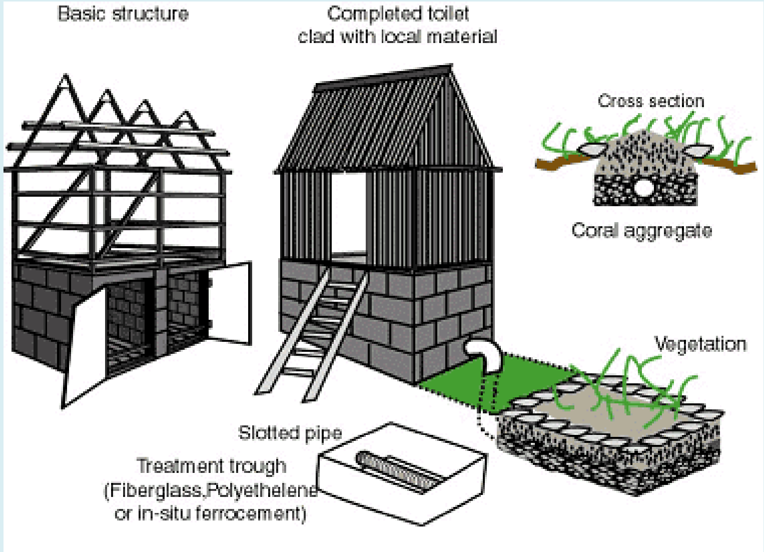
Combined On-Site Wastewater Treatment and Disposal **Mound systems (raised bed)**   Source: Daniel and Daniel Engineering Inc.	**Technology Description:** Mounds are used for those soil and site conditions where conventional disposal trenches are unsuited due to shallow soils overlaying rock, or where water tables are high in permeable soils. The mound provides for distribution of effluent onto a layer of suitable material of sufficient depth (around 600mm) to ensure satisfactory remediation before entering the natural soil and then diffuse into the water table. The mound can be constructed directly on the natural ground surface, which may be ploughed or cultivated beforehand. Wastewater treatment takes place within the fill of the mound, enabling the unit to be placed in freely permeable or slowly permeable sub-soils. The mound should be sized to accept greywater. Percolation tests should be conducted for appropriate sizing of the mound. **Extent of Use:** low usage in the Caribbean Region
Operation and Maintenance: • minimum maintenance is required • O & M reduced if septic tank or other system using trenches is maintained properly	
Advantages: • the construction of mounds is simple • better disposal method than seepage pits • increases the evapo-transpiration rate	**Disadvantages /constraints:** • large space requirements. • there is a danger of groundwater contamination
Relative Cost: • higher cost than a tile field	**Cultural Acceptability:** • culturally accepted
Energy use: • NA	**Pollution reduction:** Further polishing achieved
Suitability: • suitable to dispose of septic tank effluent where groundwater table is not high.	

Composting Toilet

Rather than the decomposition of the faecal sludge under anaerobic conditions (no oxygen) in the pit of a pit latrine, decomposition under aerobic conditions (with oxygen) can be promoted in an above ground (elevated) latrine. Air can be introduced through an opening to pass through the sludge and exit through the vent, while excess liquid is allowed to drain for collection or evaporation.

With two adjoining composting chambers or vaults used alternately, the process of composting in an already full chamber can be allowed to proceed until the chamber is to be used again, and produce mature compost for direct re-use in the garden. Other household organic wastes (e.g. food wastes) can be added to the faecal sludge, and materials such as newspaper or sawdust can be added to balance the carbon to nitrogen ratio for optimal composting. Because mature compost takes several months to produce under ambient temperatures, it is desirable for the chambers to be sized to hold at least 6 months of waste. Worms can also be added to assist with vermi-composting.

Figure 8: Composting Toilet



<table>
<tr>
<td>On-Site Wastewater Treatment

Composting Toilets

Construction of composting toilet in Fiji (Courtesy SOPAC).</td>
<td>Treatment Information

Composting is a natural process through which organic material is decomposed and returned to the soil producing a valuable soil conditioner (humus). In a composting toilet, water is not used at all and human waste and other organic materials (carbon source) are deposited into a digestion chamber where aerobic bacteria decompose solid portions and liquids are left to evaporate through a specially designed ventilation system.

Digestion chambers will take a certain period of time to fill up depending on the particular system. Once full the chamber is left to compost over a period of weeks. During this time a second chamber is used. Finished compost can be cautiously removed avoiding contact with hands and can be dug into the garden or trenched around roots of trees.

Extent of Use:
• Used to a limited extent in Dominica</td>
</tr>
<tr>
<td colspan="2">Operation and Maintenance:
• composting toilet systems require bulking material as a carbon source (wood chips, dried leaves, coconut husks, food waste etc.)
• Requires manual removal and disposal of finished composting material after a period of time.</td>
</tr>
<tr>
<td>Advantages:
• Low land space requirements
• Low operational and maintenance requirements
• No water required
• Does not pollute groundwater
• Produces valuable soil conditioner</td>
<td>Disadvantages /constraints:
• compost may still be contaminated if not fully matured
• Manual labour required</td>
</tr>
<tr>
<td>Relative cost:
• higher than traditional latrines</td>
<td>Cultural Acceptability:
• Limited acceptance within the Caribbean region</td>
</tr>
<tr>
<td>Energy use:
• NA</td>
<td>Pollution reduction:
• NA</td>
</tr>
<tr>
<td colspan="2">Suitability:
• Suitable for rural and agricultural areas</td>
</tr>
</table>

