ENVIRONMENTALLY SOUND TECHNOLOGIES FOR WASTEWATER AND STORMWATER MANAGEMENT IN SMALL ISLAND DEVELOPING STATES IN THE PACIFIC

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This report is Chapter 8 of the International Source Book on Environmentally Sound Technologies for Wastewater and Stormwater Management published under the auspices of the International Environmental Technology Centre. Within-chapter numbering of the Pacific Islands Developing States (Pacific) contribution is retained.

Attached to this report is a draft of the Source Book – useful for viewing the scope of the book and the areas of the world covered for each topic.

The International Source Book is to be formally published in the Technical Publication series of the International Environmental Technology Centre.

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8.0 Introduction

8.0.1 Background

The Pacific Ocean covers some 18 million km^2 or about 36% of the Earth's surface. Scattered throughout the Pacific are over 30 000 small islands and a number of larger islands (each over 2000 km^2 in area) which emerge from the sea floor. Of these about 1000 are inhabited. The attached Map shows the Pacific Region covered in this report.

Small Island Developing States (SIDS) are unique. They consist of relatively small landmasses completely surrounded by the sea. The ocean isolates SIDS from one another so they have no shared borders with other countries. Travel between islands may be difficult and expensive.

The natural environment throughout the Pacific SIDS is extremely fragile and is highly vulnerable to both natural and human impacts. Natural hazards like cyclones, droughts, earthquakes and tsunamis may strike at anytime and in most places within the Pacific Region. In the past decade, changing climate patterns, rapidly growing populations and increasing pressures on limited natural resources in many countries have produced a crisis of damage to, and depletion of, these resources most necessary for basic life support, especially freshwater supply. The economic and public health implications of the crisis have provoked an urgent need for greatly improved management, planning, operation, and maintenance of the water supply and sanitation sector, associated environmental protection, and conservation of both surface and groundwater resources.

Traditionally and culturally people living on SIDS have strong ties with their coastal marine areas. The disposal of wastewater and stormwater definitely has negative impacts on both freshwater and coastal marine environments affecting public health, ecosystems and the economy of SIDS. Greater efforts and resources are required regionally, nationally and individually to help minimise these impacts of land-based waste disposal on the fragile environment.

8.0.2 Overview Compiling Method

Information presented in this overview was obtained by:

- Abstraction from existing reports and studies
- Contact with individual agencies responsible for wastewater and stormwater management (see Appendix 1 for responses)
- Personal knowledge of waste disposal methods within the Region

Appendix 1 presents the information collected for this regional overview on a series of data sheets.

While compiling this overview it became obvious that there is a lack of comprehensive and on-going data collection for all wastewater parameters. Very few utilities monitor wastewater influence and/or effluence. Neither are receiving bodies of water (rivers, streams, groundwater or seawater) monitored for quality. Thus there is little hard data available for use in this overview.

The general lack of water sector monitoring and data collection is a major problem in the Region.

8.1 Wastewater Characteristics (Topic a)

Unfortunately there is lack of sufficient data available to assess typical characteristics of wastewater produced in the Region. However the following information has been obtained.

8.1.1 Domestic Wastewater

The Kinoya wastewater treatment plant in Suva, Fiji, caters for a population of 85,000. Incoming BOD and suspended solids (SS) are approximately 450mg/L and 290mg/L with final effluent at 20-45mg/L and 30-60mg/L respectively. Average dry weather flows are in the order of 270 litres per person per day (l/p/d) while peak wet weather flows are 550 l/p/d.

In American Samoa two primary treatment plants treat domestic sewage only, and have a combined average daily discharge of 8160m^3 with 2600 house and business connections. Average influent for the two plants (in October 1998) shows that BOD and SS were 70 mg/L and 50 mg/L respectively. Average effluent quality from the two plants, during the same period, was BOD at 30mg/L and SS at 17mg/L. The sewage has been descried as "weak" due to leaking faucets and running toilets. This is reflected in an estimated average flow of 520 l/p/d, which is similar to the peak wet weather flow of the Kinoya treatment plant in Fiji.

No specific information could be found on other wastewater characteristics such as nitrogen and phosphorus concentrations. However a South Pacific Regional Environment Programme (SPREP) publication *Land-Based Pollutants Inventory for the South Pacific Region*, (see Reference 2) has estimated waste loads from domestic wastewater per year that enters the environment as shown in Table 1 below. These were based on each country's estimated population, using various methods of treatment and an estimated concentration for each characteristic (ie BOD, SS, N, and P)

8.1.2 Industrial Wastewater

Most operators of regional wastewater treatment plants indicated that industrial wastes were not allowed into their collection systems. It would be naive to think that illegal connections did not exist. Major industries in the region include edible oils, sugar refining, fish canning and beer brewing. Most industrial operations provide some sort of treatment and disposal systems, but again there is little information available plus a lack of discharge monitoring. Potential economic opportunities exist with expanding industry growth along with increased industrial waste types and volumes that will have to be dealt with to protect the environment. More control over discharges will need to be exercised by government authorities to minimise adverse effects to the environment.

Table 1. Summary for waste loads from domestic wastewater.

Country	Pollutant Constituent (tonnes/yr)			
	BOD	SS	N	P
American Samoa	217.41	259.47	89.48	7.99
Cook Islands	831.02	15.28	53.27	6.46
Fed. States of Micronesia	1010.93	1314.26	53.27	6.46
Fiji	3270.31	1390.78	2043.26	240.98
French Polynesia	1251.51	0.00	812.32	98.46
Guam	2565.44	1013.54	781.70	80.27
Kiribati	409.07	406.96	174.57	21.16
Nauru	102.13	160.84	26.54	3.22
New Caledonia	948.27	1344.30	410.17	49.10
Niue	9.78	0.00	6.35	0.77
North Mariana Islands	99.36	155.07	110.60	6.27
Palau	73.29	73.33	38.63	3.78
Papa New Guinea	5665.54	2424.70	3106.91	374.49
Pitcairn	0.24	0.00	0.61	0.02
Rep. of Marshall Islands	419.05	579.70	150.54	18.11
Solomon Islands	2136.96	1762.56	979.15	139.21
Tokelau	12.42	28.80	55.94	0.72
Tonga	563.82	161.62	344.72	43.28
Tuvalu	36.48	16.92	23.00	2.79
Vanuatu	817.74	560.04	457.01	58.35
Wallis and Futuna	64.57	0.00	41.91	5.08
Western Samoa	1170.04	584.53	739.50	83.04
TOTAL	**21 675.38**	**12 252.70**	**10 499.45**	**1250.01**

Source: SPREP *Land-Based Pollutants Inventory for the South Pacific Region*

Mining activities exist in PNG, New Caledonia, Nauru, Fiji, Solomon Islands and Vanuatu all produce wastewater that requires treatment and are potentially dangerous to the environment. Each mining operation would have its own treatment facilities. The disposal of mining wastewater has not been considered in this report.

The SPREP publication also provides estimated waste loads from industrial wastewater within the Region as shown in Table 2.

Table 2. Summary table for waste loads from industrial wastewater.

	Pollutant Constituent (tonnes/yr)			
	BOD	**SS**	**N**	**P**
American Samoa	4.53	179.18	255	167.30
Cook Islands	ND	ND	ND	ND
Fed. States of Micronesia	ND	ND	ND	ND
Fiji	510.63	431.92	25.63	0.91
French Polynesia	ND	ND	ND	ND
Guam	ND	ND	ND	ND
Kiribati	ND	ND	ND	ND
Nauru	ND	ND	ND	ND
New Caledonia	37.4	6.1	ND	ND
Niue	ND	ND	ND	ND
North Mariana Islands	ND	ND	ND	ND
Palau	ND	ND	ND	ND
Papa New Guinea	508.94	1,083.40	ND	ND
Pitcairn	ND	ND	ND	ND
Rep. of Marshall Islands	ND	ND	ND	ND
Solomon Islands	513.60	494.81	18.7	0.1
Tokelau	ND	ND	ND	ND
Tonga	ND	ND	ND	ND
Tuvalu	ND	ND	ND	ND
Vanuatu	548.09	241.42	117.21	42.72
Wallis and Futuna	ND	ND	ND	ND
Western Samoa	63.7	10.42	ND	ND
TOTAL	**2186.89**	**2447.25**	**416.54**	**211.03**

Source: SPREP *Land-Based Pollutants Inventory for the South Pacific Region*
Note: ND = No data

8.1.3 Stormwater disposal

There does not appear to be any combined wastewater and stormwater collection systems in the Region. Apart from the larger urban centres in the region, stormwater collection and disposals systems do not exist. Normally stormwater would follow natural or man-made surface water channels to the sea or just left to seep into the surrounding ground. Stormwater that falls on roofs could be used for domestic water supplies in many SIDS or discharged into the surrounding ground. Potential exists to use stormwater to recharge groundwater aquifers or freshwater lenses that are used for water supply purposes. Instead of directing stormwater to the nearest outlet, the rainwater could be infiltrated into the ground by soakage wells or ponds. Photo 1 shows a stormwater disposal well use in Guam.

However, it is expected that some stormwater would enter wastewater sewer systems through old and poorly constructed pipes, and through illegal connections. An example of this would be the difference in the dry (270 l/p/d) and wet (550 l/p/d) weather flows for Fiji's Kinoya treatment plant as noted in section 8.1.1 above.

8.1.4 Cultural influences

The most drastic influence on wastewater disposal methods would have been that imposed by Western society on the indigenous people by those countries that colonised the Pacific Region. Prior to this intervention I would have imagined that waste disposal was a simple matter managed by families and villages. It was Western society that introduced systems that collected and concentrated large volumes of waste to be discharged at point sources, into the sea or rivers causing pollution of marine and freshwater resources. Many of these systems failed to be sustainable due to lack of resources and local inputs into operation, maintenance and understanding of the systems. (See Case Study 1) Photo 2 shows a community toilet in Tarawa, Kiribati that has not been maintained.

8.1.5 Environment and public health

Tables 1 and 2 indicate the order of pollutants that are discharged into Pacific SIDS environment each year. Approximately 80% of the pollutants enters the coastal marine zone. This very important zone that provides food and recreation for both SIDS residents and tourists is under attack from both land-based and on-the-water pollution. The attributes that attract tourists (sandy beaches, excellent diving and fishing) are being threatened by increasing algal blooms, dying coral and decreasing numbers of marine life. Bathing and eating seafood from polluted coastal waters puts public health at risk as well.

In many atolls freshwater lenses, that have traditionally been used as a source of water, are now being polluted by poor wastewater disposal practices and by increasing population densities of both people and animals. At times people are forced to use polluted water sources thus increasing the risk of poor public health. In many SIDS, local health centres consistently treat a large number of water borne related diseases.

Improved wastewater disposal planning, management and systems would definitely have a positive impact on the environment and improve the general health of SIDS residents.

8.2 Collection and Transfer (Topic b)

Approximately 6.1 million people live in the Pacific SIDS of which 3.7 million people (or about 60 %) live in Papua New Guinea alone. Of the total population approximately 694 200 (or 11 %) are serviced by a reticulated wastewater system. If PNG was excluded from the calculation then approximately 546 000 people out of 2.4 million (or 23 %) have access to reticulated wastewater systems. Note that of those people serviced by collection systems (694 200), wastewater from over 100 000 people is discharges direct into the coastal environment without treatment. Also many of the existing treatment plants do not preform as designed. Table 3 shows SIDS populations, the number of people served by wastewater reticulation systems and where the effluence is discharged.

The balance (or majority) of the people would dispose their waste through septic tanks, various types of latrines and over water latrines. In some SIDS composting toilets have been introduced as an alternative method of disposal. The bush and beach are still used for defecation, especially by children, in many countries.

Table 3. **Estimate of regional population and population sewered.**

Country	Population	Population Sewered	Outfall Discharge
American Samoa	35 000	15 500	Ocean
Cook Islands	18 000	None	None
Kosrae, FSM	7700	1000	Ocean
Pohnpei, FSM	35 200	14 100*	Ocean
Chuuk, FSM	52 000	9000*	Ocean
Yap, FSM	11 300	1100	Ocean
Palau	15 000	5500	Ocean
Fiji	760 000	110 000	Ocean/River
French Polynesia	196 000	ND	ND
Guam	139 000	151 000***	Ocean
Kiribati	72 000	20 000*	Ocean
Nauru	8500	3000*	Ocean
New Caledonia	165 000	92 700	Ocean
Niue	2500	None	None
Mariana Islands	59 000	39 000	Ocean
Papua New Guinea	3 700 000	138 300**	Ocean/River
Rep. of Marshall Islands	46 200	28 500*	Ocean
Solomon Islands	333 000	25 000*	Ocean/River
Tokelau	1200	None	None
Tonga	100 000	None	None
Tuvalu	9000	None	None
Vanuatu	160 000	None	None
Western Samoa	165 000	None	None
TOTAL	**6 105 600**	**694 200**	

Note: * = Sewered but not treated **=some not treated ***=includes military population
ND = No Data

It appears that combined wastewater and stormwater collection sewers are not used in the Region. However as mentioned in Section 8.1.3, stormwater does find its way into wastewater systems during periods of rainfall.

There are all types and sizes of pipes used in the Region to reticulate wastewater. Generally it is current practice in the Region to use plastic pipes, however other pipe materials that best suit the situation are used.

In Kiribati, Marshall Islands and Nauru, seawater is used to flush toilets and convey sewage to discharge outfalls. Seawater, used to conserve limited freshwater resources, is pumped to household toilet tanks and collected again for disposal in separate reticulation systems or to septic tanks.

8.3 Treatment (Topic c)

The Pacific has been described as a “junk yard” of water sector technologies with failed systems spread throughout the region. Developed country technologies have been superimposed on the Region with less then successful results mainly due to the lack of sustainable resources for on going operation and maintenance. A SOPAC organised Regional workshop on *Appropriate and Affordable Sanitation for Small Islands* was held in Kiribati in 1996. It became clear from the workshop that sanitation involves more than just physical structures for excreta disposal. Health and hygiene education is also regarded as important aspects for any proposed sanitation project. Also community involvement and participation is most important to have a successful project.

The production of the SOPAC publication *Guidelines for Selection and Development for Small Islands* (see reference 3) was a result of the Kiribati workshop.

Previous American influenced countries in the Region (American Samoa, FSM, Guam, Mariana Islands, Marshall Islands and Palau) have some sort of wastewater reticulation system and primary to secondary treatment for their main urban centres. However the standard of effluent produced ranges from raw sewage from Marshall Islands to good quality from Guam and American Samoa. All these countries discharge their wastewater into coastal areas.

Apart from the major urban centres in Fiji, PNG, Kiribati, New Caledonia and the Solomon Islands, plus the above mentioned American influenced countries, the balance of the Region's communities use septic tanks, various types of latrines and over water latrines. Composting toilets have been introduced and trialed in some SIDS including Kiribati, FSM, Fiji and Samoa (see Case study 2). The bush, beach and the sea are still used for defecation in many places (see Diagram 1).

8.3.1 Small-scale and Community Technologies

Septic tanks and various types of latrines are exclusively used in the Cook Islands, Niue, Tokelau, Tonga, Tuvalu, Vanuatu and Samoa but are used throughout the Region as well. These methods are mainly for individual family and household use. Some communities (in PNG and Kosrae) use large septic tanks along with some schools and hospitals for wastewater treatment and disposal. Appendix 2 shows various types sanitation systems plus constraints and advantages used in the Region.

UNESCO/SOPAC trials were carried in Tonga to assess what the safe distance between shallow wells and household "toilet" discharges. The study found that most wells used for the study were already polluted. The results were inconclusive suggesting that the minimum distance should be as far apart as possible.

In Yap (FSM) an Imhoff tank is use to treat wastewater. The utility reports that there is a big demand for the dried sludge taken from the Imhoff tank.

Section 8.5.2 discusses land base wastewater disposal in more detail.

Oxidation ponds only appear to be used in Fiji, PNG and Kosrae. Pond treatment methods generally do suit atoll conditions where land is very limited and ground conditions very permeable results in expansive implementation.

8.3.2 Large-scale Technologies

Again large treatment plants service the large urban centres such as in Fiji and Guam. Treatment methods include sedimentation, trickling filters, and anaerobic and aerobic lagoons. Currently the Kinoya treatment plant, that service about 85,000 people in the Suva area, is being upgraded using extended aeration and will eventually be able service 360,000 people. Raw sludge is digested and put into drying beds. The circular digester produces about $63m^3$ of sludge per day. Some of the dried sludge is used as soil conditioner and that not used is dumped into a landfill. In Guam belt presses are used to mechanically dry sludge.

In American Samoa two separate treatment plants use clarigesters for the primary treatment of wastewater. A clarigester is a clarifier that sits on top of a digester constructed as one unit. (See Diagram 2) The clarigesters separate settleable solids and floating debris from the inflow of wastewater. Settleable solids sink to the digester compartment where they undergo digestion and eventually removed as sludge. Sludge is removed from the clarigesters and dewatered in covered drying beds. Supernatant from the digester compartment and drainage from the drying beds is pumped back into the plant headworks. Clarigester treated wastewater is than disinfected using chlorine and discharged into two ocean outfalls (30 m and 45 m deep). As shown in Photo 3, the plant also has the facility to except and treat septage, trucked in from septic tanks through the island.

American Samoa and Guam are the only countries in the Region where treated wastewater is disinfected before discharging into the sea.

It should be noted that raw sewage which has been collected through sewer systems in Kiribati (Tarawa), Nauru, Marshall Islands (Majuro), Solomon Islands (Honiara) and PNG (parts of Port Moresby) is discharge into ocean outfalls with out treatment. Also some of the older treatment plants (Pohnpei and Chuuk) do not operate properly thus not improving influence quality much.