Improved On-site Treatment Units

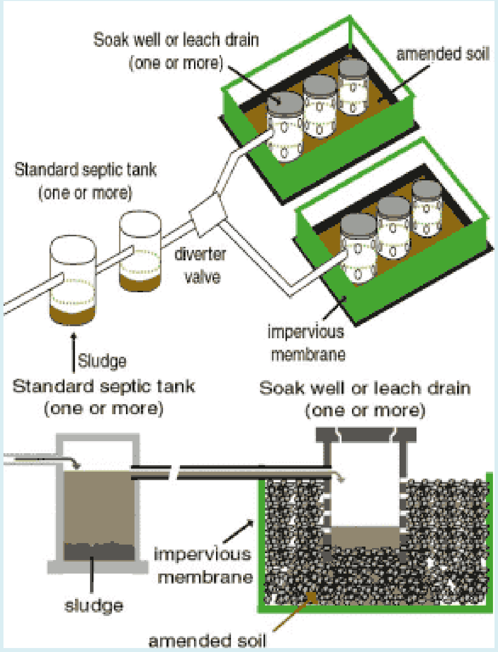
Improved on-site treatment units refer to treatment units that improve the performance of traditional on-site disposal systems, including soak-aways, pit privies and septic tanks, by reducing BOD, Suspended Solids (SS) and/or nutrients. A principal aim of the improvements is to prevent groundwater pollution or enable water reuse of the treated wastewater on-site. Many designs are available using similar principles.

Inverted trench

In the system illustrated in **Error! Reference source not found.**, a plastic or impermeable liner underlies the trench of the septic tank. The liner is filled with sand or a fairly permeable soil. Overflow from the septic tank is introduced at the base of the sand layer. It flows up through the sand layer and flows over into the surrounding soil. The sand layer acts as a slow sand filter, where bacteria growing on the surfaces of the sand particles degrade the organic substances to reduce BOD.

Because of the fluctuating flow of wastewater with peak flows in the morning and in the evening, the upper region of the sand layer alternates between aerobic and anaerobic conditions. Under these conditions a significant part of nitrogen in the wastewater can be removed by nitrification (bacterial conversion of ammonium in the wastewater to nitrate under aerobic conditions) and denitrification (bacterial conversion of nitrate to nitrogen gas under anaerobic conditions. In addition if materials that can remove phosphate are mixed with the sand, phosphorus in the wastewater is also removed. One material, that has been found to remove phosphate effectively with a capacity for phosphorus removal for several years, is bauxite refining residue (red mud).

Figure 9: Inverted Trench (Ecomax)

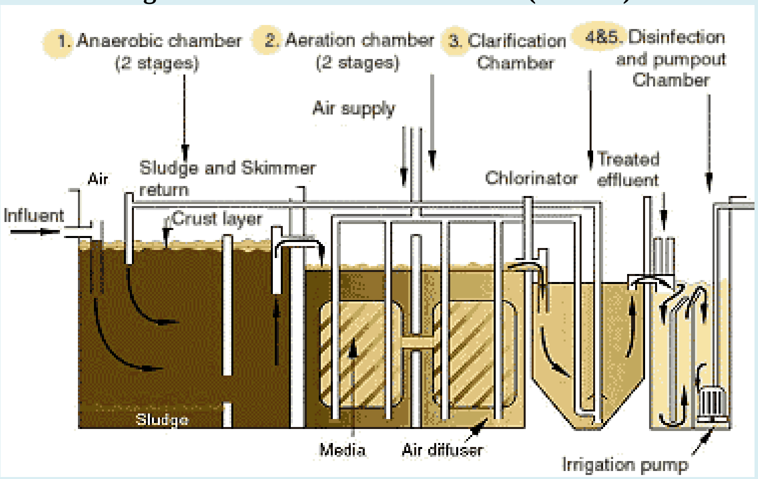


Aerobic Treatment Unit

An aerated treatment unit consists of a tank similar to a septic tank. The tank is partitioned into four compartments (Figure x). The first compartment receives the wastewater and acts as a sedimentation tank for solids. The overflow from the first compartment goes to an aeration compartment. The aeration compartment is fitted with corrugated plastic sheets to enable bacteria to attach themselves. The aeration supplies oxygen to the bacteria decomposing the organic matter in the wastewater thus reducing its BOD.

After aeration, the wastewater passes to a third compartment which acts as a second sedimentation tank. Sludge from this second sedimentation tank is pumped to the first compartment for storage. After sedimentation the wastewater overflows to a fourth compartment for storage and pumping, usually for irrigation of garden beds. If required, chlorine is applied by inserting chlorine tablets in the pipe between the third and fourth compartments. Chlorination is required when sprinklers irrigate the treated wastewater. Sub-surface irrigation is preferable, because it does not require chlorination.

Figure 10: Aerated Treatment Unit (Biomax)



Power is required for aeration and pumping. For a system serving a household of up to 10 persons, the power supply rating needed is 100 W (2.5 kWh per day). This on-site unit is a miniature of an activated sludge treatment plant usually used for centralised treatment. One difference is that surfaces are provided in the aeration tank to retain bacteria during peak flows. The other difference is that sludge from the second sedimentation tank is returned to first tank for storage.

2.2.3 *Wastewater Reuse*

Once freshwater has been used for an economic or beneficial purpose, it is generally discarded as waste. In many countries, these wastewaters are discharged, either as untreated waste or as treated effluent, into natural watercourses, from which they are abstracted for further use after undergoing "self-purification" within the stream. Through this system of indirect reuse, wastewater may be reused up to a dozen times or more before being discharged to the sea.

Such indirect reuse is common in the larger river systems of the WCR countries. However, more direct reuse is also possible: the technology to reclaim wastewaters as potable or process waters is a technically feasible option for agricultural and some industrial purposes (such as for cooling water or sanitary flushing), and a largely experimental option for the supply of domestic water. Wastewater reuse for drinking raises public health, and possibly religious, concerns among consumers. The adoption of wastewater treatment and subsequent reuse as a means of supplying freshwater is also determined by economic factors.

In many countries, water quality standards have been developed governing the discharge of wastewater into the environment. Wastewater, in this context, includes sewage effluent, stormwater runoff, and industrial discharges. The necessity to protect the natural environment from wastewater-related pollution has led to much improved treatment techniques. Extending these technologies to the treatment of wastewaters to potable standards was a logical extension of this protection and augmentation process.

Wastewater Treatment for Reuse

One of the most critical steps in any reuse program is to protect the public health, especially that of workers and consumers. To this end, it is most important to neutralize or eliminate any infectious agents or pathogenic organisms that may be present in the wastewater. For some reuse applications, such as irrigation of non-food crop plants, secondary treatment may be acceptable. For other applications, further disinfection, by such methods as chlorination or ozonation, may be necessary. Table x below presents a range of typical survival times for potential pathogens in water and other media.

Table 14: Typical Pathogen Survival Times at 20 - 30°C (in days)

Pathogen	Freshwater and sewage	Crops	Soil
Viruses	< 120 but usually <50	<60 but usually < 15	<100 but usually <20
Bacteria	<60 but usually <30	<3 0 but usually < 15	<70 but usually <20
Protozoa	<30 but usually <15	<10 but usually <2	<70 but usually <20
Helminths	Many months	<60 but usually <30	Many months

Source: UNEP-CEP, 1997

A typical example of wastewater reuse is the system at the Sam Lords Castle Hotel in Barbados. Effluent consisting of kitchen, laundry, and domestic sewage ("gray water") is collected in a sump, from which it is pumped, through a comminutor, to an aeration chamber. No primary sedimentation is provided in this system, although it is often desirable to do so. The aerated mixed liquor flows out of the aeration chamber to a clarifier for gravity separation.

The effluent from the clarifier is then passed through a 16-foot-deep chlorine disinfection chamber before it is pumped to an automatic sprinkler irrigation system. The irrigated areas are divided into sixteen zones; each zone has twelve sprinklers. Some areas are also provided with a drip irrigation system. Sludge from the clarifier is pumped, without thickening, as a slurry to suckwells, where it is disposed of. Previously the sludge was pumped out and sent to the Bridgetown Sewage Treatment Plant for further treatment and additional desludging.

Extent of Use

For health and aesthetic reasons, reuse of treated sewage effluent is presently limited to non-potable applications such as irrigation of non-food crops and provision of industrial cooling water. There are no known direct reuse schemes using treated wastewater from sewerage systems for drinking. Indeed, the only known systems of this type are experimental in nature, although in some cases treated wastewater is reused indirectly, as a source of aquifer recharge.

Table x below presents some guidelines for the utilization of wastewater, indicating the type of treatment required, resultant water quality specifications, and appropriate setback distances. In general, wastewater reuse is a technology that has had limited use, primarily in small-scale projects in the region, owing to concerns about potential public health hazards.

Wastewater reuse in the Caribbean is primarily in the form of irrigation water. In Jamaica, some hotels have used wastewater treatment effluent for golf course irrigation, while the major industrial water users, the bauxite/alumina companies, engage in extensive recycling of their process waters. In Barbados, effluent from an extended aeration sewage treatment plant is used for lawn irrigation. Similar use of wastewater occurs on Curaçao.

Table 15: Guidelines for Water Reuse

Type of Reuse	Treatment Required	Reclaimed Water Quality	Recommended Monitoring	Setback Distances
AGRICULTURAL Food crops commercially processed Orchards and Vineyards	Secondary Disinfection	pH = 6-9	pH weekly	300 ft from potable water supply wells
		BOD = 30 mg/l	BOD weekly	
		SS = 30 mg/l	SS daily	
		FC = 200/100 ml	FC daily	100 ft from areas accessible to public
		Cl_2 residual = 1 mg/l min.	Cl_2 residual continuous	
PASTURAGE	Secondary	pH = 6-9	pH weekly	300 ft from

Pasture for milking animals Pasture for livestock	Disinfection	BOD = 30 mg/l	BOD weekly	potable water supply wells
		SS = 30 mg/l	SS daily	
		FC = 200/100 ml	FC daily	100 ft from areas accessible to public
		Cl_2 residual = 1 mg/l min.	Cl_2 residual continuous	
FORESTATION	Secondary Disinfection	pH = 6-9	pH weekly	300 ft from potable water supply wells
		BOD = 30 mg/l	BOD weekly	
		SS = 30 mg/l	SS daily	
		FC = 200/100 ml	FC daily	100 ft from areas accessible to the public
		Cl_2 residual = 1 mg/l min.	Cl_2 residual continuous	
AGRICULTURAL Food crops not commercially processed	Secondary Filtration Disinfection	pH = 6-9	pH weekly	50 ft from potable water supply wells
		BOD = 30 mg/l	BOD weekly	
		Turbidity = 1 NTU	Turbidity daily	
		FC = 0/100 ml	FC daily	
		Cl_2 residual = 1 mg/l min.	Cl_2 residual continuous	
GROUNDWATER RECHARGE	Site-specific and use-dependent	Site-specific and use-dependent	Depends on treatment and use	Site-specific

Source: UNEP-CEP, 1997

In Latin America, treated wastewater is used in small-scale agricultural projects and, particularly by hotels, for lawn irrigation. In Chile, up to 220 l/s of wastewater is used for irrigation purposes in the desert region of Antofagasta. In Brazil, wastewater has been extensively reused for agriculture. Treated wastewaters have also been used for human consumption after proper disinfection, for industrial processes as a source of cooling water, and for aquaculture.

Wastewater reuse for aquacultural and agricultural irrigation purposes is also practiced in Lima, Peru. In Argentina, natural systems are used for wastewater treatment. In such cases, there is an economic incentive for reusing wastewater for reforestation, agricultural, pasturage, and water conservation purposes, where sufficient land is available to do so. Perhaps the most extensive reuse of wastewater occurs in Mexico, where there is large-scale use of raw sewage for the irrigation of parks and the creation of recreational lakes.