8.3.3 Traditional Waste Disposal Technologies

Before the arrival of missionaries, Western ways and densely populated areas, going to the bush, the beach or the sea was the normal methods to relieve one's self within the region. Water was not required for flushing, paper was not required and a disposal system was not required. All that was required was a private place and that was not too hard to find. It was the outside world that introduced toilets, collection systems and treatment plants to the Region.

The closest to a regional "small scale" traditional disposal technology would be the over water (overhung) latrines (also as known as "benjos" in FSM as described in Case Study 1). These are "latrines" that are constructed over a body of water into which excreta drops directly as shown in Diagram 3. They are cheap and easy to construct no water or paper was required, easy to clean and maintain and some had a great view. Also they were communal in nature (ie several people could use them at same time) and thus presented the opportunity to catch up on the latest gossip. What else could you ask for? However with growing populations resulting in larger discharges and pressure on marine food resources, the risk of pollution and disease also increased. The tourist industry also frowned on them lining the beaches. Over water latrines are now history however that are still use in some parts of the region.

In rural coastal areas throughout the region the over water latrine still has potential to provide an important service to the community. Under favourable conditions and good management practices the over water latrines will still be part of the region's waste disposal seen.

8.3.4 Regional Technologies

As seen from above the current wastewater treatment technologies used in the Region range from none to secondary treatment with no one method standing out as the one to use. Without performance monitoring data available, it would still be fair to conclude that many of the existing treatment plants and methods are not working, as they should. The problem may be that the systems are old, expensive to maintain, operate and to replace. The utilities do not have the resources to adequately provide an environmentally friendly service to its customers and the customers cannot afford to pay for an adequate service. Therefore service deteriorates and the environment suffers.

As concluded from the SOPAC workshop on *Appropriate and Affordable Sanitation for Small Islands,* for a sanitation project to be understood, accepted and used, the community must support and be involved with the project's development. Public education and awareness is needed so that the community can see the benefits of both improved health and environment brought about through improved wastewater disposal facilities.

8.4 Reuse (Topic d)

The reuse of wastewater in agriculture and aquaculture has much potential and is used in many other regions. It can replace the use of limited freshwater for the irrigation of crops or be used as an additional source to increase production of crops and in the forestry industry. Aquaculture is becoming popular and may provide additional economic opportunities in developing countries. Nutrients found in wastewater discharges, that normally pollute the environment, are beneficial when used with irrigation and aquaculture applications. However the reuse of wastewater is currently not practiced in the Pacific Region. With many SIDS experiencing limited water resources the reuse of wastewater would be attractive by conserving water and reducing pollution potential to marine and surface water resources.

There is potential in Fiji to use wastewater to irrigate sugarcane and/or for fish farming that has been recently established there. However these rural activities are generally remote from urban centres where treated wastewater is available. SIDS priorities to provide appropriate and affordable sanitation facilities should explore all possibilities to reuse wastewater where ever possible.

In many SIDS and in especially in Papua New Guinea there are strong traditional feelings against the reuse of wastewater. Much talking and convincing would be required to introduce this concept. The issue of 'most appropriate' technology needs to be explored and thoroughly discussed with potential users before proceeding with any new development. Also irrigation is not practice extensively in the Pacific thus water for irrigation use is not a high priority in most SIDS.

It should be noted in Kiribati, Nauru and Majuro saltwater is reticulated to households for toilet flushing to reduce the stress on limited freshwater resources. However the potential to reuse human waste mixed with saltwater would be limited to non irrigation usage.

8.5 Disposal (Topic e)

Table 3 notes the Regional SIDS that discharge wastewater through ocean and river outfall systems (see Photo 4 a typical ocean outfall in Honiara). Over water latrines also uses the ocean and rivers to dispose of waste. All countries in the Region use land based disposal systems of various types. With SIDS populations concentrated on coastal areas, much of the land based wastewater discharges would eventually enter the ocean through groundwater and surface water flows. Many coastal areas are being polluted by wastewater disposal resulting in large algae blooms, dying corals (reefs) and the decline in marine life. This all impacts on traditional food resources, public health and the tourism industry. With most SIDS relaying on tourism for economic growth, pristine marine environments are essential to attract tourists and getting them to come back. Thus the promotion of suitable wastewater disposal facilities should be encourage by governments.

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8.5.1 Ocean and River Outfalls

Detrimental effects to the environment from areas that are sewered, with various degrees of treatment, can be minimised by using good effluent disposal practices. Locations of ocean outfalls ideally should be beyond the reef, in high circulation areas and below the thermocline. No outfall disposal system in the region meets all these criteria while a few systems do meet some of the criteria. All too often the outfall locations are chosen by treatment plant or pump station siting opposed to the best outfall locations. These basic design criteria should be investigated for the construction of any new system or the upgrading of an existing system to avoid problems currently experienced by many SIDS. The regional organisation, SOPAC, has both the expertise and equipment to implement outfall location investigations.

The use of wetlands for wastewater is not used much in the Region with only PNG indicating its use. Overseas, wetlands have proved to be an acceptable alterative to discharge of treated wastewater. Wetlands may be either natural or artificial. There is be potential in the Region to develop wetlands for the disposal of treated effluent.

8.5.2 Land Based

In the Region the Cook Islands, Niue, Samoa, Tonga, Tokelau, Tuvalu and Vanuatu exclusively used land-based disposal of wastewater. Note that groundwater is the main water source for Niue and Tonga hence protection from wastewater pollution is most important. All other countries use this method as well especially in rural areas and on remote islands.

In the urban areas septic tanks are normally use to treat wastewater. If properly designed, constructed and maintained, septic tank systems can treat wastewater adequately. However it is the author's observation that too much effort goes into the sizing and construction of the septic tank itself and very little effort goes into the design and installation of disposal systems for the septic tank effluent (see Photo 5 where septic tank effluent is discharge into unsuitable soils in Suva). In most low island cases the effluent from the septic tanks is discharged into a "soakage" pit giving more or less direct access to the groundwater instead of using the soil as a filter to further improve effluent quality. Infiltration drains may over come this problem but generally are not implemented for digging a soakage pit is less of a task and cheaper then laying a drain. Often when located in urban communities there is insufficient area available to construct adequate effluent disposal systems. In this case the groundwater should not be used for domestic use unless it is treated in some way.

Pollution of groundwater is common in the Region especially on crowded atolls due to ineffective land based disposal methods. On Funafuti, Tuvalu, the groundwater is not used for domestic use due to land based pollution from wastewater disposal. Groundwater reserve areas have been created in Tarawa, Kiribati to protect groundwater lens resources, used for suppling populated areas with water, from pollution. Both Tonga and Niue use the unpopulated areas of the islands to supply freshwater from groundwater lenes. Increasing population growth in the Region is creating pressure on reserve areas to be used for settlement and this may adversely affect the groundwater quality.

With populated areas located on coastal margins, poor land based disposal methods still have impacts on reef and lagoon areas with pollutants being conveyed by groundwater and surface water flows. Hence any improvement to land based treatment and disposal methods would benefit the Regions residents in many ways.

The use of composting toilets, currently being trialed in the region, has much potential to reduce groundwater pollution, eliminate the need for "flushing" water, and the compost material generated can be use to improve soil conditions (see case study two). Photo 6 shows the construction of a composting toilet in Fiji while Diagram 4 shown the type of composting toilet used in Kiritimati, Kiribati.

8.6 Policy and Institutional Framework (Topic f)

There is a general lack of effective policy, regulation and institutional structure within the region's water sector. Also more emphases is placed on providing safe water to households than the disposal of wastewater, and the protection of the environment. Stormwater disposal is given even less attention regarding policy and regulations.

8.6.1 Regulatory Framework

In the old American associated SIDS, where wastewater disposal is generally regulated by the Environmental Protection Agencies (EPA) established in each country or state. EPA standards are normally very strict requiring resources that are not available in most SIDS to ensure compliance. This works satisfactorily in Guam and American Samoa. In other countries/states regulations exist, but there are little or no resources allocated to monitor and enforce regulation compliance. Hence the environment continues to suffer at the expense of wastewater disposal.

Health Departments in some SIDS monitor groundwater and surface waters for pollution but again they have little authority and resources to act accordingly. Many countries in the Region have neither regulations nor standards regarding the discharge of wastes into the environment. Building code standards for septic tank sizing and construction exist throughout the Region, but this do not guarantee an adequate discharge quality. Little attention is given to the disposal of septic tank effluent into the ground, which is a common source of groundwater pollution.

8.6.2 Institutional Arrangement

National management of water sector activities within the region is generally very fragmented with many ministries, government departments, boards, authorities and utilities responsible for an array of activities. Table 4 below indicates the responsible agencies for the disposal of wastewater for urban areas in the Region. Note that rural areas and outer islands usually come under national health departments for providing assistance in sanitation issues.

Table 4. Agencies responsible for wastewater disposal.

Country/State	Wastewater Discharges	Monitoring and Standards
American Samoa	American Samoa Power Authority	EPA monitoring and standards
Cook Islands	Individuals	No monitoring or standards
Kosrae, FSM	Dept. of Transportation & Utility	No monitoring; US EPA standards
Pohnpei, FSM	Pohnpei Utilities Corporation	EPA monitoring and standards
Chuuk, FSM	Chuuk Public Utilities Corporation	EPA monitoring and standards
Yap, FSM	Yap State Public Services Corp	EPA monitoring and standards
Palau	Ministry of Natural Resources & Development	
Fiji	Ministry of Communication, Works and Energy	Ministry of Environment; no standards
Guam	Guam Water Works Authority	EPA monitoring and standards
Kiribati	Public Utilities Board	No monitoring or standards
Nauru	Nauru Phosphate Company	No monitoring or standards
New Caledonia	ND	ND
Niue	Individuals	No monitoring or standards
Mariana Islands	Commonwealth Utilities Corp.	EPA?
Papua New Guinea	The Water Board plus private companies	Royal Commission Standards
Marshall Islands	Majuro Water & Sewer Company	EPA monitoring and standards
Solomon Islands	Solomon Islands Water Board	No monitoring or standards
Tokelau	Individuals	No monitoring or standards

Tonga	Individuals	Health Dept. monitors groundwater
Tvualu	Individuals	No monitoring or standards
Vanuatu	Individuals	
Western Samoa	Samoa Water Board	No monitoring or standards
Schychells	Public Utilities Corporation	Ministry of Environment & Transportation monitor pollution

Individuals = responsible for provide own disposals facilities ND = No Data

8.6.3 Policy Framework

Most government polices are general, stating that everyone should have access to safe water and sanitation facilities plus the importance of a healthy environment. However with limited monetary and human resources, most countries relay on bilateral support in the development of national master plans. Often these master plans suggest policy and legislation changes and additions to enable the implementation of sound wastewater disposal practices. Also loaning agencies, like the Asian Development Bank, may put conditions on loans to encourage sustainable sanitation development.

Governments must provide the framework, through policy and legislation, to allow its implementing bodies (ie government departments, utilities, boards or authorities) to be able to operate efficiently. The results would be better disposal systems, healthier people and a cleaner environment. This can be difficult for promoting polices like “user pays”, that would provide the resources to improved wastewater disposal methods and the environment, would be very unpopular with both the public and politicians.

8.7 Training (Topic g)

Regionally there is a lack of adequately trained national personnel within the water sector at all levels. Many utilities still rely on expatriates to plan, operate and maintain water sector systems and project developments.

Most utilities have some sort of in-house training for trades personnel. Treatment plant operators are often trained overseas through both utility and bilateral funding. The American Samoan utility provides training to other American associated SIDS using its own staff. Buddy systems have been established where personnel are exchanged to learn from each other’s utilities. This system has appeared to work well.

Water sector engineers and planners are generally educated overseas on bilateral scholarships. The University of Lae in PNG has a school of engineering and has produced water sector engineers that currently still practice in the Region. However many trained national engineers and planners have left the Region in pursuit of higher compensating employment in New Zealand, Australia and the USA. Hence it is not only training but the retention of trained personnel that has been an on going problem in the Region.

In past years PNG has had the facilities to provide water sector training. However these facilities are now not Regionally utilisation to its potential.

The University of the South Pacific located in Fiji and the University of Guam contributes to the Regions human resources development. Both universities run environment programs but neither have specific water sector engineering programs. Guam University does have a Water & Environment Research Institute.

Often decision makers make discussions that are outside their field of expertise because they are put in position as being the best person available.

Regional organisations like SOPAC, SPREP and SPC have provided water sector training opportunities and short term expertise to the member countries. The Water Resources Unit at SOPAC currently tries to coordinate Regional water sector activities and develop donor funded programs and projects. SPREP also runs programs to assist in waste management. Regional workshop like that ran by SOPAC on *Appropriate and Affordable Sanitation for Small Islands* bring together and expose local practitioners to current sanitation ideas.

The newly formed Pacific Water and Wastewater Association (PWA) potentially will be able to assist with training activities. It gives utilities an opportunity to discuss comment problems that may have been solved by another utility in the Region.

UN originations like UNEP, UNDP, WHO, UNESCO and ESCAP are all potential sources for Regional training opportunities and have already contributed much to human resources development in the Region.

Not only is more and better training required in the region but better incentives by utilities and governments to retain qualified personnel.

8.8 Public Education (Topic h)

Regionally very little effort is put into educating the public about the disposal of wastewater. It's one of those subjects that Pacific residents do not like to hear about and utilities do not like to talk about. Never the less public education and awareness is a very useful tool in promoting good health and hygiene practices as well as the adverse impacts on the environment related to wastewater disposal.

Utilities in Yap (FSM), American Samoa and in PNG have indicated that they undertake public education through awareness campaigns, public meetings, printed materials and the radio. The Solomon Island Water Authority (SIWA) has a very active Public Relations section but its main focus is in providing freshwater to customers.

When trying to introduce a new technology like composting toilets or when promoting new or upgraded projects, the public must be informed to gain their confidence and support.

8.9 Financing (Topic i)

Paying for the collection, treatment and disposal of wastewater is generally expensive in the Region. None of the utilities in the region even recover their costs in providing a wastewater disposal service. Hence this is a major problem in providing a service that protects public health and is friendly to the environment.

Most utilities in the region, charge for wastewater services on the basis of the amount of freshwater supplied to each connection. A few utilities do not specifically charge for wastewater services. In all regional utilities the wastewater services are subsidised by either or their water and electricity charges. No where in the region does wastewater charges cover the costs of providing the service.

In Fiji and Kosrae (FSM), and maybe other SIDS, respective governments subsidise wastewater disposal. The Nauru Phosphate Company pays for wastewater disposal costs in Nauru.

At least six Pacific SIDS do not have any sanitation services provided, thus there are no charges. Individual households and businesses are responsible for providing and maintaining their own disposal systems in these countries.

In most countries where wastewater systems exist, governments initially were responsible for providing the infrastructure and then turned them over to boards, authorities or companies to run. Generally governments still maintain some control or interest in the utilities especially regarding charging.

Finance for major projects and master plans are still normally channelled through governments to either guarantee loans and/or negotiate bilateral funding. The Asian Development Bank has prepared many Technical Assistance wastewater studies in the Region and has loaned money to implement projects.

8.10 Information Sources (Topic j)

The following are contacts for various national, regional and UN agencies that are involved with the water sector in the Pacific Region: (Note that some Indian Ocean SIDS are given as well)

American Samoa Power Authority (ASPA)
P O Box PPB
Pago Pago 96799
American Samoa
Telephone : 684 644 2772
Fax : 684 644 1337/5005
Email : sewer@satala.aspower.com
Contact : Chief Excitative Officer

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	A public utility that plans, develops and provides electricity, water and wastewater services to the people American Samoa.
Format of information	:	Report, regulations, polices, guidelines, project funding, public relations
Internet	:	None
Language	:	English
Consulting or support services	:	In house and regional training programs.

Appropriate Technology Enterprises, Inc.
PO Box 607
Chuuk
Federated States of Micronesia
Telephone : 691 330 3000
Fax : 691 330 2633
Email : swinter@mail.fm
Contact : Dr Stephen J Winter

Topics covered: **c, d, e, g, h**

Description	:	Private consultant who has much practical experience (former Director of WERI in Guam) in small island water issues and

		may provide information on the water sector within the Federated States on Micronesia.
Format of information	:	Reports
Internet	:	NA
Language	:	English
Consulting or support services	:	May provide technical advice.

Asian Development Bank (ADB)
P O Box 789
Manila
Phillippines
Telephone : 632 632 6835
Fax : 632 636 2445
Email : NA
Contact : Manager Pacific Region

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	Regional development bank that can provide information, technical assistance and finance on the water sector activities for Pacific SIDS
Format of information	:	Reports
Internet	:	www.asiandevbank.org.mainpage.asp
Language	:	English
Consulting or support services	:	Regional data collection and technical assistance leading to possible ADB finance of water sector projects.

Caledonienne Des Eaux
15 rue Jean Chalier – P K 4 – BP 812
98845 Noumea Cedex
Nouvelle
Caledonie
Telephone : 687 282 040
Fax : 687 278 128
Email : NA
Contact : Philippe de Greslan

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	A public utility that provides water supply services to the people on the New Caledonia.
Format of information	:	Reports, regulations
Internet	:	None
Language	:	French
Consulting or support services	:	In house training

Central Water Authority
Head Office
St. Paul
Mauritius
Telephone : 230 686 5071
Fax : 230 686 6264
Email : NA

Contact : Director

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	A public utility that provides water and wastewater services to the people on the Mauntius.
Format of information	:	Reports, regulations, project funding
Internet	:	http://nub.intnet.mu/mpu/wwa
Language	:	English
Consulting or support services	:	In house training

Chuuk Public Utilities Corporation
Box 1507
Wono
Chuuk 96942
Telephone : 691 330 2400
Fax : 691 330 3259
Email : NA
Contact : General Manager

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	A public utility that plans, develops and provides electricity, water and wastewater services to the people Chuuk.
Format of information	:	Report, regulations, polices, guidelines
Internet	:	None
Language	:	English
Consulting or support services	:	In house training

Department of Resources & Development
PO Box 12
Palikir
Pohnpei
Federated States of Micronesia
Telephone : 691 3202620
Fax : 691 3205854
Email : NA
Contact : Director

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	Government department that can provide water sector information for the Federated States of Micronesia
Format of information	:	Report, regulations, polices, project funding
Internet	:	None
Language	:	English
Consulting or support services	:	Project funding through regional and international organisations

Department of Water Works Ministry or Works, Environment & Physical Planning
P O Box 102
Rarotonga

Telephone : *682 20034*
Fax : *682 21134*
Email : *nbp@oyster.net.ck*
Contact : *Director*

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	Government department that provides water sector services to the people of Rarotonga
Format of information	:	Report, regulations, polices, project funding
Internet	:	None
Language	:	English
Consulting or support services	:	In house training

Guam Environmental Protection Agency - Water Pollution Control Program
Post Office Box 22439
GMF
Barrigada
Guam 96921
Telephone : *671 472 9505*
Fax : *671 477 9402*
Email : *NA*
Contact : *The Manager*

Topics covered: **a, c, e, h, i**

Description	:	Government agency that regulates, set standards, monitors, collects and enforces water sector performance in Guam
Format of information	:	Reports, regulations, standards, guidelines
Internet	:	NA
Language	:	English
Consulting or support services	:	Monitoring of water and wastewater quality standards.

Guam Water Works Authority
P O Box 3010
Agana 96932
Telephone : *671 647 7606/7826*
Fax : *671 649 0369*
Email : *NA*
Contact : *General Manger*

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	A public utility that plans, develops and provides water and wastewater services to the people Guam.
Format of information	:	Report, regulations, polices, guidelines
Internet	:	None
Language	:	English
Consulting or support services	:	In house training

Majuro Water & Sewer Company
P O Box 1751
Majuro

Marshall Islands 96960
Telephone : 692 625 8934
Fax : 692 625 3837
Email : NA
Contact : The Manager

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	A public utility that plans, develops and provides water and wastewater services to the people Majuro.
Format of information	:	Report, regulations, polices, project funding
Internet	:	None
Language	:	English
Consulting or support services	:	In house training

Maldives Water & Sanitation Authority
Ameenee Magu,
Machchangolhi
Male 20-04
Republic of Maldives
Telephone : 960 317 568
Fax : 960 317 569
Email : NA
Contact : Director

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	A public utility that provides water and wastewater services to the people on the Maldives.
Format of information	:	Report, regulations, standards, funding
Internet	:	None
Language	:	English
Consulting or support services	:	In house training

Marshall Islands Environmental Protection Authority
PO Box 1322
Majuro
Marshall Islands
Telephone : 692 6253035
Fax : 692 6255202
Email : NA
Contact : Mr Abe Hicking

Topics covered: **a, g, h**

Description	:	Monitor and water quality testing of water supplies in the Marshall Islands
Format of information	:	Reports, regulations, standards
Internet	:	None
Language	:	English
Consulting or support services	:	Monitoring and water quality analyses

Ministry of Health and Medical Services, Rural Water Supply and Sanitation Section
Ministry and Health and Medical Services
Honiara
Solomon Islands
Telephone : 677 20830
Fax : 677 20085
Email : n/a
Contact : Mr Robinson Figue

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	This section provides assistance to the rural areas of the Solomons in developing sustainable water, sanitation and health facilities as well as training locals in these areas.
Format of information	:	Reports, manuals, and guidelines
Internet	:	None
Language	:	English
Consulting or support services	:	Training is all aspects of rural water and waste

Ministry of Natural Resources & Development
Division of Utility, Water & Sewer Branch
P O Box 100
Koror
Palau 96940
Telephone : 680 488 2438
Fax : 680 488 3380
Email : NA
Contact : Chief

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	A public utility that plans, develops and provides water and wastewater services to the people Palau.
Format of information	:	Reports, regulations, project funding
Internet	:	None
Language	:	English
Consulting or support services	:	In house training.

Ministry of Outer Island Development
Rarotonga
Cook Islands
Telephone : 682 20321
Fax : 682 24321
Email : NA
Contact : Mr Tenga Mana

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	A government department that provides a water and sanitation service for the people who live on the outer islands in the Cook Islands.

Format of information	:	Reports, guidelines, funding
Internet	:	None
Language	:	English
Consulting or support services	:	Provides water sector assistance

Pacific Water Association (PWA)
Naibati House
Goodenough Street
Suva
Fiji
Telephone : 679 306 022
Fax : 679 302 038
Email : Ppa@is.com.fj
Contact : Executive Director

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	Regional organisation consisting of most Pacific water sector utilities plus suppliers, consultants and other interested in promoting safe water supply and wastewater disposal
Format of information	:	Reports, guidelines, regional data and information on member utilities
Internet	:	www/sopac.org.fj/wru/#PWA
Language	:	English
Consulting or support services	:	Provides technical support and training for water sector utilities

Pohnpei Utilities Corporation
P O Box C
Kolonia
Pohnpei
FSM 96941
Telephone : 691 320 2374
Fax : 691 320 2422
Email : Puc@mail.fm
Contact : General Manager

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	A public utility that plans, develops and provides electricity, water and wastewater services to the people Pohnpei.
Format of information	:	Report, regulations, polices, guidelines
Internet	:	None
Language	:	English
Consulting or support services	:	In house training

Public Utilities Board
P O Box 443
Betio
Tarawa
Kiribati
Telephone : 686 262 92
Fax : 686 26106

Email : *NA*
Contact : *Chief Executive Officer*

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	A public utility that plans, develops and provides electricity, water and wastewater services to the people Kiribati.
Format of information	:	Report, regulations, polices, guidelines, project funding
Internet	:	None
Language	:	English
Consulting or support services	:	In house and regional training

Public Utilities Corporation (Water & Sewerage Division)
P O Box 34
Unity House, Victoria
Seychelles
Telephone : *248 322 444*
Fax : *248 321 020*
Email : *NA*
Contact : *General Manager*

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	A public utility that provides water and wastewater services to the people on the Seychelles Islands
Format of information	:	Reports, guidelines, regulations
Internet	:	None
Language	:	English
Consulting or support services	:	In house training

Public Works Department
Private Mail Bag
Funafuti
Tuvalu
Telephone : *688 203 00*
Fax : *688 203 01*
Email : *NA*
Contact : *Director*

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	Government department that can provide water and wastewater services.
Format of information	:	Reports, regulations, and guidelines.
Internet	:	None
Language	:	English
Consulting or support services	:	In house training.

Rural Water Supply Department
Private Mail Bag 001
Port Vila
Vanuatu

Telephone : *678 23179*
Fax : *678 25639*
Email : *NA*
Contact : *Mr Roy Matariki*

Topics covered: **b, c, e, f, g, h, i**

Description	:	Government department that assists rural communities with the planning and implementation of water sector services.
Format of information	:	Reports, guidelines
Internet	:	None
Language	:	English
Consulting or support services	:	Training and public education

Samoa Water Authority

P O Box 245
Apia
Samoa
Telephone : *685 204 09*
Fax : *685 212 98*
Email : *swalatu@samoa.net*
Contact : *General Manager*

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	A state owned utility that provides water and wastewater services to the people of Samoa.
Format of information	:	Report, standards, regulations, guidelines, project funding, public relations
Internet	:	None
Language	:	English
Consulting or support services	:	In house and regional training

School of Pure and Applied Science

The University of South Pacific
P O Box 1168
Suva
Fiji
Telephone : *679 313 900*
Fax : *679 302 548*
Email : *lsalat@usp.ac.fj*
Contact : *The Director*

Topics covered: **g, h**

Description	:	Regional educational organisation that can provide water sector information
Format of information	:	
Internet	:	www.usp.ac.fj
Language	:	English
Consulting or support services	:	Education and training

Solomon Islands Water Authority (SIWA)
P O Box 1407
Honiara
Solomon Islands
Telephone : 677 239 85
Fax : 677 207 23
Email : Dmakini@welkam.solomon.com.sb
Contact : General Manager

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	A public utility that provides water and wastewater services to the people on the Solomon Islands
Format of information	:	Reports, regulations, public relations, funding
Internet	:	None
Language	:	English
Consulting or support services	:	In house and regional training

SOPAC Secretariat
Private Mail Bag
GPO Suva
Fiji
Telephone : 679 381377
Fax : 679 370040
Email : alf@SOPAC.org.fj
Contact : Director

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	Regional organisation that can provide water sector information for most Pacific SIDS. A Water Unit exists at SOPCA to provide technical support, guidance, training plus actively seeks donor funding for water sector projects.
Format of information	:	Reports, guidelines, standards, newsletters, training reports, educational materials
Internet	:	www.sopac.org.fj
Language	:	English
Consulting or support services	:	Has resources to provide water sector support for all member SIDS including data collection, technical services, training and project proposal preparation.

South Pacific Community (SPC)
B P D5 98848
Noumea Cedex
New Caledonia
Telephone : 687 260 000
Fax : 687 263 818
Email :
Contact : Director

Topics covered: a, b, c, d, e, g, h, i

Description	:	A regional organisation that in the past provided sanitation resources for Pacific SIDS. However there are no current sanitation programs in operation.
Format of information	:	Reports, guidelines
Internet	:	www.spc,org.fj
Language	:	English/French
Consulting or support services	:	Training

South Pacific Regional Environment Programme (SPREP)
PO Box 240
Apia
Samoa
Telephone : *685 21929*
Fax : *685 20231*
Email : *Sprep@talofa.net*
Contact : *The Director*

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	A regional organisation that has the resources to implement wastewater and environmental programs to enhance the SIDS environment of member countries.
Format of information	:	Reports, guidelines, and newsletters
Internet	:	http://www.sidsnet.org/pacific/sprep/whatsprep_.htm
Language	:	English
Consulting or support services	:	May seek funding and implement programs.

The Water Board
P O Box 2779
Boroko
Port Moresby
Papua New Guinea
Telephone: *675 323 5700*
Fax: *675 323 1453*
Email: *NA*
Contact: *Managing Director*

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	Public utility that provides water and wastewater services to the people of Papua New Guinea.
Format of information	:	Reports, standards, regulations, funding
Internet	:	None
Language	:	English
Consulting or support services	:	In house and regional training

Tonga Water Board
P O Box 92
Nuku'alofa
Tonga
Telephone : *676 232 99*
Fax : *676 235 18*

Email : twbhelu@candw.to
Contact : General Manager

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	A state owned utility that provides water and wastewater services to the people of Tonga.
Format of information	:	Reports, regulations, funding
Internet	:	None
Language	:	English
Consulting or support services	:	In house and regional training

UNELCO
B.P. 26
Port Vila
Vanuatu
Telephone : 678 222 11
Fax : 678 250 11
Email : uncelco@uneclo.co.va
Contact : Water Supply Manager

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	A private utility that provides water supply services to the people of Port Vila, Vanuatu.
Format of information	:	Reports, regulations, and standards.
Internet	:	None
Language	:	French/English
Consulting or support services	:	In house training.

United Nations Development Program (UNDP)
Private Mail Bag
Suva
Fiji
Telephone : 679 312500
Fax : 679 301718
Email : webweaver@undp.org.fj
Contact : Resident Representative

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	*:*	*UN organisation that can provide information on the water sector*
Format of information	*:*	*Reports, and educational materials*
Internet	*:*	*www.undp.org.fj*
Language	*:*	*English*
Consulting or support services	*:*	*Have the resources to arrange water sector country projects.*

Water and Energy Research Institute of the Western Pacific (WERI)
UOG Station
Mangilao
Guam
Telephone : 671 7343132

Fax : 671 734-8890
Email : lheitz@uog.edu
Contact : The Director

Topics covered: **a, c, d, e, g, h, i**

Description	:	Regional educational organisation part of the University of Guam that can provide water sector information.
Format of information	:	Reports, guidelines, educational materials, newsletters
Internet	:	http://uog2.uog.edu/weri/index.htm
Language	:	English
Consulting or support services	:	Technical and educational assistance

Water and Sewerage Division
C/- Ministry of Communication, Works & Energy
Private Mail Bag
Suva
Fiji
Telephone : 679 384 111
Fax : 679 383 013
Email : NA
Contact : The Director

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	Government department that provides water and wastewater services to the people of Fiji.
Format of information	:	Report, standards, regulations, guidelines, project funding
Internet	:	None
Language	:	English
Consulting or support services	:	In house and regional training

Water for Survival
PO Box 6208
Wellesley Street
Auckland
New Zealand
Telephone : 64 9 5289759
Fax : 64 9 5289759
Email : johnwfs@clear.net.nz
Contact : Mr John La Roche

Topics covered: **c, d, e, f, g, h, i**

Description	:	Volunteer organisation that can provide water sector information
Format of information	:	Reports, newsletters
Internet	:	None
Language	:	English
Consulting or support services	:	May provide information and funding for small projects.

Water Supply and Sanitation, Department of Health
PO Box 807
Waigani
Port Moresby
Papua New Guinea
Telephone : *675 3248698*
Fax : *675 3250826*
Email : *NA*
Contact : *Mr Joel Kolam*

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	Government department that provides sanitation assistance to the rural communities of Papua New Guinea.
Format of information	:	Reports, guidelines, general data
Internet	:	None
Language	:	English
Consulting or support services	:	Reports, collection on data, guidelines

Water Supply & Sanitation Division, Public Works Department
PO Box 38
Alofi
Niue
Telephone : *683 4297*
Fax : *683 4223*
Email : *waterworks@mail.gov.nu*
Contact : *The Director*

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	A government department that provides water and wastewater services to the people of Niue.
Format of information	:	Report, standards, regulations, guidelines, project funding
Internet	:	None
Language	:	English
Consulting or support services	:	In house training

World Health Organisation
P O Box 5898
Boroko
N.C.D
Papua New Guinea
Telephone : *675 324 8698*
Fax : *675 325 0568*
Email : *info@who.ch*
Contact : *Regional Representative*

Topics covered: **a, b, c, d, e, f, g, h, i**

Description	:	UN organisation that may provide resources on public health and how it effects water and wastewater.
Format of information	:	Reports, standards, and newsletters.
Internet	:	http://www.oms.ch/aboutwho/

Language	:	English
Consulting or support services	:	May provide resources with public health issues.

Yap State Public Service Corporation
P O Box 667
Colonia
Yap 96943
Telephone : *691 350 4427*
Fax : *691 350 4518*
Email : *Robwesterfield@mail.fm*
Contact : *General Manager*

Topics covered: a, b, c, d, e, f, g, h, i

Description	:	A public utility that plans, develops and provides electricity, water and wastewater services to the people Yap.
Format of information	:	Report, regulations, polices, guidelines
Internet	:	None
Language	:	English
Consulting or support services	:	In house training

8.11 Case Studies (Topic k)

The following two case studies demonstrate the use of on-site deposal methods that are most commonly used in the region as well as composting toilets that are currently being trialed. Both studies were commissioned by SOPAC.

8.11.1 Case Study 1: Sanitation in the Federated States of Micronesia

by Dr Stephen Winter
Appropriate Technology Enterprises, Inc.
Chuuk, FSM

Introduction

In the 1970's the "benjo" represented the state of the art in sanitary facilities in Micronesia. There were two types: over-water and over-land. The over-water benjo was the most conspicuous and often desecrated an otherwise pristine beach. It consisted of a small enclosure (a privy) with a hole in the floor elevated on poles over the intertidal zone. One would get to this facility by negotiating various types of cat-walks (not always an easy task for the new comer!). At low tide, the mess below these facilities was in plain view. At high tide, one was lucky if it got washed away. The bay in Colonia, Yap, was affectionately called "Benjo Bay" because of the prevalence of these facilities. Similar facilities could be found over rivers (even up-stream of bathing areas) and in mangroves (where there is little or no movement of the water). The over-land benjo was essentially an unimproved pit latrine --- little more than a hole in the ground with a house over it. The user of these benjos would wish he could fly into and out of them and perform his mission without touching anything. In many of the remote atoll islands, there were no toilet facilities at all. The beach or bush were the bath room.

In 1983 a cholera epidemic occurred in Chuuk. Some people say it was a blessing in disguise because it opened people's eyes to the possible consequences of the prevailing sanitary practices.

As a result of the epidemic, an effort was made to outlaw benjos of all types and a massive program of building water-sealed toilets in the remote areas was undertaken. Hundreds of them were built such that every household that wanted one could have one. The materials for the construction of these facilities were provided by the Chuuk State Rural Sanitation Program by means of aid from the U.S. government. In the district centre, a house-sewer connection program was implemented. Although the epidemic was confined to Chuuk, other parts of Micronesia took measures to improve the sanitary facilities on their islands as well.

Today, more than a decade later, it is interesting to observe the state of affairs with respect to toilet facilities throughout Micronesia. To be sure, the classic over-water benjo no longer exists. Has the situation improved? What is the status of all those water-sealed toilets that were installed? Are other types of sanitary facilities being used? This report attempts to answer these and other questions. First, some cultural factors are presented that are relevant to toilet use. Then, three types of toilets are discussed with particular attention being paid to their water requirements, their potential for polluting groundwater, and their cultural acceptability.