In the United States, the use of reclaimed water for irrigation of food crops is prohibited in some states, while others allow it only if the crop is to be processed and not eaten raw. Some states may hold, for example, that if a food crop is irrigated in such a way that there is no contact between the edible portion and the reclaimed water, a disinfected, secondary-treated effluent is acceptable. For crops that are eaten raw and not commercially processed, wastewater reuse is more restricted and less economically attractive. Less stringent requirements are set for irrigation of non-food crops.

International water quality guidelines for wastewater reuse have been issued by the World Health Organization (WHO). Guidelines should also be established at national level and at the local/project level, taking into account the international guidelines. Some national standards that have been developed are more stringent than the WHO guidelines. In general, however, wastewater reuse regulations should be strict enough to permit irrigation use without undue health risks, but not so strict as to prevent its use. When using treated wastewater for irrigation, for example, regulations should be written so that attention is paid to the interaction between the effluent, the soil, and the topography of the receiving area, particularly if there are aquifers nearby.

The application of wastewater to land (for irrigation) may be by:

- Surface flow: Wastewater is applied at one end of an area and allowing it to spread to the other end by gravity. Runoff control may be a problem.
- Sprinkler distribution: Wastewater is applied by over-ground sprinklers (either stationary or moving). Normally pumping is required and as a result aerosols may be produced.
- Subsurface and localised irrigation: This includes the use of drip and trickle irrigation methods which require a good quality effluent to avoid clogging. Using these methods could reduce microbial contamination of crops.

The following table provides information on selecting a suitable application method for land disposal of wastewater.

Table 16: Factors affecting choice of irrigation method, and special measures required when wastewater is used.

Irrigation Method	Factors Affecting Choice	Special Measures for Wastewater
Border (flooding) irrigation	Lowest cost, exact levelling not required	Thorough protection for field workers, crop handlers and consumers
Furrow irrigation	Low cost levelling may be needed	Protection for field workers, possible crop handlers and consumers
Sprinkler irrigation	Medium water use efficiency, levelling not required	Some crops, especially tree fruit, should not be grown. Minimum distance 50 – 100m from houses and roads. Anaerobic wastes should not be used because of odour nuisance
Subsurface and localised irrigation	High cost, high water use efficiency, higher yields	Filtration to prevent clogging of emitters

Source: Mara and Cairncross, (1989)

Operation and Maintenance

The operation and maintenance required in the implementation of this technology is related to the previously discussed operation and maintenance of the wastewater treatment processes, and to the chlorination and disinfection technologies used to ensure that pathogenic organisms will not present a health hazard to humans.

Additional maintenance includes the periodic cleaning of the water distribution system conveying the effluent from the treatment plant to the area of reuse; periodic cleaning of pipes, pumps, and filters to avoid the deposition of solids that can reduce the distribution efficiency; and inspection of pipes to avoid clogging throughout the collection, treatment, and distribution system, which can be a potential problem. Further, it must be emphasized that, in order for a water reuse program to be successful, stringent regulations, monitoring, and control of water quality must be exercised in order to protect both workers and the consumers.

Level of Involvement

The private sector, particularly the hotel industry and the agricultural sector, are becoming involved in wastewater treatment and reuse. However, to ensure the public health and protect the environment, governments need to exercise oversight of projects in order to minimize the deleterious impacts of wastewater discharges. One element of this oversight should include the sharing of information on the effectiveness of wastewater reuse. Government oversight also includes licensing and monitoring the performance of the wastewater treatment plants to ensure that the effluent does not create environmental or health problems.

Costs

Cost data for this technology are very limited. Most of the data relate to the cost of treating the wastewater prior to reuse. Additional costs are associated with the construction of a dual or parallel distribution system. In many cases, these costs can be recovered out of the savings derived from the reduced use of potable freshwater (i.e., from not having to treat raw water to potable standards when the intended use does not require such extensive treatment).

The feasibility of wastewater reuse ultimately depends on the cost of recycled or reclaimed water relative to alternative supplies of potable water, and on public acceptance of the reclaimed water. Costs of effluent treatment vary widely according to location and level of treatment (see the previous section on wastewater treatment technologies). The degree of public acceptance also varies widely depending on water availability, religious and cultural beliefs, and previous experience with the reuse of wastewaters.

Effectiveness of the Technology

The effectiveness of the technology, while difficult to quantify, is seen in terms of the diminished demand for potable-quality freshwater and, in the Caribbean islands, in the diminished degree of degradation of water quality in the near-shore coastal marine environment, the area where untreated and unreclaimed wastewaters were previously disposed.

The analysis of beach waters in Jamaica indicates that the water quality is better near the hotels with wastewater reuse projects than in beach areas where reuse is not practiced: Beach #1 in Table 20 is near a hotel with a wastewater reuse project, while Beach #2 is not. From an aesthetic point of view, also, the presence of lush vegetation in the areas where lawns and plants are irrigated with reclaimed wastewater is further evidence of the effectiveness of this technology.

Table 17: Water Quality of Beach Water in Wastewater Reuse Project in Jamaica

Site	BOD	TC	FC	NO_3
Beach # 1	0.30	<2	<2	0.01
Beach # 2	1.10	2.400.00	280.00	0.01

Source: UNEP-CEP, 1997

Suitability

This technology has generally been applied to a small-scale projects, primarily in areas where there is a shortage of water for supply purposes. However, this technology can be applied to larger-scale projects. In many developing countries, especially where there is a water deficit for several months of the year, implementation of wastewater recycling or reuse by industries can reduce demands for water of potable quality, and also reduce impacts on the environment.

Large-scale wastewater reuse can only be contemplated in areas where there are reticulated sewerage and/or stormwater systems. (Micro-scale wastewater reuse at the household or farmstead level is a traditional practice in many agricultural communities that use night soils and manures as fertilizers.) Urban areas generally have sewerage systems, and, while not all have stormwater systems, those that do are ideal localities for wastewater reuse schemes.