Cultural factors

The outer islands of Yap are closely tied to Chuuk culturally and linguistically. Customs (and language, especially) have little to do with Yap proper; the state boundary is a political one. There is a continuum of customs that varies from the most traditional in the outer islands of Yap to the least traditional in the high islands of Chuuk proper. The degree to which the islands follow traditional practices probably varies something like what is indicated below:

most traditional	outer islands of Yap Pattiw islands in Chuuk Namonweito Atoll in Chuuk Pafeng islands in Chuuk Mortlock Islands in Chuuk
least traditional	high lagoon islands in Chuuk proper

In a report to the UNDP concerning the design of sanitary facilities for Woleai Atoll in Yap State (1), the writer noted that:

"Three cultural factors exist that must be considered in the design of sanitary and bathing facilities for Woleai. The first is that brothers and sisters and, to a lesser extent, other males and females in the same household can not use the same toilet. Separate male and female toilets must be provided. The second is that water for toilet flushing must be available at the toilet. This is required because defecation is a very personal matter that is never announced verbally or, in the case of flushing a toilet, by carrying a bucket from a distant well to the toilet. If one desires to use a toilet, he simply leaves the group he is in without announcing the purpose of leaving. This especially applies to women in a mixed group. This factor necessitates pumping of groundwater from the source to the toilet facilities (because wells cannot be located adjacent to toilets). A third factor, that may be of lesser importance, is that men's and women's clothing are hung in separate areas after washing. This implies a need for a separate male and female bathing/washing areas".

On the other hand, on the high islands of Chuuk lagoon, it would not be a problem for brothers and sisters to use the same toilet. However, a person (especially a woman) would be embarrassed to be seen carrying a bucket of water in the direction of a toilet. Like so many aspects of island cultures, it is easy for an outsider to make an assumption that is way off base and that will seriously jeopardize the chances of success of a project. Customs vary from island to island. All that can be said is that the person who intends to introduce any change in lifestyle should do his best to first seek out reactions to a proposed project from candid sources. Island people are very polite. Often, rather than give a contrary view, a view that could save a project from failure, people will simply be quiet.

The income level on some of the traditional islands is extremely low. It is certain that some families can not even afford the cost of toilet tissue. This is a consideration that must obviously be factored into any program directed at improving sanitary facilities. A response to this issue is that many water-sealed toilets can tolerate other types of paper. This solves the financial aspect of the problem. All that is needed is a source of paper!

Water-sealed toilets

Like a conventional flush toilet, a water-sealed toilet employs a water trap to seal or confine odors to the sewer pipe or waste storage area. Unlike a conventional toilet, flushing is done manually with a bucket of water. Generally speaking, the types of water-sealed toilets in use in Micronesia are functional but lack the aesthetic qualities of the toilet found in the modern home. However, compared to nothing --- the beach or bush --- they are certainly an improvement.

On the high islands of Chuuk, the water-sealed toilets promoted in the cholera era are gradually disappearing and are not being replaced. Some have been damaged by typhoons. In other cases, the 220 litre drum beneath the toilet has become filled. Many have simply deteriorated with age. According to the former director of the Chuuk Rural Sanitation Program, there is a feeling among the general population that it is the government's responsibility to replace the toilets. Rather than reverting to use of the benjo, people are using the beach and the bush.

On one of the high islands of Chuuk, the writer has observed a new type of benjo --- although its designers probably would not like that designation. It consists of a neat hollow box-like foundation of rock in the intertidal area over which a privy is built. Although the wastes are not exposed to view, the intertidal waters are surely contaminated with them.

Even on Weno, the commercial and governmental centre of Chuuk, it is common at sunrise to see people of all ages, shapes, and sizes taking a walk to the beach or bush in the early morning. The reason is that, even though the area is sewered, toilets might not be functional and/or there is no city water with which to flush them.

On some of the atoll islands of Chuuk there essentially are no toilet facilities. This is at least true in Namonweito Atoll and in the Pattiw area. It is probably true in some other areas as well. Even though water-sealed toilets were installed in these areas following the cholera epidemic, they were quickly abandoned because of the previously described cultural factors.

The writer suspects (but has not confirmed) that the Mortlock Islands in Chuuk State may make more use of water-sealed toilets. Nama Island has fairly well developed rainwater catchment and storage systems, the writer believes, due to the influence of a number of Chuuk State Rural Sanitation Program employees who were (now deceased) from that island. It is probable that they influenced the construction of toilets as well.

In 1990, the writer spent a month on Woleai Atoll, again gathering field data to assist him in the design of appropriate water supply and sanitation facilities. The only toilet on that atoll (5 inhabited islands) was for the UNV stationed on Falalop. This trip resulted in the recommendation of the same toilet design used in Maloelap (1). However, the UNDP did not provide funds for construction of the facilities. That was to be a local effort. The state of affairs in Woleai had not changed in 1992 when a water supply and sanitation survey was made on 13 of the outer islands of Yap State (4). Aside from the same single toilet on Woleai, only two of the islands in the survey group had toilets. One of these islands had 3 water-sealed toilets, all public; the other supposedly had 70 toilets, 45 of them being public. The writer suspects that public toilets might not be such a good idea owing to the prevailing cultural factors and to the problem of determining who will clean them. However, this opinion is unconfirmed.

The writer recently made a survey of rainwater catchment and storage systems on Pohnpei Island. Although he was not specifically looking for toilet facilities, they did not seem apparent. It may be that in the rural areas of Pohnpei the bush is the prevailing sanitary facility as well.

An often cited objection to water-sealed toilets is that they require water for flushing. This is a valid objection if water from a household's rainwater storage tank is used. However, if groundwater (assumed to be available in unlimited quantities) or seawater is used, it is not. This approach deserves consideration by any community contemplating construction of water-sealed toilets. Unfortunately, toilets are often constructed without first resolving the issue of a source of water for flushing.

Another common objection to water-sealed toilets is that they will pollute the groundwater, especially on atoll islands. This is indeed a valid objection. The writer would strongly suspect that, for example, in the model situation of Mwoakilloa, there is a high level of background contamination of groundwater due to human waste. This situation is probably unavoidable when toilets are sited near to closely spaced homes. Typically, dug wells are in place before the introduction of toilets and, typically, they are also near the home. It is easy to see that, in a populated community, there is a very high probability that groundwater will become contaminated after a program of toilet building. Ten years ago on Chuuk, when there was still a proliferation of water-sealed toilets, the writer recalls that it was frequently difficult to find an acceptable site for a new well because toilets seemed to be everywhere.

There are a few approaches to this problem. One is to only use a well for non-consumptive purposes. Toilet flushing and washing clothes can certainly be done with slightly contaminated water. One can also bathe in it (if he keeps his mouth closed!). However, this is probably an impossible rule to enforce in the case of small children. If one has a large enough rainwater storage tank, it might be possible to use it for bathing except in extremely dry periods. The important point is that, within reason, for some uses it doesn't matter if a well is polluted. In so far as acceptable coliform levels are concerned, a possible guideline might be to require wells used for non-consumptive purposes to have faecal coliform counts that would be acceptable for recreational waters (less than 200 col/100 ml).

The problem of groundwater contamination by water-sealed toilets depends on the siting of these facilities. If one is fortunate enough to able to locate a home in a pristine area, it is easy to site wells and toilets properly. This was discussed in the first section of this report.

VIP toilets

The ventilated improved pit latrine has recently been introduced to Chuuk State. The writer is not aware of its use elsewhere in Micronesia. The reason it was introduced is that it requires no water for flushing. Thus, it eliminates the problem of water supply which was often a concern for many of the users of water-sealed toilets. It also has other interesting features.

A VIP toilet is really nothing more than a pit latrine (over-land benjo) with a vent pipe added to the waste area. The logic of the procedure is that air passing over the end of the vent pipe will induce a draft resulting in a flow of air down the toilet and out the vent. When not in use, the toilet seat should be closed. This prevents light from entering the waste area by means of the toilet. If any flies have entered the toilet, they will ultimately try to exit via the vent pipe (flies are attracted to light). If the vent pipe is screened, two of the chief objections to the pit latrine can be eliminated: flies and odor.

During the early 1990's, over 400 of these toilets were installed on the various islands of Chuuk. In general, they have been favourably received. The writer had the opportunity to inspect (use) one of them that was in service. To his surprise, it was indeed odour-free. Sometimes, it is hard to believe that a concept really does work!

These toilets were installed by the Rural Sanitation Program in Chuuk. According to its former director, the toilets are apt to develop odours in low-lying areas. He suspects that this occurs when the groundwater table rises to the level of the wastes in the container. It is noted that this is not a good location for a water-sealed toilet either.

Personal taste is also involved in the selection of a toilet facility. One person that the writer spoke to concerning this type of toilet indicated that some people do not like them because you can see the waste products in the container. This appears to be a matter that could be addressed in public education programs.

An important feature of this toilet is that, if toilet tissue is unavailable, any of the wide variety of alternative traditional materials (that can fit through the opening of the riser!) are acceptable. As indicated in the discussion of cultural factors, this is an important economic consideration for some families.

Although VIP toilets do not involve the addition of significant amounts of contaminated liquids to the groundwater, it would appear that they would still degrade groundwater quality. The first section of this report indicated that research is required to determine acceptable distances between water-sealed toilets and wells. The same questions apply to VIP toilets.

VIP toilets have only been in use in Micronesia for a few years. They are slightly simpler to maintain than water-sealed toilets, do not require water for flushing, and will accept any alternative to tissue that is available. For these reasons they would appear to deserve consideration for application elsewhere.

Composting toilets

A number of composting toilets have been built as demonstration projects in Micronesia (6). At least two have been built in Yap, six in Pohnpei, and one in Kosrae. Other pilot projects may be in progress. Composting toilets have a number of desirable features. Like the VIP toilet, they do not require water for operation. However, in addition, they convert the waste into a resource that can be use as a soil conditioner. Thus, they cause no pollution of groundwater.

The earliest demonstration projects began in 1992. After around two years of operation, the users were happy with the units and report that they are pretty much odour-free.

Some of composting toilets are commercially available models. Others are based on a design developed by Greenpeace (7). The intent of the Greenpeace design is that it will be applicable for use in the remote areas of Micronesia. While it does use locally available materials, the construction of it is significantly more complex than a VIP or water-sealed toilet.

The major unanswered question with respect to composting toilets is how users will react to the requirement that the decomposed wastes must be removed from them periodically and spread on the soil somewhere as a conditioner. It may take a great deal of public education to convince people to do this. The long term success of the pilot projects in Micronesia still remains to be demonstrated.

References

1. Winter, S.J. 1991. Water supply and sanitation design study, Woleai Atoll, Yap State, FSM. ATE. v + 46p.
2. Winter, S.J. 1988. Construction manual for a water-sealed toilet. UNDP. 38p.
3. Winter, S.J. 1986. Water supply and sanitation facilities for Maloelap Atoll. ATE Tech. Rept. No. 1. vii + 36p.
4. Seyange, K.V. 1992. A field trip report to the outer islands on Yap State.
5. Winter, S.J. 1988. Operation and maintenance of the Moen water treatment plant chlorination equipment. The development of a VIP toilet for use in the rural areas of Micronesia. ATE. iv + 30p.
6. Rapaport, D. 1995. Sewage pollution in Pacific island countries and how to prevent it. 39p. Center for Clean Development, Eugene, Oregon.
7. Rapaport, D. 1995. The Yap head start nonpolluting bathroom. 42p. Center for Clean Development, Eugene, Oregon.

8.11.2 CASE STUDY 2: Composting Toilet Trial on Kiritimati

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Introduction

In June 1995 a trial of composting toilets was initiated and funded on Kiritimati in Kiribati by AusAID, the Australian government aid agency. The trial was conducted by a multi-disciplinary team from the Centre for Environmental Studies at the University of Tasmania in co-operation with I-Kiribati counterparts.

This summary of the 14 month project on Kiritimati will demonstrate the technical, cultural, social and economic issues that are involved in the introduction of composting toilets, and suggest future directions.

Location

Kiritimati (Christmas Island) is a coral atoll in the Line Islands, in the Republic of Kiribati. Kiribati is a small island nation of 33 coral atolls dispersed along the Equator in the Central Pacific. There are three groups of islands and atolls, and Kiritimati is the southernmost atoll in a chain of islands known as the Northern Line. Islands Kiritimati has a highly variable rainfall pattern with an average of about 860 mm per year.

Deterioration in the quality of the ground water has occurred through localised over pumping of the lenses causing 'upconing' of the underlying transition zone and seawater, especially during periods of average or lower rainfall. The ground water is also affected by bacteriological and chemical pollution from human activities. Ground water can be polluted from sources such as domestic animals particularly pigs and dogs, latrines and septic tanks, greywater soaks, fuel storage, agricultural activities, and open rubbish and Babai (taro) pits. The degree and extent of pollution from these sources is not known and would merit extensive study.

The Kiritimati composting toilet trial became part of the Water Supply project that had been planned since 1982, and the recent inclusion of the trial reflected reluctance by the donor government to reticulate contaminated water to the community. It was considered that effective sanitation should be attended to at the same time that the water supply implementation took place. There is a high incidence of enteric disease on Kiritimati and one source of transmission of these diseases is likely to be as a result of faecally contaminated water. The community is encouraged to boil the water before consumption but this does not always happen. Other sources of disease transmission would be through lack of hand washing after defecation, and from flies that come in contact with exposed faecal deposits.

Installation of pre-fabricated imported toilets

In November 1994, 12 toilets were installed in three villages on Kiritimati.

The Wheelibatch toilets were installed in domestic locations on Kiritimati and the two large Cage Batches were installed at the primary schools in two of the villages. One of the smaller Cage Batches was installed at a community clinic that was being funded by the village residents, and the other was installed in a domestic location where the extended family members often numbered more than twenty.

Education/community consultation program

An education program was undertaken to inform the community of the trial and to explain the use and reason for composting toilets. As each culture has different attitudes about sanitation, and each community has different requirements and limitations, ongoing consultation with the residents was a critical aspect of implementation. The development of the education program was based on the advice and assistance of I-Kiribati counterparts, the Community Health Educator and the Assistant Health Inspector.

Introduction of new sanitation technology in any culture is a complex and sensitive process as it affects peoples' lives in the most intimate manner. In Australia, the occasions when composting toilets have failed has been due to a lack of an education component in implementation, or as a result of inadequate pre-sales consultation and after-sales support. In the Kiritimati context, the Australian project team were somewhat handicapped by being unable to speak or understand Kiribati and by being largely unaware of the variety of cultural and political issues that affected the complex social mix on the island.

Installation of locally built toilets

During the reconnaissance visit in June 1994, staff from the Ministry of Line and Phoenix Development which administers island affairs expressed concern that use of the prefabricated toilets would not be sustainable as supply would depend on aid, and maintenance would be difficult due to lack of locally available spare parts and expertise. The Australian project team shared this concern and recommended to AusAID that more toilets be built employing an owner-built design that they had used in Australia for domestic application.

Fortunately, the opportunity arose for the construction of three more toilets because of a decision to extend the trial to non-government housing. Most of the trial participants for the 9 domestic toilets were transient government employers (usually three year terms on Kiritimati), and it was considered necessary to also trial the toilets at non-government houses where people are long term residents and responsible for their own dwellings and leased land. It was thought that the response of these residents would be more likely to reflect that of the normal I-Kiribati villager who owns his or her house-site and has a long term relationship with the land.

The reasons given for installing a local design at that stage of the trial were

- increased local participation in, and ownership of the project
- increased familiarity with the concept and principles of composting toilets through owner-building
- increased likelihood of sustainable maintenance due to the use of locally available materials

- avoid delay to construction which would be caused by having imported materials shipped from Australia to Kiritimati
- allow a comparison in community response to the pre-fabricated and locally built designs.

The agreement was that the men of each household who were to receive the toilet would be involved in the construction of their own toilet. When the time came for the installations in May 1995, most of these men were working on other building projects and so the construction team was composed of members of the Mayor's family. The Mayor provided invaluable assistance and support during this stage of the project.

As these locally built alternating batch toilet designs are considered the most suitable for small island conditions, details of materials, costing, installation and management recommended in those circumstances follow.

Design features of locally built toilet

The locally built dual chamber batch composting toilets are characterised by the following design features: (see diagrams 4 & 5)

- the toilet base comprises two adjacent chambers which each form a cube with approximately 1m sides, the top of which forms the floor of the toilet building;
- material is deposited through a pedestal or squat plate into one chamber until it is full and then that chamber is closed off to compost and the pedestal or squat plate changed to the alternate side;
- the two chambers each have a floor grate to allow drainage of liquid into a drainage tray below;
- the drainage tray has a 50 mm outlet approximately 25 mm above the base of the tray that allows a standing liquid level, and allows for access in case of blockage;
- the two chambers have hinged doors closing onto a frame which allows for a seal against the entry of flies;
- the chamber doors have mesh covered vent holes which allow the entry of air but offer a seal against the entry of flies;
- each chamber is vented with a vent pipe that extends from the top of the chamber to approximately 1.5 m above the roof of the toilet building;
- the frame of the toilet building is built on top of the two chambers with the stairs and the door on the opposite side of the toilet building to the chamber doors.

Liquid drainage

Evapo-transpiration trench (see Diagram 5)
The purpose of the evapo-transpiration trench is to ensure that excess liquid that is drained from the toilet does not reach the surface or contaminate the ground water. This is achieved by:

- sizing the trench such that the probability of surcharging is very low;
- planting the top and adjacent areas with species that will maximise evapo-transpirati from the trench.
- bunding and raising the trench to prevent surface run-off into the trench and to maximise rainfall run-off from the top of the trench.

Food crop trees, such as papaya, banana or breadfruit can then be planted adjacent to the trenches to further assist evapo-transpiration. Plants or trees which provide bulking agent could also be planted on trenches.

Costing

The approximate unit cost of the locally built composting toilets on Kiritimati including the toilet building based on the specified design is AUS$2500 to AUS$3000. This includes all materials, I-Kiribati labour costs and the liquid drainage trench requirements.

Cultivation

From the results of the education component in the sanitation pilot on Kiritimati, it is recommended that an incentives package be offered to encourage the widespread acceptance and use of the composting toilet on the island and to effect an understanding of the direct relationship between sanitary habits, water quality and hygiene, and the connection with health and nutrition. This package should include a well fenced garden area, seed, trees and plants and gardening assistance and advice. This strategy may not be an effective educational tool in some other cultural context, and community feedback will indicate which strategy is most appropriate in each application. What can be undertaken is, of course, also dependent on available funds and resources.

Results of the Trial

The sanitation project was conducted from June 1994 to September 1995, to ascertain whether the composting toilet was appropriate to Kiritimati from a cultural, technical and environmental point of view. An appraisal team of four consultants visited the island to assess the trial in September 1995. The prefabricated toilets had been trialed for ten months and the locally built units were trialed for 3 months prior to the appraisal. The trial project team recommended that this was much too short a trial period to fully cover all the issues involved. However there was considerable pressure to proceed with the long delayed Water Supply project and now that it entailed a sanitation component it was necessary to proceed with the larger Water and Sanitation strategy as soon as possible. A survey was conducted and 258 households out of 316 said they would like a composting toilet. It was decided that the 'pilot' trial had been sufficiently successful to justify an extended trial of some 200-300 composting toilets with the intention that the whole island would eventually be using composting toilets.

a. Usage

Usage of the prefabricated toilet during the 10 months that the Wheelibatch and Cage Batch toilets were trialed usage slowly increased in the domestic applications. Given the number of people in the households it was obvious from the rate at which the bins filled up that only a percentage of the household were using the toilets in the early stages. The women were more inclined to use the toilets as they offered some privacy. Teenage boys reported that they were embarrassed to be seen entering the toilets. The men preferred to use the bush or the beach. After the video was shown throughout the community, usage increased. Toward the end of the trial some families reported that everyone was using the toilet including the men. The gardening program resulted in a significant increase in the trial participants' interest in the composting toilets.

Usage of locally built toilets was much more consistent from the outset. It appeared from the rapid rate at which the bins filled up that all household members were using the toilet. This may have been due to the more integrated design and it may also have been due to the toilets being within the non-government village and being built by village residents.

At the schools, the usage was consistently low for a number of reasons. The toilet was rather conspicuous and the children were sometimes teased for using it. The teachers insisted on locking the toilet so the children had to ask the head teacher for the key. As many of the children have chronic diarrhoea this would have been a demanding requirement. Most of the teachers did not use the compost toilet but continued to use flush toilets in the teachers nearby houses, which would not have provided very encouraging example to the children. The teachers became more interested in the composting toilet through the gardening program. It is thought that when a greater number of people have composting toilets at home the children will feel less conspicuous using the toilets at school.

b. Cultural issues

Taboos related to sorcery and faeces were a concern with regard to containing excrement in a bin that may be accessible to prohibited persons. Certain taboos relating to menstruating women using the toilets were also raised. However these issues did not seem to be a problem within the family and as the trial progressed, people became more comfortable using the toilet regardless of these concerns. At the outset of the trial, there was a definite aversion to the prospect of using the end product for fertiliser or any other method of disposal that might allow contact. It was difficult for people to believe that excrement would be transformed into an acceptable material. However when the piles in the toilets did actually produce compost there was a relieved and surprised response, and a marked increase in interest in the toilets. Neighbours to trial participants, who had previously been disinterested or even hostile to the project, requested a composting toilet because they wanted to be able to have a garden and use the compost as a soil improver.

People objected to the height of the buildings. They said they felt uncomfortable using a toilet, which was elevated, above ground. Some said they feared that a person may be underneath. This probably relates to the traditional use of latrines that are suspended over water. The height of the buildings caused embarrassment to some people because they were conspicuous when they climbed the stairs and used the toilet.

A request was made by householders that the toilet doors be made lockable in case strangers used their toilet. However most people lost their keys within a short time and so the toilets then remained unlocked, except for the schools and the clinic.

During the reconnaissance trip in June 1994, the community was asked whether they would prefer squat plates or pedestals for the toilets. Most people replied that they would prefer pedestals but it was indicated that in fact many people would still wish to squat, so a compromise was made by designing a low pedestal which allowed sitting in a semi-squatting position. The pedestal was also made strong enough to support considerable weight for squatting on the seat if desired.

c. The compost and hygiene

To keep the composting toilet system simple and sustainable it is important that the end product can be disposed of by the users within the house site. Therefore the compost should be free of disease causing organisms. Testing the compost reveals how effective the composting process has been within a particular time frame, and indicates guidelines for usage.

Six of the toilets were ready to be emptied of compost during the September 1995 visit. The compost in each case had the appearance of decomposing bulking agent (whichever leaves or fibre had primarily been added to the toilet during use) and had a pleasant humus odour.

Maintenance

To maintain the composting process, it is preferable that a small handful of bulking agent such as dry leaves or coconut fibre be deposited in the toilet after defecation to allow a suitable mix of material containing nitrogen and carbon. If people forget to add the bulking agent, the pile will eventually smell unpleasant. Usually if a quantity of leaves is then deposited in the toilet the smell disappears.

As many housewives on Kiritimati sweep up leaves around the house each day and the burn them, it was not too difficult for them to collect enough leaves to have a ready supply by the toilet.

When the bin that is being used is full, it is simply a matter of unscrewing the pedestal and changing it over to the side of the empty bin. The toilet can also be designed to have a pedestal or squat plate over each bin so there is no need to make a change. However changing the pedestal and closing the first bin ensures that no one will mistakenly use the bin that is now undergoing a fallow period.

When the fallow period is complete the compost can be shovelled out of the bin and mulched around fenced fruit trees. If the trees are not fenced pigs and chooks will dig up the compost and scatter it around.

The pedestal rarely requires cleaning as it is low and splayed to avoid material collecting on the inside. If the seat becomes dirty it can be wiped with wet leaves or rags and then these can be dropped into the toilet.

As Kiribati women are responsible for sanitation in the home, all the above chores were conducted by the female head of the family, without any apparent difficulty. Most women reported that it was easier than looking after a water based toilet.

It would be unusual for the drain to become blocked as solid matter is filtered through the false floor at the base of the bin. However, if necessary, the pipe to the trench is approximately half a meter long and could be cleared with a stick through the access point.

Material for repairs to the building frame or the concrete bins would be available on the island. There is little else that requires maintenance in this alternating batch composting toilet design.

Personnel

The introduction of composting toilets requires considerable input from local personnel skilled in a health education and community consultation probably over 2-3 years. A Curriculum Development Officer to work with teachers and students in the schools on water quality and sanitation issues would be most useful at the beginning of the project. For government housing a Sanitation Officer responsible for basic maintenance of toilet structure and on-going advice as to usage of the toilet and the compost would need to be on call in the same way as a plumber would be readily available for attention to waterborne systems. This person should receive remuneration that reflects his or her essential role in the community to counteract any negative association attached to people who take care of toilets. For long term residents in non government housing most maintenance issues could be handled by the householder once they have been exposed to the initial education program, and are in the habit of using the composting toilet.

If composting toilets are initially to be introduced by expatriates it is important to include both female and male team members. Implementation will depend primarily upon the co-operation of the women in the community, and sensitive issues are more effectively discussed between persons of the same gender. Initiating the gardening program should be undertaken by a person with cultural awareness and good people skills in addition to having experience with the hygienic use of human excreta in cultivation, and small plot gardening in physically antagonistic circumstances.

Water Based Sanitation Systems

A centralised sewerage system was installed in Tarawa the capital of Kiribati and some maintenance and pollution problems have been experienced as a result. Pits, aqua privies and septic tank toilet systems have also been installed with the assistance of aid donors and used on Kiritimati for many years. It is often considered to be an indication of status to have a flush toilet in the house. Health education programs have been conducted throughout Kiribati over the last 40 years to deter people from using the traditional location of the bush and the beach for defecation, and to use a water based toilet or pit latrine instead. In some places people have been fined a dollar if they were caught using the beach and their excrement was not immediately removed by the tide. I-Kiribati initially found the water based toilets unacceptable for a variety of reasons but over time and with the persistent efforts of community heath educators the flush toilets have been accepted and increasingly desired by the I-Kiribati. It is therefore a very difficult adjustment to be now told (once again by outsiders) that water borne sanitation systems may be contributing to the high incidence of enteric disease on the island and that a practice that was advocated as a health measure may be a cause of ill health. It is understandable that the composting toilet trial has been viewed with considerable wariness and scepticism, and technology transfer must be conducted with caution, patience and some degree of humility.

In the case of the aqua privy and the septic tank system the effluent from the toilet is discharged directly to the ground water. The septic tank if well maintained provides primary sedimentation but in any circumstances does little to reduce pathogens, BOD or nutrients in the effluent. Berg *et al.* (1976:: 175) suggests that primary sedimentation will not remove viruses at all, and if such effluent is chlorinated will only remove 50% of viruses. If the septic tank is not emptied when necessary then solids will also overflow into the leachfield. The truck used for emptying septic tanks has been out of action for some time on Kiritimati so the residents either allow the tank to overflow or empty the tanks by hand and dispose of the sludge nearby, or in the lagoon. The appropriately sized horizontal trench that can ordinarily provide some treatment of the effluent from septic tank is not used in Kiribati because of the highly porous soil and the inclination to flooding in the rainy season. The leachfield is instead a vertical funnel that facilitates direct drainage to the ground water. As water borne enteric diseases such as Giardiasis are very common on Kiritimati, it is likely that reinfection is maintained partly through contaminated water. However, this has not been empirically proven. Transmission of disease would also be caused through not washing hands after defecation and from flies that come in contact with exposed faecal deposits.

Conclusion

Thorough research and development of mesophilic composting toilets for application in a variety of resource constrained circumstances in the developed and developing world is a relatively recent phenomena. This study is certainly not presented as the final word on the subject. It is hoped that the technical and educational developments that have occurred to date will be expanded upon by those most suited to do so, that is, the individuals and communities that use the toilet, and adapt it to their own needs. Although the composting toilet is strongly recommended as a simple sustainable sewage treatment option it is not the intention of the author to be a technological missionary on this issue.

While advocating due consideration of composting toilets it is not implied that centralised sewerage systems or on-site water borne methods such as septic tanks or pourflush latrines do not have a valid role. It is rather to suggest that in any country, the most appropriate technology should be applied in each location, and that the selection from a range of equally accessible technical options should be based on a thorough appraisal of the cultural, socio-economic and ecological context to be serviced.

NOTE: An Australian funded project constructing composting toilets on Kiritimati is currently being implemented. Thus the suitability of composting toilets on Kiritimati will not be know for another year or two.

References

1 Burke, E. 1996: Report on the Workshop on Technologies for Maximising and Augmenting Freshwater in Small Islands (South Pacific, Indian Ocean and South China Sea Region) held in Suva, Fiji, 6-8 February 1996. SOPAC Miscellaneous Report 223. South Pacific Applied Geoscience Commission, Suva, Fiji.

2 Convard, N. 1993: Land-Based Pollutants Inventory for the South Pacific Region. SPREP Reports and Studies Series no. 68: South Pacific Regional Environment Programme, Apia, Western Samoa.

3 Depledge, D. (Comp) 1997: Sanitation for Small Islands: Guidelines for Selection and Development. SOPAC Miscellaneous Report 250. South Pacific Applied Geoscience Commission, Suva, Fiji.

4 Dillion, P. 1997: Groundwater Pollution by Sanitation on Tropical Islands, International Hydrological Program Report IHP-V no. 6, UNESCO, Paris

5 Mogensen, Ulla. (Comp) 1996:Technologies for Augmenting Freshwater Resources in Small Island Developing States: Source Book for Managers and Planners. UNEP/SOPAC Joint Contribution Report 112. UNEP

6 Rapaport, D. (Comp) 1996: Sewage Pollution in the Pacific and How to Prevent It. Greenpeace Pacific Ldt. Suva, Fiji.

7 WHO 1989: Health Guideline for the Use of Wastewater in Agriculture and Aquaculture, Technical Report Series 778, World Health Organization, Geneva.

APPENDIX 1

Regional Wastewater Agencies Data Sheets

Country/State	Waste Characteristics	Collection and Transfer
American Samoa	8160 m^3/d	2600 house & business connections. AC; PVC & fibreglass pipes pumped systems
Cook Islands	ND	No reticulation system except some hotels
Kosrae, FSM	ND	- oxidation ponds to outfall - septic tanks to outfall
Pohnpei, FSM	2520 m^3/d SS~100 mg/l	1120 connections gravity system
Chuuk, FSM	3000 m^3/d	- 475 + connection - gravity/pump system - AC/cast iron pipes
Yap, FSM	1600 m^3/d domestic	Less than 3000 people pumped system
Fiji	47 000 m^3/d BOD 450 to 20-44 mg/l SS 290 + 30-60 mg/l	20 700 connections 148 000 people
French Polynesia	ND	ND
Guam	54 000 m^3/d total 34 800 m^3/d domestic	
Kiribati	BOD 70 to 320 mg/l	- 2000 connections - pumped raw to outlet saltwater flush
Nauru	ND	Pumped raw to outlets using saltwater flush
New Caledonia	ND	ND
Niue	ND	No reticulation 400 septic tanks
Mariana Islands	ND	ND
Palau	ND	ND
Papa New Guinea	ND	Urban centres only
Marshall Islands	ND	1300 households on Majuro, saltwater flush
Solomon Islands	ND	25 000 people reticulated pumped raw to outfall
Seychelles	2500 m^3/day	6 % of population has access to reticulation system
Tokelau	ND	No reticulation system
Tonga	ND	No reticulation system
Tuvalu	ND	No reticulation system
Vanuatu	ND	No reticulation system
Western Samoa	ND	No reticulation system

ND = No Data

Country/State	Disposal	Policy & Distortional
American Samoa	Treated effluence discharged into two deep sea outfalls	ASPA utility, EPA standards
Cook Islands	Into ground	Build codes for septic tanks, No standards
Kosrae, FSM	Deep sea outfall (30m), River discharges	Regulations but not enforced
Pohnpei, FSM	Sea outfall	Pohnpei Utility Corp.
Chuuk, FSM	Sea outfall	Chuuk Utility Corp.
Yap, FSM	Sea outfall	Yap State Public Services Corp. EPA but no legislation
Fiji	Sea and river outfalls	Public Works but will be corporatised soon
French Polynesia	ND	ND
Guam	Sea outfall	EPA regulation
Kiribati	3 sea outfalls	Public Utilities Board, No standards
Nauru	5 sea outfalls	Nauru phosphate Corporation
New Caledonia	ND	ND
Niue	Into ground	Building codes for septic tanks, No standards
Mariana Islands	ND	ND
Palau	ND	ND
Papa New Guinea	Sea outfall	The Water Board, Private Companies
Marshall Islands	Sea outfall	Major Water & Sewer Corp. EAP regulations, little enforcement
Solomon Islands	17 sea outfall for Honiara	Solomon Islands Water Authority
Seychelles	Marshes & rivers	Public Utility Corp, Division of Environmental monitors pollution.
Tokelau	Into ground	ND
Tonga	Into ground	Tonga Water Board
Tuvalu	Into ground	Public Work, Building code for septic tanks
Vanuatu	Into ground	ND
Western Samoa	Into ground	Samoa Water Board, No standards

ND = No Data

Country/State	Treatment	Reuse
American Samoa	Primary treatment	None
Cook Islands	Septic tanks & latrines	None
Kosrae, FSM	Oxidation ponds, septic tanks	None
Pohnpei, FSM	Activated sludge but not working	None
Chuuk, FSM	Secondary treatment but not working	None
Yap, FSM	Primary treatment, Imhoff tanks	None
Fiji		None
French Polynesia	ND	ND
Guam	Secondary treatment	ND
Kiribati	None for reticulated, septic tanks & latrines	
Nauru	None for reticulation, septic tanks	None
New Caledonia	ND	ND
Niue	Septic tanks, latrines	None
Mariana Islands	Secondary treatment	ND
Palau	ND	ND
Papa New Guinea	Preliminary, oxidation ponds, septic tanks	None
Marshall Islands	None for reticulation, septic tanks	None
Solomon Islands	None for reticulation, septic tanks and latrines	None
Seychelles		Minimal to gardens
Tokelau	Septic tanks, latrines & over water latrines	None
Tonga	Septic tanks	None
Tuvalu	Septic tanks & latrines	None
Vanuatu	Septic tanks & latrines	None
Western Samoa	Septic tanks & latrines	None

ND = No Data

Country/State	**Training**	**Public Education**
American Samoa	ASPA privative on state training and regional training	In-house training, buddy system with neighbouring SIDS
Cook Islands	Minimal	None
Kosrae, FSM	Minimal	None
Pohnpei, FSM	In-house training	None
Chuuk, FSM	In-house training	None
Yap, FSM	Local on-going	Yes, radio & public meeting
Fiji	Local & overseas	Minimal
French Polynesia	ND	ND
Guam	ND	ND
Kiribati	Minimal	Minimal
Nauru	In-house	Minimal
New Caledonia	ND	ND
Niue	None	Minimal
Mariana Islands	ND	ND
Palau	ND	ND
Papa New Guinea	In-house & overseas	Public awareness campaigns
Marshall Islands	Minimal	Minimal
Solomon Islands	Minimal	Minimal
Seychelles	ND	ND
Tokelau	None	None
Tonga	Minimal	Minimal
Tuvalu	Minimal	Minimal
Vanuatu	Minimal	None
Western Samoa	Minimal	Minimal

ND = No Data

Country/State	Financing	Stormwater Disposal
American Samoa	Wastewater charged to water bill but still a deficit that is covered by surplus in power sector	Not managed by any agency but Public Water Dept. maintain culverts.
Cook Islands	None	None
Kosrae, FSM	No changed Wastewater budget $US14,000	None Drainage of road areas
Pohnpei, FSM	Through water charges	None
Chuuk, FSM	ND	None
Yap, FSM	No charges, subsided by water/power	Ground soakage, no system, no legation
Fiji	$US0.11/m^3 of water used	Drainage disposal for in urban areas only
French Polynesia		
Guam	ND	Drainage diverted into deep soakage wells
Kiribati	No charges, subsided by water/power	None
Nauru	Paid by Nauru Phosphate Company	Roadside
New Caledonia	ND	ND
Niue	None	Roadside
Mariana Islands	ND	ND
Palau	ND	ND
Papa New Guinea	Based on % of metered water supply	In urban centres only
Marshall Islands	Subsided by water/power	None
Solomon Islands	No charged, subsided by	Honiara by Municipal Authority oversee statements
Seychelles	1/3 of water bill and subsided by water rates	Not allowed into public sewers
Tokelau	None	None
Tonga	None	Roadside
Tuvalu	None	None
Vanuatu	None	Roadside
Western Samoa	None	Roadside

ND = No Data

APPENDIX 2

Regional Wastewater Systems plus Constraints and Advantages

Appendix 2: Regional Wastewater Systems plus Constraints and Advantages

(Two sheets: one showing sketches of wastewater systems and one noting constraints and advantages)

APPENDIX 3

Draft copy of International Source Book on Environmentally Sound Technologies for Wastewater and Stormwater Management

for scope of study

IETC

International Environmental Technology Centre

INTERNATIONAL SOURCE BOOK ON ENVIRONMENTALLY SOUND TECHNOLOGIES FOR WASTEWATER AND STORMWATER MANAGEMENT

TECHNICAL
PUBLICATION
SERIES
[number]

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Introduction

The deterioration of water quality and the consequence public health problems facing many communities worldwide have been recognised for sometime. The United Nations Water Decade (1981-1990) was a major initiative to address the need to provide safe drinking water and sanitation to the two-thirds world without access to these. These problems still exist due to the increasing world population, and the proportion of communities without adequate sanitation has remained at approximately two thirds. These problems are compounded by the rapid migration of rural population to the fringes of cities. This trend of urbanisation has been forecast to continue for sometime into the future. Communities growing rapidly around urban areas are also those with little resources and with low incomes.