Wastewater for reuse must be adequately treated, biologically and chemically, to ensure the public health and environmental safety. The primary concerns associated with the use of sewage effluents in reuse schemes are the presence of pathogenic bacteria and viruses, parasite eggs, worms, and helminths (all biological concerns) and of nitrates, phosphates, salts, and toxic chemicals, including heavy metals (all chemical concerns) in the water destined for reuse.

Advantages

- This technology reduces the demands on potable sources of freshwater.
- It may reduce the need for large wastewater treatment systems, if significant portions of the waste stream are reused or recycled.

- The technology may diminish the volume of wastewater discharged, resulting in a beneficial impact on the aquatic environment.
- Capital costs are low to medium, for most systems, and are recoverable in a very short time; this excludes systems designed for direct reuse of sewage water.
- Operation and maintenance are relatively simple except in direct reuse systems, where more extensive technology and quality control are required.
- Provision of nutrient-rich wastewaters can increase agricultural production in water-poor areas.
- Pollution of seawater, rivers, and groundwaters may be reduced.
- Lawn maintenance and golf course irrigation is facilitated in resort areas.
- In most cases, the quality of the wastewater, as an irrigation water supply, is superior to that of well water.

Disadvantages

- If implemented on a large scale, revenues to water supply and wastewater utilities may fall as the demand for potable water for non-potable uses and the discharge of wastewaters is reduced.
- Reuse of wastewater may be seasonal in nature, resulting in the overloading of treatment and disposal facilities during the rainy season; if the wet season is of long duration and/or high intensity, the seasonal discharge of raw wastewaters may occur.
- Health problems, such as water-borne diseases and skin irritations, may occur in people coming into direct contact with reused wastewater.
- Gases, such as sulfuric acid, produced during the treatment process can result in chronic health problems.
- In some cases, reuse of wastewater is not economically feasible because of the requirement for an additional distribution system.
- Application of untreated wastewater as irrigation water or as injected recharge water may result in groundwater contamination.

Cultural Acceptability

A large percentage of domestic water users are afraid to use this technology to supply of potable water (direct reuse) because of the potential presence of pathogenic organisms. However, most people are willing to accept reused wastewater for golf course and lawn irrigation and for cooling purposes in industrial processes. On the household scale, reuse of wastewaters and manures as fertilizer is a traditional technology.

Further Development of the Technology

Expansion of this technology to large-scale applications should be encouraged. Cities and towns that now use mechanical treatment plants that are difficult to operate, expensive to maintain, and require a high skill level can replace these plants with the simpler systems; treated wastewater can be reused to irrigate crops, pastures, and lawns. In new buildings, plumbing fixtures can be designed to reuse wastewater, as in the case of using gray water from washing machines and kitchen sinks to flush toilets and irrigate lawns. Improved public education to ensure awareness of the technology and its benefits, both environmental and economic, is recommended.

Table 18: Summary Comparison of Design Considerations for Appropriate Treatment and Disposal Systems

Appropriate Technology	Relative Cost (High, Medium, Low)	Level of O&M	Environmentally-Friendly	Cultural-acceptability	Use in WCR	Potential barriers to Implementation
Rotating Biological Contractors	High	Skilled labour required	Yes	Yes	Not widely used. Used successfully in St. Kitts and St. Lucia	High energy requirement Energy required on a 24/7 basis for bacterial activity
Sequential Batch Reactors	High	High O&M Requires skilled installation	High	Yes	Limited use. Growing use in Antigua, St. Kitts, T&T, Barbados and St. Lucia	Requires electricity Only receives liquid waste. Requires reliable water supply
Membrane Reactor	Moderate		High	Yes	Increasing use within the region	Requires electricity Requires reliable water supply
Imhoff Tanks	Low	Requires removal of scum and sludge at regular intervals	Moderate	Yes	Limited use in the Caribbean	Effluent requires tertiary treatment
Activated Sludge Process	High	Skilled labour required	High	Yes	Widely used	High energy requirement for bacterial activity
Constructed Wetland	Low	Low. Plants require maintenance/ manual harvesting	High	Yes. Growing	Moderate use (St. Lucia, Grenada, Jamaica).	Large land area Pest/ insect control
Anaerobic Ponds	Low	Low	High	Yes	Increasing use in the region.	Land space Pest and odour control
Facultative Ponds	Low	High	Moderate	Yes	Increasing use in the region.	Land space High energy use if mechanical aerators are used
Maturation Ponds	Low	Low	High	Yes	Increasing use in the region.	Land space
Upflow Anaerobic Sludge Blanket (USAB) Reactor	Low	Low	High	Limited	In Jamaica for agro-industrial wastewater and centralised sewerage systems.	Start up time not immediate
Conventional Sewerage	High	High	Moderate	Yes	Widely used in major cities	Technology requiring skilled engineers High, reliable water supply
Small Bore (Settled) Sewerage	Low	High. Skilled personnel	Moderate	Yes	Increasing use e.g. Grenada	Technology requiring skills engineers