Urban managers are faced with the problem of how to provide adequate wastewater and stormwater services, and how to allocate priorities with competing demands for other urban infrastructure such as roads, hospitals and schools. Communities themselves are aware on a daily basis of the lack of services and are similarly confronted by the problem of how to overcome them with very limited available resources within the community. Although these problems are severe in urban areas, many rural communities are also faced with poor or deteriorating sanitation facilities.

Developing countries experience the largest share of the problems described above. Countries in economic-transition also suffer from inadequate or deteriorating infrastructure needing restoration. Even in the developed countries questions have been asked as to whether the current way of providing wastewater and stormwater infrastructure is environmentally sustainable in the longer term. It has been recognised that the very large sewerage system and wastewater treatment plant is not generally a good model for developing countries to follow.

Purpose and intended audience of the Source Book

The solution to the problem of lack of wastewater and stormwater management does not lie simply in expending more of the limited available funds. Access to information has been identified as a major issue, and is the reason for this Source Book. It follows an earlier publication by UNEP-IETC covering the management of municipal solid waste (International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management), and for largely the same reason. Lessons learned from the adoption of technologies in a particular situation have not often reached people elsewhere who can benefit from them. Practices that are deemed to constitute 'environmentally sound technologies' in one place are not generally known in another. A case in point is the highly successful low-cost 'condominium sewerage' first practised in Brazil but largely unknown elsewhere. There also appears to be a lack of appreciation amongst those with the responsibility for providing wastewater treatment of the basis of the treatment technology. High technology processes, such as the activated sludge process, have been equated with better-treated wastewater, when simpler technologies, such as lagooning, can achieve the same or better quality water. The scientific basis for the physical and biochemical processes is largely the same for both, and the same processes operate in natural purification of human excreta. Thus providing information and understanding, and where further information can obtained, is an aim of the Source Book. In addition the Source Book attempts to provide guidance on how to synthesise the available information for application in a particular setting.

The primary intended audience of the Source Book is decision-makers who are involved in providing wastewater and stormwater services. Decision-making takes place at various levels. Politicians/ top ranking government officials/ city mayors represent one level, where prioritising the need for the services and providing funding is the concern. Professionals provide advice to the above and are involved in implementing wastewater and stormwater projects. Community leaders need to be involved in any service provision to the community. The private sector may be involved in financing, constructing or operating a service.

The Source Book has been written to cater to the general needs of the above, but has been aimed more particularly to the middle to upper levels of decision-making. Training modules have been prepared for three levels of decision-making. A one to two day workshop module for top level decision makers; a 5 to 10 day module for professionals from government and the private sector, and a half-day to one day seminar for community leaders and the public.

The Source Book brings together experiences and ideas from all regions of the world: Africa, Asia and the Pacific, Europe, Latin America and the Caribbean, and North America. There are vast differences among and within these regions in social, economic and environmental conditions. But there are also many similarities across the regions and over time. The dire sanitation problems in many cities in developing countries were experienced in European cities during the industrial revolution period. People can learn from both avoiding the mistakes and adopting sound practices applied elsewhere, provided that information is made available. The Source Book aims to facilitate the sharing of information among all regions with the aim of promoting environmentally sound technology practices.

The need for better access to information on sanitation has also been felt by other organisations. UNEP-IETC is collaborating with United Nations Development Programme/World Bank (UNDP/WB) Water and Sanitation Program in producing a complementary Resource Guide on Urban Environmental Sanitation. This Source Book will focus primarily on technology and its practice, while the Resource Guide on the economic, social and institutional issues that affect sound technology practice. UNEP-IETC is also collaborating with WHO Sewage Clearinghouse by providing information on sanitation technology through its maESTro Environmentally Sound Technology data-base.

Structure of the Source Book

Section 1: Toward a framework for wastewater and stormwater management

Wastewater and stormwater management, though important in itself, needs to be placed in the wider context of improving public health and the environment. It needs to be integrated with municipal solid waste management and hygiene promotion to achieve significant overall public health improvement. It also needs to be practised in the context of physical, geographical, economic, institutional, social and historical context of the community provided with the services. The need for all of these is illustrated by considering the problems facing communities without adequate sanitation.

This section touches on the importance of planning, community participation and sound financial planning and management, and suggests a broad framework for wastewater and stormwater management to achieve long term sustainability. These aspects are discussed in greater detail in the UNDP/WB Resource Guide.

Section 2: Environmentally Sound Technologies and Practices

The aim of the Sound Practices section is to describe major technology options for collection, treatment, reuse and disposal of wastewater and stormwater. Understanding the basis of the technology is important in helping to make the correct technology choice. This understanding, which is derived from an understanding of the physical, chemical and biological bases of the technology, is emphasised, as well as the corresponding processes taking place in nature. In the latter, the cycling of elements is crucial to maintenance of ecosystems, and is the basis for reuse of wastewater and stormwater, and indeed the basis for environmental sustainability.

The choice of technology amongst the options will be governed by local factors. These include existing technology, facilities and services, availability of land, ability to raise fund and pay for the on-going costs of operation and maintenance, as well as climatic conditions, soil type, and social and cultural settings of where the technology is to be used. These factors are discussed, and a community-scale technology is suggested as one possible model to achieve environmentally sound technologies for long term sustainability.

Section 3: Regional Overviews and Information Sources

For each region an overview is presented in 10 sub-topics with the aim of sharing information on experiences and practices. These sub-topics include those covered in Section 2 and additional topics on Policy and institutional framework, Training, Public Education and Financing. There is unavoidable overlap between what is covered in Sections 2 and 3. In discussing a technology practice in a region, there may be a need to describe the technology even though it is a variant of a major option. The appropriateness of the technology in the regional context may also be commented. Not all Regional Overviews follow the sub-topics in a strict manner or order, where there is justifiable reason to highlight, for example, a historical approach or current trends in technology covering several sub-topics.

It is not possible to provide all the information required by decision-makers in a single publication. At the end of each Regional Overview, a list of information sources is provided. The names of institutions that can provide additional information is given, covering international, national and local government agencies, professional and industry associations, tertiary educational institutions and some non-government organisations. Private firms providing technology, equipment or consultant services have not been included.

A number of case studies are provided at the end of each Regional Overview to illustrate sound practices that may have applicability in other regions. It should be noted that sound practices are community and locality specific, and application in other community and locality needs to consider local physical, economic and social conditions.

Appendix 1: Public Health Aspects of Wastewater and Stormwater Management

A primary reason for providing wastewater and stormwater management is to safeguard public health. Decision-makers and community members need to be informed about the health implications of not providing adequate sanitation services. One reason for the lack of priority given to the provision of sanitation services is inadequate appreciation of the health impact of human wastes. A public health crisis (e.g. Surat) usually makes a community aware of the importance of wastewater and stormwater management and a high priority is given to it. Information on the health impact of human wastes is available from the World Health Organization (WHO). An extract has therefore been included.

Appendix 2: Costs of Wastewater and Stormwater Management

When evaluating technology for its affordability it is critical to know what it costs and the costs of alternative technologies. Costs vary with local conditions. The Source Book provides information on relative costs of the major technology options.

Appendix 3: UNEP-IETC Contact Information

Information on UNEP-IETC and its maESTro data base on environmentally sound technologies is provided to facilitate contact with organisations providing these technologies.

Bibliography

The Source Book includes a bibliography of selected items that may be useful to decision makers and others working in wastewater and stormwater management. The Bibliography includes books, reports, conference proceedings as well as journals.

Glossary

As a reference for terms used in the book, a glossary of words and phrases relevant to wastewater and stormwater is included.

How to use this book

This book is intended to be used in a number of ways by using information from a combination of sections or sub-sections. To gain an appreciation of the problem of sanitation, Section 1 and Appendix 1 provide a broad overview. This information may be what community leaders need to appreciate to consult with community members on priority to be given to wastewater and stormwater management. For a professional who wishes to familiarise with major technology options in sewerage, Section 2 (sub-section 2) provides this overview. This can be combined with relevant sections in the Regional Overviews (Section 3, sub-sections 2). On the other hand an urban manager in a South American city may want to read the whole of the South American Regional Overview, and Section 2 (sub-section 2) if low cost sewerage is being considered. If further information is required the list of information sources at the end of the Regional Overview can be consulted.

The Training Modules produced with the Source Book cater to three levels of decision-making (see above under Purpose and Intended Audience)

The Source Book, as compared to a technical manual

The Source Book is not intended to be a technical manual. It does not provide technical details or design procedures. Many excellent technical manuals and handbooks are available. This Source Book lists some of these in the Bibliography. Furthermore the Information Sources listed at the end of each Regional Overview can provide further information (e.g. Professional Associations). Similarly the Source Book does not provide detailed costs for the technologies or cost-benefit analysis for each technology option. Such analyses should be done in the context of a particular local application.

The Source Book, however, provides a broad overview of technology options, which can achieve protection of public health and the environment. Furthermore it points to practices that can be environmentally and financially sustainable. These are because resources in the wastewater and stormwater are recycled rather than disposed, and that the technology is acceptable and affordable to the community it serves.

Note on the coverage of stormwater management: Wastewater and stormwater are inevitably intertwined, because wastewater may be disposed into stormwater drainage, wastewater and stormwater may be collected in the same sewer, and inevitably there is cross-connections even when wastewater and stormwater are separately collected. The treatment principles for stormwater are similar to those for wastewater. The subject of stormwater management is in itself very wide ranging, from estimating run-off from rainfall or storm events to control of flooding. Coverage of stormwater management in the Source Book has been confined to stormwater generated on-site and where stormwater and wastewater are collected or treated together. Basin wide stormwater management and control of flooding (stormwater diversion canals, floodgates) are not specifically covered. Nonetheless if the same technologies presented in this Source Book for stormwater collection, treatment, reuse and disposal are applied on a river basin wide basis, then significant contribution to preventing flooding will be achieved.

Section 1
Toward a framework for wastewater and stormwater management

This section develops a framework for wastewater and stormwater management by first describing the problems facing communities without adequate sanitation. This is to provide a background for the type of management that is required to address the problems. The concept of integrated waste management is then introduced and the wider issues, besides those of technology, are discussed. A framework for wastewater and stormwater management is then outlined.

1. Problems facing communities without adequate sanitation

Inadequate sanitation facing a substantial proportion of the world's population is well documented. The overview on each region in the Source Book provides a summary of conditions in the regions. Many of those without sanitation are in rapidly growing cities in developing countries, affecting the poor in general, though the situation is not confined to these cases. Following the considerable effort during the UN Decade of Water and Sanitation (1981 – 1990) much discussion and analyses have been undertaken to find the causes for the lack of success in providing sanitation for all, and many ideas have been put forward to overcome the problems. The Water Supply and Sanitation Collaborative Council (WSSCC), for example, has prepared thematic papers on the subject (WSSCC, 1999a) in preparation for developing a framework for future action, Vision 21: A shared vision for water supply, sanitation and hygiene (WSSCC, 1999b).

The issues involved in providing sanitation for much of the world's population are complex. It is difficult to cover the technical, social, economic and environmental dimensions in a brief space. It is also difficult to generalise the setting or circumstances of these communities. Each has its own physical, cultural and political setting. Nonetheless it is desirable to portray the physical setting facing communities without adequate sanitation so that we can gain a perspective of how the problems develop, and how communities have responded to these problems.

In general these communities are located in an environment which has a relatively high population density. Water supply may or may not be adequate. In cases where water is supplied through pipes, there are not the corresponding pipes for removing the wastewater generated. The wastewater is simply allowed to flow by gravity through the natural drainage of the landscape ending in low lying areas, water courses, lakes or the sea. The natural drainage carries stormwater run-off during rainfall events, and during flood events stormwater mixes with wastewater, and polluted water is spread over a much wider area than the drains. In addition solid waste is also generally dumped into the drains or natural water courses resulting in flooding at lower rainfall events. Water-borne diseases are therefore endemic in these communities. The environmental conditions of the area are degraded, because water containing decaying organic substances from sewage and garbage give foul odour, the water is depleted of oxygen and is putrid. Groundwater in the area is also generally polluted, because of the infiltration of polluted water to the groundwater aquifer. The general physical environment is as illustrated in Figure 1.1.

Figure 1.1 Urban settlement with high population density, sewage disposed to drains, pollution of drains, streams, river/sea and groundwater.

If the population density is very low, the environment has the capacity to absorb the wastes generated and environmental degradation is negligible. Water quality of streams and rivers in this environment is generally excellent. Figure 1.2 illustrates a very small population in a natural forest setting. The natural processes involved in the assimilation of the wastes are elaborated in Section 2 (2.2).

Figure 1.2 Small settlement in a natural forest.

When the amount of wastes disposed to the environment increases with the increase in settlement population, the capacity of the receiving environment to assimilate the wastes is exceeded and degradation of the environment takes place (Figure 1.1). Communities have responded in different ways to the public health problem and environmental degradation that are created. Even though there have been numerous ways in which the problem has been addressed, we may generalise these in terms of stages depicted in Figures 1.3 – 1.5.

Because of the importance of dealing with health problems caused by wastewater within the community, wastewater is transported away from the community. This is done by improving drainage, while still conveying both wastewater and stormwater through the same drains. Measures to reduce the incidence of flooding are usually applied, by for example, deepening drainage channels, preventing solid wastes from being dumped into drains, and covering of the drains represents the first attempt to provide a sewerage system (Figure 1.3). In this way wastewater and the inherent human pathogens in it are removed from the community as a source of public health threat.

Figure 1.3 Sewerage system to convey wastewater and stormwater away from communities.

Environmental degradation of the receiving water still continues. If the wastewater is disposed to a river the water will affect people using it for bathing and washing, and downstream communities may withdraw the water for drinking purposes. The amenity value of the river for recreational purposes, for fishing, agriculture and industry is devalued. The classification of rivers is a good illustration of how the quality of a river is determined by its pollution load (Table 1.1).

Table 1.1 River pollution classification (based on National Water Council (UK) classification, 1970)

Class	Description	DO. & BOD*	Characteristics

Class I	Unpolluted or recovered from pollution	BOD < 3 mg/L	No toxic or suspended discharges which affect the river
Class II	Doubtful quality and needing improvement	BOD > 3 mg/L, toxic and reduced DO in dry flow times	Toxic and suspended discharges occur but have no major effect on biota
Class III	Poor quality, improvement is a matter of some urgency	DO < 50% for considerable periods	River changed in character, suspected of being actively toxic. Subject to serious complaint
Class IV	Grossly polluted rivers	BOD > 12 mg/L, completely deoxygenated	Incapable of supporting fish life, grossly offensive

*DO = dissolved oxygen; BOD = biochemical oxygen demand

Biochemical Oxygen Demand (BOD)

In Table 1.1 the river water pollution load is indicated by its biochemical oxygen demand (BOD) concentration. BOD is a measure of the amount of biodegradable organic substances in the water. As naturally occurring bacteria consume these organic substances they take up oxygen from the water for respiration, while converting the substances into energy and materials for growth. On average each person produces about 60 g of BOD in faecal and other materials. This is equivalent to 60,000 mg of BOD. Depending on the volume of water used to convey the faecal materials, the concentration of the BOD in the wastewater varies. For example if the total water usage per person is 200 L per day, then the resulting wastewater will have a BOD concentration of 300 mg/L. Upon discharge to a river the concentration is further diluted by the river water.