Appropriate Technology	Relative Cost (High, Medium, Low)	Level of O&M	Environmentally-Friendly	Cultural-acceptability	Use in WCR	Potential barriers to Implementation
		required. Maintenance and cleaning of septic tanks.				High, reliable piped water supply
Cluster Systems	Moderate	Low	Moderate	Yes	Used in the region	More than one collection and disposal system
Dual Distribution (Reticulation) Systems	High	High	Moderate	Yes	Used in US Virgin Islands, Turks and Caicos, the Bahmas, Cayman Islands	Technology requiring skilled expertise
Cistern-Flush Toilet	Low	Moderate		Yes	Used extensively	High, reliable water supply
Pour-Flush Toilet	Low	Low			Limited use in the region	Requires storage and handling of water
Ecological Sanitation	Low	Moderate			Not widely used	
Pit Latrine	Low	Low	Low	Yes	Widely used especially in rural areas	
Ventilated Improved Pit (VIP) Latrine	Low	Low	Moderate		Actively promoted	
Pour-flush Latrine	Low	Low	Moderate	Yes	Not commonly used	
Septic Tank	Low			Yes	Used extensively	Effluent requires further treatment
Septic Tank with Evapo-transpiration Bed	Low	Low	High	Yes	Widely used	Large land area required
Biodigester	Low	Low	High	Yes	Widely used (e.g. Jamaica, Guyana, Barbados, T&T, Grenada)	Skilled labour required for construction
Sanitary Bio-latrine Unit		Low	Moderate	Yes	Limited use in Jamaica in camping sites and inner city and rural communities	Effluent requires tertiary treatment
Biodigester Septic Tank	Low	Low. Relatively skilled personnel required	High	Yes	Used in Jamaica in single households, apartments and townhouse complexes	Effluent requires tertiary treatment
Tile Field (with septic tank)	Low to moderate	Low if constructed properly	Moderate	Yes	Low usage	Large space rquirements
Soakaway (Seepage) Pit	Low	Low	Low to Moderate	Yes	Used extensively	

Appropriate Technology	Relative Cost (High, Medium, Low)	Level of O&M	Environmentally-Friendly	Cultural-acceptability	Use in WCR	Potential barriers to Implementation
Mound Systems (Raised Bed)	Low	Low		Yes	Low usage in the Caribbean	Large space requirement
Composting Toilet	Low	Requires occasional manual removal of finished composting material	Yes	No	Used to a limited extent in Dominica	Time for maturation of compost

Section 3: Barriers to Adopting Alternative Technologies - Underlying Issues and Challenges

Certain general criteria and issues must be considered in the adoption of innovative and appropriate technologies, some of which were discussed in the previous section. Failure to do so is likely to result in poor uptake of the technology and management failures in the long run. Therefore, consideration should be given to:

- Technical feasibility
- Environmental sustainability
- Financial sustainability
- Institutional manageability
- Legality and policy conflicts
- Cultural acceptability

However, a 1992 report prepared by CEHI (Assessment of Operational Status of Wastewater Treatment Plants in the Caribbean) cited several interrelated reasons for the low status of operation of treatment plants in the Caribbean region. These included:

- Lack of adequate regulations and approval procedures;
- Limited inspection procedures and programmes;
- Poor financial resources allocations;
- Weak operational skills and process understanding;
- Absence of operation and maintenance manuals;
- Limited operational support and service contracts;
- Lack of maintenance and absence of preventative maintenance;
- Inadequate process monitoring and inadequate laboratory facilities;
- Inappropriate selected technologies; and
- Unavailability of spare parts.

Technical Feasibility

The average, or typical, efficiency and performance of the technology should be examined within the context of the prevailing conditions of the proposed site. This is usually the criterion considered to be best in comparative studies. Certain critical questions must be asked including: Is the proposed technology likely to accomplish its purpose in the circumstances where it would be used? More specifically, is it technologically feasible and appropriate, given the financial and human resources available?

The possibility that the technology might remove other contaminants than those which were the prime target should also be considered an advantage. Similarly, the pathways and fate of the removed pollutants after treatment should be analysed, especially with regard to the disposal options for the sludges in which the micro-pollutants tend to concentrate.

The reliability and durability of the technology is a critical factor. The process should, preferably, be stable and resilient against shock loading, i.e. it should be able to continue operation and to produce an acceptable effluent under unusual conditions. Therefore, the system must accommodate the normal inflow variations, as well as infrequent, yet expected, more extreme conditions. This pertains to the wastewater characteristics (e.g. occasional illegal discharges, variations in flow and concentrations, high or low temperatures) as well as to the operational conditions (e.g. power failure, pump failure, poor maintenance). During the design phase, "what if scenarios should be considered. Once disturbed, the process should be fairly easy to repair and to restart.

The effectiveness of existing sewage collection and treatment facilities in the WCR is usually constrained by limited capacity, poor maintenance, process malfunction, poor maintenance practices, and lack of experienced or properly trained staff.

Technical and technological capacity is considered by CEHI to be a major weakness within the region (source). The technical capability to design and implement wastewater management projects varies greatly among countries and utilities in the region. Many utilities have completed feasibility studies, cost benefit analysis, and preliminary design work for pending projects; some have developed long-term capital plans but not specific project preparation. Virtually all projects would benefit from external technical assistance to reach financing stage.

Several of the wastewater infrastructure improvement projects no ongoing in the region are donor funded, and countries are supported by technical expertise provided by donors. The greatest value proposition for technical assistance is financial structuring and design for projects. However, a bank of local technical knowledge and skills must also be built for sustainability.

Environmental Sustainability

The environmental benefits and costs of the system must be assessed in relation to cost and culture. This assessment may, therefore, beg the question: Could the environmental soundness of the proposed practice be significantly enhanced by a small increase in costs? If so, do the environmental benefits justify budgeting for these costs?

Resource recovery contributes to environmental as well as to financial sustainability. It can include agricultural irrigation, aqua- and pisci-culture, industrial cooling and process water re-use, or low-quality applications such as toilet flushing. The use of generated sludges can only be considered as crop fertilisers or for reclamation if the micro-pollutant concentration is not prohibitive, or the health risks are not acceptable.

Financial Sustainability

On one hand, it can be argued that the lower the financial costs, the more attractive the technology will be. However, even a low cost option may not be financially sustainable, because this is determined by the true availability of funds provided by the polluter. In the case of domestic sanitation, the people must be willing and able to cover at least the operation and maintenance cost of the total expenses. The ultimate goal should be full cost recovery although, initially, this may need special financing schemes, such as cross-subsidisation, revolving funds, and phased investment programmes.

The sustainability of financing is a major limiting factor in WCR countries. The broad conclusion of the Assessment of Operational Status of Wastewater Treatment Plants in the Caribbean (CEHI, 1992) study was that the performance of the treatment plants was generally poor, and this was accounted for as a result of poor maintenance and management owing to poor financial resources for these activities.

In the Caribbean, the primary source of funding for wastewater management initiatives is annual grants to utilities from the central government. Some countries engage in borrowing arrangements, and in a one case (Grenada), financing comes from the national social security fund.

The countries of Central America typically fund projects through grants and loans from central government to local water providers, while in Mexico grants are received from Federal Government to state provider along with private investment from the concessionaire (in Cancún). Prospects for sustainable private investment and financing are more advanced in South America thorough PPPs and public sector financing (e.g., in Colombia from FINDETER, a national government lending agency).

Within the Wider Caribbean Region, some of the main challenges to private sector financing of wastewater projects include:

- Difficult sector for attracting private capital, operational skills, and management expertise;
- High capital intensity;
- Political pressure on tariffs and conviction of water and wastewater services as a “free” good;
- Deficient regulations;
- Lack of sub-sovereigns access to financing;
- Poor condition and insufficient knowledge of networks and customer bases;
- Currency mismatch between revenues and financing sources;
- Local governments and utilities lack the financial capacity or regulatory framework and governance to act as credible financial partners; and

- Low level of risk mitigation instruments.

Utilities and countries in the WCR tend to engage in opportunistic capital planning based on availability of donor or government funds – projects based on eligibility for donor assistance or local political pressure. This places many countries at a disadvantage because is does not always ensure good planning and the best value for money.

Institutional Manageability

The technology options selected should be administratively feasible and sensible. This is an important consideration which should never be over-looked. In developing countries few governmental agencies are adequately equipped for wastewater management. In order to plan, design, construct, operate and maintain treatment plants, appropriate technical and managerial expertise must be present. This could require the availability of a substantial number of engineers with postgraduate education in wastewater engineering, access to a local network of research for scientific support and problem solving, access to good quality laboratories, and experience in management and cost recovery.

In addition, all technologies (including those thought "simple") require devoted and experienced operators and technicians who must be generated through extensive education and training. There may also be need to involve the informal sector and small and micro enterprises, and to develop feedback mechanisms to ensure stakeholder satisfaction.

With very few exceptions, the existing institutional framework for wastewater management within the Wider Caribbean Region is generally weak and is characterised by diverse ownership structures with some sub-regional groupings.

Wastewater treatment is last priority of water utilities, taking a back seat to water supply in favour of political advantages, and covered sewage systems in the interest of avoiding health concerns. Sewage treatment is often seen as a burdensome activity involving higher maintenance costs and lower socio-economic or political gain. According to UNEP/GPA (2006) the high costs of building and maintaining traditional sewage treatment plants are frequently the reason for not treating sewage before its disposal.

Within the Caribbean region (e.g. Jamaica, St. Lucia, Barbados), water and wastewater utility companies are primarily government owned island-wide. State-owned centralised systems serve mainly urban areas and the overall sewerage system is deficient and under-funded. There is a proliferation of poorly constructed and ill-maintained on-site household disposal systems (pit latrines, septic tanks etc.).

Limited institutional capacity, the lack of innovative system of incentive and weak enforcement and monitoring frameworks are come of the main barriers to the adoption of appropriate technologies in these countries. For instance, 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.

The Central American region has a mixture of municipalities, municipal enterprises (e.g. Belize) and one private mixed-capital company (e.g. Honduras), along with some national governmental entities that provide services. In South America, wastewater is management by local and regional governments and private companies (e.g. Colombia). Although decentralisation of wastewater management services presents opportunities, the weak institutional capacity of delegated and/ or constitutionally responsible agents is a major constraint.

Legality and Policy Conflicts

Increasingly, regulations with respect to the desired water quality of the receiving water are determined by what is considered to be technically and financially feasible. The regulatory agency then imposes the use of specified, up-to-date technology upon domestic or industrial dischargers, rather than prescribing the required discharge standards.

In addition, many countries have laws governing the degree of decentralization; management authority; authorisation for funds etc. There may also be some legal issues surrounding budget allocations for waste management.

Care should be taken to ensure that the selection of certain technologies does not conflict or contradict national goals and objectives. Do these effects promote or conflict with overall social goals of the society? How would specific sectors of society be affected by the adoption of this technology or policy?

Cultural Acceptability

Residents' knowledge, attitude, opinions, and prejudices about waste disposal can determine whether a treatment technology will work in a particular culture. Certain technologies are already well established within certain countries. For example, 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. The design, construction and use of these systems are entrenched in many societies. Therefore, behaviour change and adoption of new approaches will require immense education and awareness-raising.

APPENDICES

APPENDIX A: POLLUTION CONTROL TECHNOLOGIES

(Taken from CEP Technical Report No. 40: Appropriate Technology for Sewage Pollution Control in the Wider Caribbean Region, March 1998)

Fact Sheets on Specific Sewage Pollution Control Technologies

TABLE OF CONTENTS

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

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.

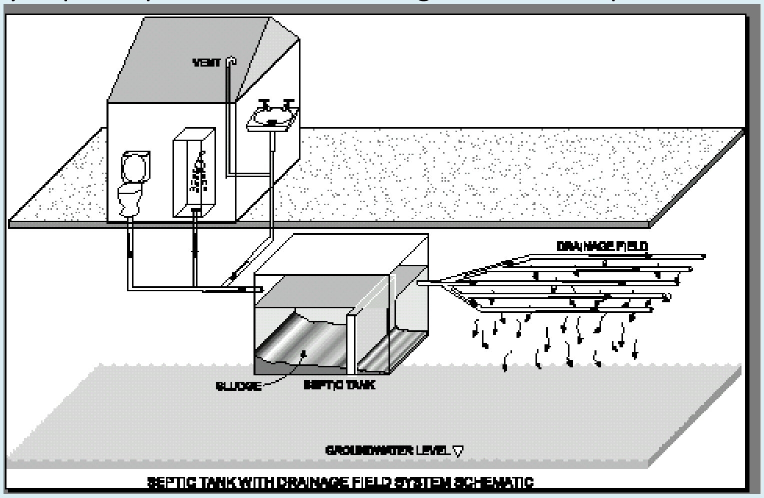
The most typical onsite system in the WCR is the septic tank followed by a drainage field or absorption pit. In many areas soil drainage systems are inappropriate for onsite wastewater disposal because of poor soil permeability or high ground water. Alternative systems for wastewater disposal in these 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.