The river pollution classification (Table 1.1) provides an illustration of the ability of the environment (here the river) to cope with small waste discharges of organic wastes. Small discharges of BOD are diluted by the river water to low levels. If the concentration of BOD in the river water is less than 3 mg/L the river remains ‘unpolluted’. The oxygen uptake by bacteria, as they consume the organic wastes, is replenished by the continuous transfer of oxygen from the atmosphere to the water. The dissolved oxygen (DO) concentration in the water remains high. This simple process explains the reason why a stream in an undisturbed forest remains clean despite the natural organic wastes produced by animals in the forest. Other physical, chemical and biological processes take place which help in the ability of nature to purify wastes. These are elaborated in Section 2 (2.2).

On the hand the river pollution classification shows that it does not take much for an unpolluted river (class I) to become a grossly polluted river (class IV). When the BOD concentration in the river water is greater than 12 mg/L, the transfer of oxygen from the atmosphere cannot replenish the oxygen demand and the water becomes completely deoxygenated. It is incapable of supporting fish life. The water is dominated by bacteria that thrive on the organic wastes but able to extract oxygen chemically from substances like sulphates in the wastes. Gases such as hydrogen sulphide (rotten egg gas) and methane are generated by these bacteria. Foul odours are the result, and the appearance of the water is grey black with bubbles frothing up.

To prevent degradation of the receiving environment wastewater needs to be treated. This treatment is usually carried out at the point of discharge, also called 'end of pipe' treatment (Figure 1.4). Treatment consists of removing solids from the wastewater and reducing its BOD. The degree of treatment that is required is dependent on the capacity of the receiving environment to assimilate the remaining organic wastes.

Figure 1.4 End of pipe treatment of wastewater prior to discharge to the environment.

Because the wastewater treatment facility is generally designed for dry-weather flow, its capacity is exceeded in wet weather. Treatment efficiency drops during wet weather, and in high rainfall events a significant volume of combined wastewater and stormwater is not effectively treated. To overcome the problem of wet-weather flow, and recognising that stromwater may not be as contaminated as wastewater, separate collection of wastewater and stormwater have been implemented (Figure 1.5), with stormwater treated only to remove gross solids.

Figure 1.5 Separate collection of wastewater and stormwater.

If wastewater is collected separately, there is no reason why stormwater should be collected in pipes. A recent trend is for stormwater to be channelled through the landscape's natural drainage, and for the drains to be landscaped to resemble a more natural landscape with vegetation in their flood plain (Figure 1.6). In addition there is the desire to reuse the treated wastewater with its nutrients for purposes such as irrigation of parks and gardens.

Figure 1.6 Separate collection of wastewater for end of pipe treatment, and stormwater allowed to flow through natural waterways and their flood plain. Reuse of treated wastewater for irrigation purposes.

It is worth noting that the severe sanitation problems currently facing many cities in developing countries were experienced in Europe as recently as at the end of the nineteenth century, with epidemics of water borne diseases occurring in London then. The section of river Thames passing through London was grossly polluted until the 1970s. Sewage discharges to the river were treated to reduce BOD concentration and raise DO to enable fish to return.

While the stages of development of sewerage and drainage portrayed above are generalisation of observation in many cities, they are by no means the only way to overcome the problems of sanitation. Various options are described in Section 2 together with their advantages and disadvantages, and a general strategy for selecting the most appropriate option for a particular case suggested.

2. Integrated waste management

The description of problems facing communities without adequate sanitation above shows the importance of addressing the problems in an integrated manner. Simply solving the problem of wastewater without taking into account of solid wastes and stormwater will not achieve sufficient sanitation improvement to protect public health and the environment. UNEP IETC has published an International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management, which provides guidance on the selection of technology for the management of solid waste. The present UNEP IETC Source Book complements this publication, and is intended to provide the means to achieve the integrated approach.

In discussing integrated waste management we need also to consider solid wastes and wastewater produced by industry. In many instances these may not differ in characteristics from domestic wastes, consisting primarily of biodegradable organic substances. Industry, however, produces numerous types of wastes which may be toxic to bacteria that are utilised to treat domestic wastewater. The practice in many communities is for industrial wastes to be disposed with domestic wastes.

One principle that logically emerges from adopting an integrated approach to waste management is that different types of waste should not be mixed (Figure 1.7). Solid wastes should not be dumped into stormwater drains, but should be collected, recycled, reused, or treated and disposed separately. Dumping of solid wastes in stormwater drains will not only restrict the flow of stormwater, they contaminate stormwater. Treatment of the stormwater will involve separating the solids and other contaminants from the water. Similarly industrial wastes should be treated separately, and industrial wastewater should be pre-treated if they are to be discharged to the sewer.

Figure 1.7 Integrated waste management. All wastes should be considered together to achieve environmental and public health improvement. Wastes should be separately collected and managed.

A useful tool that can help towards achieving integrated waste management is the waste management hierarchy. It has been used to direct waste management towards achieving environmentally sound practice. The waste management hierarchy in its most general form is shown in Table 1.2.

Table 1.2 The waste management hierarchy

1	Prevent or reduce waste generation
2	Reduce the toxicity or negative impact of the waste
3	Recycle waste in its current form
4	Reuse waste after further processing
5	Treat waste before disposal
6	Dispose in an environmentally sound manner

We cannot prevent the production of human excreta or stormwater, but we can prevent other materials from being disposed with human excreta, or solid waste with stormwater. We can use less water to achieve the same purpose (e.g. flushing toilet) and hence produce less wastewater. We can avoid toxicity of wastewater by preventing toxic household or industrial wastes to be disposed with biodegradable organic wastes. A reuse example is the use of urine as a liquid fertiliser, while composting can convert human excreta into a soil conditioner. Other examples will be discussed in Section 2, but it should be recognised that all waste management practices have costs as well as benefits. The application of the waste management hierarchy therefore needs to consider economics as well as other factors (e.g. some culture may not allow reuse of human wastes).

3 Cross-cutting issues

From examining how sanitation problems develop in a community (Figure 1.1 to 1.6) it becomes obvious that they are related to population density relative to the ability of the environment to cope with the wastes generated, and the ability of the community to respond to the problems that arise. Thus besides the public health and environmental aspects that we have discussed, there are the social and institutional dimensions that have to be taken into account. These refer to the way communities organise themselves to manage their common affairs, such as arranging collection of household solid wastes, laying of sewer pipes, and financing these activities. Each community has generally developed means of carrying out these tasks, which may be unique to a particular community or communities in a region. The institutional arrangements in a community evolve with time to meet changes in culture and technology, and may or may not cope with external changes. One of the latter is rapid urbanisation, and it is generally in such a situation of rapid population growth that severe sanitation problems occur.

The issues associated with how communities manage their common endeavour, which in our case is managing wastewater and stormwater, are termed 'cross-cutting' issues. These issues are elaborated further and addressed in a complementary United Nations Development Programme/World Bank (UNDP/WB) publication 'Resource Guide in Urban Environmental Sanitation' published concurrently as the present UNEP-IETC Source Book. Readers should refer to the Resource Guide, which cover the three areas of wastewater, stormwater, and urban solid wastes, for a more detailed discussion of the issues and suggested strategy to address these issues.

The major issues are (Figure 1.8)

Figure 1.8. Major cross cutting issues of planning, community participation and finance

Setllement planning

Planning appears to be a major and key issue for a community to address. Ideally settlements should be planned ahead of their occupation. Areas should be set aside for treatment and disposal of solid wastes which cannot be recycled or reused. Easement should be provided in the plan if wastewater is to be collected through a sewerage system, or if on-site treatment is chosen lot sizes should be able to adequately accommodate the treatment system. Planning should also take into account the natural drainage of the landscape to enable stormwater run-off to flow freely by gravity and minimise flooding. Water reuse should also be carefully planned. Generally a sufficient area must be set aside for water reuse, which can take the form of water for agriculture, aquaculture, tree plantation or for irrigation of public parks and gardens.

New approaches to planning to achieve long-term resource sustainability for wastewater and stormwater management should be considered in a planning process. Stormwater infiltration at source to reduce heavy downstream run-off is an example. Water conservation measures can reduce wastewater volume, and dry sanitation where appropriate merits consideration.

In a rapid urbanisation process and with illegal settlements occurring, the situation is far from ideal. Decisions have to be made based on the existing far-from-ideal situation. In most cases no action is taken until the legal status of the land occupation is clarified, and this can take quite some time. In the meantime temporary measures need to be taken to provide sanitation services to prevent disease outbreak and downstream environmental problems. In the first instance piped water may be provided from standpipes. If no corresponding measure is taken to provide for wastewater collection, then invariably poor sanitation conditions result. This illustrates an important point in planning and integrated waste management that when water is provided, wastewater disposal should be considered at the same time, because provision of water means wastewater is simultaneously generated. Disposal of the wastewater into stormwater drains is clearly not satisfactory as mentioned earlier. The problems arising from the provision of water may be negated by the problems caused by the wastewater.

Community participation and hygiene promotion

Much has been said about the need to involve the whole community in provision of sanitation services to ensure that any service that is provided is what the community wants. This will help ensure the viability of the service and its long term sustainability. The need to involve women has been emphasised, because women are generally responsible for the day to day management of wastes at the household level. How far community participation can be implemented depends on the social, cultural and political practices within the community.

The decisions taken by a community are influenced by its knowledge base. One aspect that may be lacking is the awareness of the relationship between illnesses and lack of hygiene and sanitation. This may be reflected in the low priority given to provision of sanitation services. Promotion of hygiene is therefore an important issue that has to be addressed. The promotion materials should include not only the relationship between health and sanitation services, but also the correct choice of sanitation hardware, and in its maintenance and operation. It has been argued that sound hygiene practices, even with inadequate sanitation provision can improve health outcome. It is, however, preferable to have sound hygiene practices go hand in hand with environmentally sound sanitation hardware.

Financing of sanitation services and cost recovery

Sanitation services require investment and continuing costs of operation and maintenance. The level of investment is dependent on the technology that is chosen. The technology also determines the costs associated with its operation and maintenance. A community may be able to provide in-kind contribution such as labour towards the construction of a wastewater collection system. With a simple on-site wastewater system the community may be able to do most of its construction. Knowledge of technology options is therefore essential to a community to decide which one to choose, because in the end they have to pay for both the investment and operating costs if the service is to be sustainable in the long term. Technology options are presented in Section 2.

4. Framework for wastewater and stormwater management

Integrated waste management requires the involvement of all stakeholders, and these include policy makers (governments), investors (governments/private sector companies), managers (public and private sectors) and users (communities/community organisations). Figure 1.9 illustrates the relationship between the major stakeholders. It is important to appreciate the jurisdiction and responsibility of each to achieve the coordination that is vital in achieving the integrated approach.

Governments have generally final jurisdiction and responsibility in waste management by setting overall policy, whether they are involved in performing the management functions or not. Many government departments play crucial roles in the management of wastewater and stormwater. Public health departments have jurisdiction over the maintenance of public health. In an intregated system a public health department has responsibilities in monitoring, inspection and enforcement of public health and in general hygiene promotion. Public works departments have jurisdiction over large infrastructure projects in wastewater and stormwater. They have the responsibility for operating and maintaining centrally operated wastewater/stormwater systems, and overview the systems operated by private contractors.

Figure 1.9 Relationship between major stakeholders in integrated waste management.

Often environmental departments assist in providing policy input in waste management as wastes can seriously impact on the environment. They formally assess environmental impacts of major infrastructure projects. These departments can play a major role in the coordination of major stakeholders in an integrated waste management system. Often the above jurisdiction and responsibilities are devolved to provincial or municipal governments with the central government setting general policies and planning parameters. With many stakeholders involved, the crucial factor is the coordination of all the major stakeholders. Responsibility and authority, including final responsibility for decision making, need to be clearly spelt out.

Private sector companies provide a range of services ranging from being contractors to government in conducting feasibility studies, community consultation, drawing master plans for wastewater and stormwater infrastructure, to constructing the infrastructure and operating wastewater and stormwater facilities. Private sector companies operate with the aim of making a profit. Unlike governments they do not have direct responsibility in maintaining public health or quality of the environment. Pressures on government to reduce taxes have resulted in privatisation of services such as wastewater and stormwater management. The stages in privatisation are illustrated in Figure 1.10.

Figure 1.10 Various phases in privatisation of waste management services.

The importance of community involvement as users of wastewater and stormwater management services has been pointed out in (3b) above. This is to ensure that the services are what the community desires and is able to pay for to ensure long-term sustainability of the services. Community participation can be facilitated by community based organisations or non-government organisations in the area.

Communities without legal status of land they occupy in rapidly growing peri-urban areas present a special problem. These communities usually require urgent sanitation services because of serious local public health threat as well as downstream impacts of the wastewater. These communities have inadequate resources and may not be able to afford any form of paying sanitation service. Because of the threat to public health generally and downstream impact of wastewater from these communities, a case can be made for governments to provide the very basic sanitation services. The involvement of the informal sector already operating in these communities is crucial to ensure that the services are what the community wants and willing to contribute (e.g. labour and cash towards operation and maintenance).

Integrated waste management involving all stakeholders and coordination of all aspects of waste management should provide the basis for long term sustainability of wastewater and stormwater services. Factors which need to be taken into account include characteristics of the wastes, how communities want them to be collected, treated, reused or disposed, policy setting, information available to the community, public education, training, method of financing and cost recovery. The Source Book includes a section on these, as well as a description of the experiences and practices in each of the regions.

Section 2
Environmentally Sound Technologies and Practices

1. Overview of the Sound Technologies and Practices section

Technologies which are environmentally sound are technologies which help protect the quality of the environment. It may be argued that technologies used to manage wastewater and stormwater are inherently environmental technologies, because without these technologies the pollutants in wastewater and stormwater will negatively affect the environment (Section 1). Some of these technologies may utilise less energy than others, produce less air pollution or hazardous sludge, or more suited to wastewater and sludge reuse. Hence some of these technologies are more sustainable. The application of a technology is dependent on local physical factors of land availability, its topography, climate, soil, availability of energy and existing land uses. Sound technology practice is therefore dependent on being able to fit the technology to the local conditions.

Sound practice is also dependent on the context of the local community where the technology is to be applied. Long term sustainability is a function of community resources (funds, skills) to afford the technology and its willingness to pay for the technology and its operation. Sound practices are therefore practices which fit into the environmental, economic, social and institutional setting of the community.

In this Section wastewater and stormwater characterteristics are described to set the context for technologies that need to be used to manage the pollutants they contain. The description is also meant to indicate the resources that are contained in human excreta, and therefore its potential for reuse. Technologies for collection, treatment, reuse and disposal are then described, so that options for the different local environmental, economic and social contexts described above can be evaluated. The description is not meant to be exhaustive, but to enable the scientific basis of the technologies to be understood. The relationship between processes in engineered systems and natural purification processes is also presented, so that simple engineered systems that are more akin to natural systems can be appreciated. Sludge is produced from treatment systems, and a section is devoted to its characteristics, treatment, reuse and disposal. Finally sound technology practices are reviewed in the context of environmental, economic and social conditions of a community.

2. Wastewater and stormwater characteristics (Topic a)

Household wastewater derives from a number of sources (Figure 2.1). Wastewater from the toilet is termed 'blackwater'. It has a high content of solids and contributes a significant amount of nutrients (nitrogen, N and phosphorus, P). Blackwater can be further separated into faecal materials and urine. Each person on average excretes about 4 kg N and 0.4 kg P in urine, and 0.55 kg N and 0.18 kg P in faeces per year. In Sweden it has been estimated that the nutrient value of urine from the total population is equivalent to 15 – 20 % of chemical fertiliser use in 1993 (Esrey et al. 1998). Table 2.1 shows characteristics of human excreta and a comparison with nutrient contents of plant matter to indicate its value as a soil conditioner and fertiliser.

Table 2.1 Human excreta – per capita quantities and their resource value (Strauss, 1985)

	Faeces	Urine	Excreta
Quantity and consistency			
Gram/capita/day (wet)	250	1,200	1,450
Gram/capita/day (dry)	50	60	110
Chemical composition (% of dry solids)			
Organic matter	92	75	83
Carbon C	48	13	29
Nitrogen N	4-7	14-18	9-12
Phosphorus (as P_2O_5)	4	3.7	3.8
Potassium (as K_2O)	1.6	3.7	2.7

Comparison with other wastes (% of dry solids)	N	P_2O_5	K_2O
Human excreta	9-12	3.8	2.7
Plant matter	1-11	0.5-2.8	1.1-11
Pig manure	4-6	3-4	2.5-3
Cow manure	2.5	1.8	1.4

Greywater consists of water from washing of clothes, from bathing/showering and from the kitchen. The latter may have a high content of solids and grease, and depending on its intended reuse/treatment or diposal can be combined with toilet wastes and form the blackwater. Both greywater and blackwater may contain human pathogens, though concentrations are generally higher in blackwater.

Figure 2.1 Sources of household wastewater, showing wastewater from toilet, kitchen, bathroom, laundry and others.

The volume of wastewater and concentration of pollutants produced depend on the method of anal cleaning, volume of water used and water conservation measures. Dry anal cleaning results in higher solids and fibre content. The use of dry pit latrines and the practice of water conservation produce low volume and high concentration wastewater, while use of flushing toilets results in higher wastewater volumes and lower concentrations. The characteristics of wastewater in the Regions are described in the Regional Overviews under Topic a.