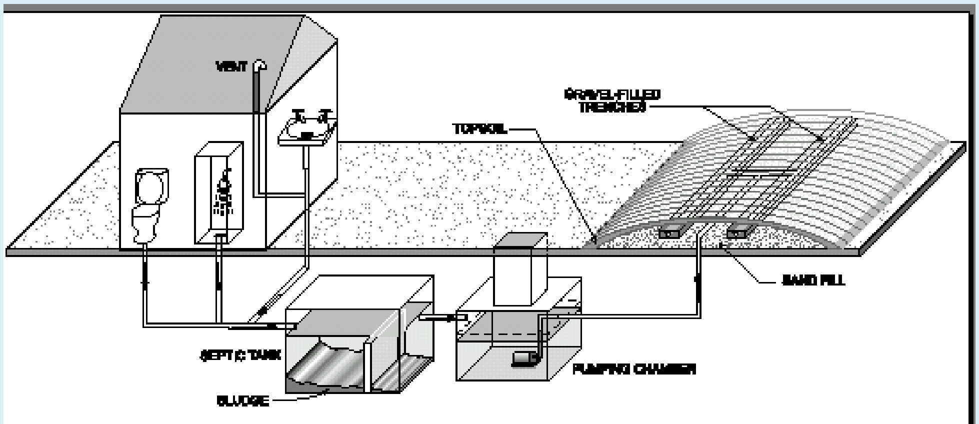
If possible, drainage fields should be used intermittently to allow a drying out period. Drying also can be accomplished by providing two drainage fields and alternating between the two. This will significantly improve performance and lengthen the life span of the drainage field.



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.

OPERATION & MAINTENANCE
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

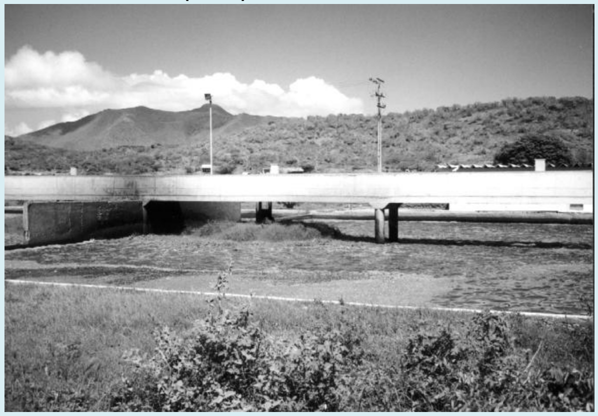
In secondary treatment processes, aerobic, anoxic, and anaerobic bacteria feed on organic material in the wastewater, transforming the BOD in the sewage to bacterial mass. Aerobic bacteria, the most commonly used type for secondary treatment, consume organic material only in the presence of oxygen. Anoxic 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.

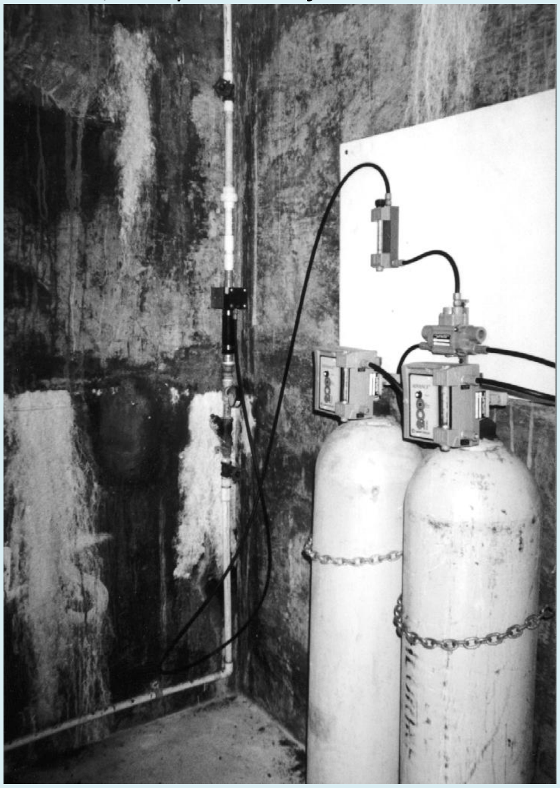
REFERENCES

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 feed 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

Alaerts, S. et al. 1993; Boopathy, R. et al. 1991; Borzacconi, L. et al. 1995; Capobianco, D.J. et al. 1990; Carter, J.L. et al. 1992; Chigusa, K. et al. 1996; Copeland, E.C. et al. 1991; Eckenfelder, W.W. 1989; Filho, B.C. et al. 1996; Galil, N. et al. 1990; Gavala, H.N. et al. 1996; Martinez, J. et al. 1995; Park, T.J. et al. 1996; Polprasert, C. et al. 1996; Sendic, M. 1995; Tyagi, R.D. et al. 1993; Viraraghavan, T. et al. 1994; Yue-Gen Y. et al. 1996; Zhang, R. et al. 1996.

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 Digestion	20 15	40 60
Air Drying	0	90
Anaerobic Digestion	35-55 20	15 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.

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