The flow of wastewater is generally variable with peak flows coinciding with high household activities in the morning and evening, while in the night minimal flow occurs. Pollutant loads vary in a similar manner.

Stormwater in a community settlement is produced from house roofs, paved areas and from roads during rainfall events. In addition stormwater is produced from the catchment of a stream or river upstream of the community settlement. The amount of stormwater is therefore related to the amount of rainfall precipitation, and the nature of surfaces, with impervious surfaces producing more run-off. During a storm event the peakflow is higher and duration shorter with an impervious surface, while the peakflow is lower and duration longer with a vegetated surface (Figure 2.2).

Figure 2.2. Rainfall runoff relationship showing two different surrfaces (impervious and natural)

Stormwater run-off may contain as much solids as household wastewater depending on the debris and pollutants in the path of the stormwater run-off, although in general the pollutant load of stormwater is lower than that of wastewater. Table 2.2 shows a comparison of urban stormwater sources and untreated sewage in North America.

Table 2.2 Comparison of the characteristics of stormwater sources and untreated sewage (Novotny and Olem, 1994)

Type of wastewater	BOD_5 (mg/L)	Suspended solids (mg/L)	Total N (mg/L)	Total P (mg/L)	Total Coliforms (MPN/100mL)
Urban stormwater	10-250 (30)	3-11,000 (650)	3-10	0.2-1.7 (0.6)	10^3-10^8
Construction site run-off	NA	10,000-40,000	NA	NA	NA
Combined sewer overflows	60-200	100-1,100	3-24	1-11	10^5-10^7
Light industrial area	8-12	45-375	0.2-1.1	NA	10
Roof run-off	3-8	12-216	0.5-4	NA	10^2
Untreated sewage	(160)	(235)	(35)	(10)	10^7-10^9
Wastewater treatment plant effluent (secondary treatment)	(20)	(20)	(30)	(10)	10^4-10^6

Figures in brackets = mean values; NA = not available; MPN = most probable number

2.1 Impact of wastewater and stormwater

The impact of organic substances in wastewater is discussed in Section 1, while the impact of pathogens in wastewater on human health is discussed in detail in Appendix 2. Solids in both wastewater and stormwater form sediments and can eventually clog drains, streams and rivers. Grease particles form scum and are aesthetically undesirable.

The nutrients N and P cause eutrophication of water bodies, with lakes and slow moving waters affected to a greater degree than faster flowing waters. In the former the algae which are fertilised by the nutrients settle as sediment when they decay. The sediment acts as a store of nutrients and regularly releases the nutrients to the water column, thus the cycle of bloom and decay of the algae is intensified. In the early stages of eutrophication aquatic life is made more abundant, because fish, for example, graze on the algae. With too high a concentration of algae, the decaying algae contribute to BOD and the water is deoxygenated. Thus wastewater, which has been treated to reduce BOD but still high in nutrients, can still have a significant impact on the receiving water. Some algae produce toxins which can be harmful to bird life and irritate skins coming into contact with the water. Eutrophic water adds to the cost of water treatment, when the water is used for drinking purposes.

Other pollutants in wastewater and stormwater are heavy metals and possible toxic and household hazardous substances. Heavy metals include copper, zinc, cadmium, nickel, chromium and lead. The content and concentration are dependent on the pipe materials employed to convey drinking water, household cleaning agents used, and for stormwater the type of materials used for roofing and guttering. In high enough concentrations these heavy metals are toxic to bacteria, plants and animals, and to people. Toxic materials may also be disposed with household wastewater. These could be medicines, pesticides and herbicides which are no longer used, excess solvents, paints and other household chemicals. These substances can corrode sewer pipes and seriously affect operation of treatment plants. They will also limit the potential of water reuse, and therefore should not be disposed with household wastewater.

Spills of chemicals, particulates from motor vehicle exhaust and deposition of atmospheric pollutants can similarly contaminate stormwater. These pollutants will affect downstream receiving waters, and treatment systems if the stormwater is treated.

Wastewater and contaminated stormwater can contaminate groundwater. This is through infiltration of the wastewater or stormwater through the soil to unconfined groundwater aquifer. Soil can filter some pollutants (see 2.2 Natural purification processes), but soluble pollutants (e.g. nutrients and heavy metals) and very small particles (e.g. virus) travel with the water to the groundwater aquifer.

Heavy storm events can cause flooding. The effects of flooding can be severe. Water levels in drain, stream and rivers rise considerably and the flow of water can erode soils and embankments. Sediments which have been deposited in quiescent stretches of a stream can be resuspended and transported further downstream. In urban areas the water picks up litter and solid wastes in its path as well as other diffuse pollution sources, and spread these in the downstream flooded areas. Aquatic environments and water-fowl habitats can be destroyed, and these may take some time to recover. The amenity value of these, as well as recreational lakes, is therefore degraded. Engineered structures, such as culvert and bridges, can be choked with wastes and debris, causing more wide-spread flooded areas.

2.2 Natural purification processes

Before considering technologies for wastewater and stormwater management it is instructive for us to examine natural processes that cycle waste materials. In nature waste materials are produced by living organisms (plants, animals and people). These wastes include faecal materials, leaf litter, food wastes and dead biomass. Yet streams and rivers flowing through a forest, or freshwater lakes in a forest, have generally an excellent water quality. Thus there are natural processes which purify the naturally produced wastes. These wastes are characterised by their organic nature (that is derived from living or once living organisms). They consist of carbon, nitrogen, phosphorus and other elements which constitute the building blocks of living organisms. These elements are continuously cycled in nature. Three of them (carbon, nitrogen and phosphorus cycles) and the water cycle are relevant to wastewater and stormwater management. Figure 2.3 shows the natural carbon cycle.

Figure 2.3 Carbon cycle

The following transformation processes occur in the carbon cycle. Plants photosynthesise glucose from carbon dioxide gas and water, and in turn more complex organic matter is synthesised. Plants are consumed by plant-eating animals, which in turn are consumed by meat-eating animals. Organic carbon compounds are digested by these animals and re-synthesised into other forms, which are useful for energy, cell growth and cell multiplication. Carbon dioxide is released into the atmosphere during the process of respiration. The respiration process releases energy for the organism through oxidising the organic carbon. Plants and animals produce waste materials and will eventually die. Leaf litter, animal wastes and dead organic matter are decomposed by bacteria and other decomposers releasing the carbon as carbon dioxide thus completing the carbon cycle. Oxygen is required in the process of respiration and oxidation of organic carbon, and this is the reason for the oxygen demand of organic wastes. Some organic matter from dead animals and plants is, however, stored in nature, particularly in sediments, and slowly turns into peat or more stable carbon-rich materials.

In the process of decomposition not only is carbon released as carbon dioxide, but other minerals are released. These minerals are involved in other cycles, such as the nitrogen cycle (Figure 2.4) and phosphorus cycle (Figure 2.5).

Figure 2.4 Nitrogen cycle

Ammonia is generally the form of nitrogen released from the decomposition of organic wastes. Provided that oxygen is available the ammonia is oxidised by a group of bacteria (termed nitrifiers) to nitrate. This process is another that exerts oxygen demand on the environment. Nitrate is the form of nitrogen that is normally taken up by plants for protein synthesis. Nitrate may on the other hand, under conditions devoid of oxygen (anaerobic conditions), be converted by a group of bacteria (termed denitrifiers) to nitrogen gas. Denitrification generally takes place in sediments, where anaerobic conditions and availability of organic carbon promote the process.

Nitrogen gas in the atmosphere is very large in quantity, but is inert. Relatively small quantities are converted into forms that can be utilised by plants. These are converted through the activity of nitrogen-fixing bacteria in the root-nodules of some plants, nitrogen-fixing blue-green algae or through lightning. Some is contributed by volcanic eruption. The amount of nitrogen cycled in a natural environment is therefore relatively small and is rapidly absorbed by plants.

Figure 2.5 Phosphorus cycle

Phosphates are the products of decomposition of organic matter by decomposers and these are also the forms that are taken by plants. Phosphate rock, from which phosphate for fertiliser is mined, is an accumulation of phosphorus from the excretion of the guano birds and that is not utilised by plants at the deposition site.

From examination of the above natural cycles it is clear that very little organic wastes and nutrients are leached from natural ecosystems. In addition in a forest ecosystem the surface run-off has a low peak and extends over a longer period, thus solids are filtered from the water, and nutrients have a higher likelihood of being absorbed by plants. The soil in a forest ecosystem can provide additional purification processes. Soil bacteria will consume organic carbon and reduce BOD. Soil minerals (particularly clay minerals) can adsorb metals and phosphates. Plant roots take up nutrients released by bacterial decomposition from water percolating through the soil.

Pathogens, if any, generally die-off, because of unfavourable conditions outside their hosts for an extended period and competition with naturally occurring mirco-organisms. The water cycle therefore produces surface water and groundwater of very high quality (Figure 2.6).

Figure 2.6 Water cycle

The natural cycles (also termed biogeochemical cycles) can provide an insight into the natural basis of wastewater and stormwater management. For disposal of wastewater and stormwater into a natural ecosystem, as long as the natural purification capacity of the ecosystem is not exceeded, we can rely on the existing natural processes to assimilate the wastes without degrading the quality of the environment. On the other hand once the natural capacity is exceeded, engineered systems are required. There is no reason, however, why the same physical, chemical and biological processes taking place in nature cannot be used as a basis for technology development and for waste management.

We note that in nature the cycling of the elements provide a pathway for reuse of the materials in the wastes. We should consider how we can use the same processes to recycle wastewater and stormwater. A limitation of natural purification processes is that they can only handle naturally occurring wastes. The latter can include human wastes, but not toxic chemicals that stop the natural processes. In addition a large human settlement removes a large area of natural ecosystem and generates a large amount of wastes, and the combination of the two rapidly and significantly impact on our natural environment. Clearing of vegetation reduces evapotranspiration, while roads and houses introduce impervious surfaces. Consequently rainfall run-off has a higher peak and is generated rapidly, promoting local flooding.

2.3 The role of micro-organisms

As can be seen in Section 2 (2.2) micro-organisms, such as bacteria, play an important role in the natural cycling of materials and particularly in the decomposition of organic wastes. The role of micro-organisms is elaborated further here because they are also important in the treatment of wastewater. What is waste for humans and higher vertebrates becomes a useful food substrate for the micro-organisms. In both natural and engineered treatment systems micro-organisms such as bacteria, fungi, protozoa, and crustaceans play an essential role in the conversion of organic waste to more stable less polluting substances. They form what is termed a 'food chain'. For example inorganic and organic substances in wastes are consumed by bacteria, fungi and algae. These are in turn consumed by protozoa and nematodes (some fungi however trap nematodes) and the latter by rotifers.

In a natural water body, e.g. river or lake, the number and type of micro-organisms depends on the degree of pollution. The general effect of pollution appears to be a reduction in species numbers. For example in a badly polluted lake, there are fewer species but in larger numbers, while in a healthy lake there can be many species present but in lower numbers.

Micro-organisms are always present in the environment and given the right conditions of food availability, temperature and other environmental factors, they grow and multiply. Figure 2.7 shows a generalised pattern of growth of micro-organisms.

Figure 2.7 Generalised representation of growth of micro-organisms

Micro-organisms require cellular building blocks, such as (carbon) C, (hydrogen) H, (oxygen) O, (nitrogen) N, (phosphorus) P, and minerals for growth. These can be obtained through consuming organic substances containing these elements, or from inorganic materials, such as carbon dioxide, water, nitrate and phosphate. Micro-organisms also require energy. They obtain this through respiration. In this process organic carbon is oxidised to release its energy. Oxygen or other hydrogen acceptors is needed for the respiration process. Algae and photosynthetic bacteria can also utilise energy from sunlight, while certain types of bacteria can utilise energy from chemical reactions not involving respiration. The building blocks and energy are used to synthesise more cells for growth and also for reproduction.

In the treatment of wastewater three types of overall processes are distinguished to represent the conversion of organic wastes by micro-organisms. The classification is based on whether the environment where the process takes place is aerobic, anaerobic or photosynthetic. Under aerobic conditions (in the presence of oxygen), micro-organisms utilise oxygen to oxidise organic substances to obtain energy for maintenance, mobility and the synthesis of cellular material. Under anaerobic conditions (in the absence of oxygen) the micro-organisms utilise nitrates, sulphates and other hydrogen acceptors to obtain energy for the synthesis of cellular material from organic substances. Photosynthetic organisms use carbon dioxide as a carbon source, inorganic nutrients as sources of phosphate and nitrogen and utilise light energy to drive the conversion process.

Micro-organisms also produce waste products, some of which are desirable and some undesirable. Gases such as carbon dioxide and nitrogen are desirable, since they can be easily separated and do not produce pollution. Gases such as hydrogen sulphide and mercaptans, although easily separated require treatment for odour. Micro-organisms' cellular materials are organic in nature and can also cause pollution. It would be desirable if the cellular materials have undergone self oxidation (endogeneous respiration utilising own body cells) to produce non-biodegradable materials that are relatively stable. Self-oxidation is achieved when there is no substrate/food available.

The microbiological conversion reactions of organic waste into cellular material can be empirically represented as shown below.

(i) Conversion under *aerobic conditions*:

$$C_a H_b O_c N_d + eO_2 \rightarrow C_w H_x O_y N_z + sCO_2 + rH_2O + tNH_3$$

Organic waste

where $C_a H_b O_c N_d$ and $C_w H_x O_y N_z$ represent on an empirical basis the composition of the organic substances initially and at the conclusion of the process. The latter consists mainly of bacteria and their waste products. Under aerobic conditions ammonia is further oxidised to nitrate; phosphorus and sulphur contained in the organic substances are oxidised to phosphate and sulphate. These can be further utilised by the micro-organisms for synthesis.

(ii) Conversion under *anaerobic conditions*:

$$C_a H_b O_c N_d \rightarrow nC_w H_x O_y N_z + mCH_4 + sCO_2 + rH_2O + tNH_3$$

Organic waste

Methane (CH_4) is a useful gaseous by-product of anaerobic conversion, because it can be combusted to produce heat/energy. On the other hand if it is released to the atmosphere without being combusted, it contributes to the greenhouse gas effect.

(iii) Conversion under *photosynthetic conditions*:

$$aCO_2 + rH_2O + tNH_3 \xrightarrow{\text{sunlight}} C_w H_x O_y N_z + bO_2$$

As shown by the conversion reactions (the utilisation of organic wastes for food by micro-organisms) the product is mainly the cellular material of the micro-organisms i.e. more organisms are produced. The growth yield is the weight of micro-organisms produced per unit weight of organic substances consumed by the micro-organisms. The growth yield depends on the type of substrate and environmental conditions. The smaller the value of the growth yield the better it is for waste treatment, because less sludge is produced which requires disposal. Its value is usually between 0.2 and 0.5 for aerobic conversion, while the corresponding value for anaerobic conversion is smaller.

2.4 Sustainable versus unsustainable wastewater and stormwater management

The natural purification processes and biogeochemical cycles described in section 2 (2.2) provide a basis for determining what is environmentally sustainable management practices for wastewater and stormwater. Discharge of wastewater and stormwater into an environment exceeding the natural purification capacity of that environment will result in the accumulation of organic materials (carbon), nitrogen, phosphorus or other pollutants that cannot be absorbed by the ecosystem constituting the receiving environment. Accumulation of organic materials will result in a high oxygen demand that cannot be met by oxygen transfer from the atmosphere. Undesirable anaerobic conditions are a consequence (See section 1 (1) on discharge of wastewater with a high BOD to a river). Figure 2.8 illustrates an unsustainable practice where the natural purification capacity of a river into which wastewater is discharged is exceeded, and where in addition the local biogeochemical cycles are not closed.

Figure 2.8 Unsustainable wastewater management practice from not closing the local biogeochemical cycles resulting in the natural purification capacity of the receiving environment to be exceeded.

Nitrogen and phosphorus in wastewater are discharged to a river resulting in their accumulation in the river. Eutrophication of the river is an outcome. The nitrogen and phosporus in the wastewater come from food consumed by people. To grow this food fertilisers containing nitrogen and phosphorus are required. These are manufactured chemically from atmospheric nitrogen and from phosphate rock. The flow of materials (N & P) is one way from the atmosphere for N and from the phosphate rock mine for P into the river. There is depletion of a resource (mined phosphate rock) and accumulation and pollution in the river. This practice is unlikely to be sustainable in the long term, because phosphate rock deposits will be exhausted and pollution of the river by N and P needs further treatment of the wastewater.

One way of managing the wastewater sustainably is by closing the material cycles locally (Figure 2.9).

Figure 2.9 Sustainable wastewater management practice by closing the local biogeochemical cycles.

Nutrients in the wastewater are reused to grow food. In this way there is not the need to manufacture chemical fertilisers and at the same time there no discharge of nutrients to the river. The problem of resource depletion and pollution of the river is overcome by closing the material cycles. Figure 2.9 also emphasises the need to treat industrial wastewaters containing toxic substances separately, and not to mix industrial wastewaters with domestic wastewater. In addition stormwater should be separately collected and treated and infiltrated locally.

3 Wastewater and stormwater collection (Topic b)

Collection of wastewater is by use of a sewerage system. Depending on whether blackwater is generated separately from greywater, or mixed with it, we need to collect greywater or the mixture of blackwater and greywater (sewage). Gravity is used wherever possible to convey the wastewater. It is not surprising therefore that natural stormwater drainage has been used, because this is how rainwater run-off is conveyed in nature by gravity. The stages of development of the use of a natural drainage system for conveying both wastewater and stormwaster have been described in Section 1, outlining its evolution from lining and covering of the drains, to the trend of separately collecting wastewater and returning the stormwater drainage to its more natural state.

The principle of using gravity as the driving force for conveying wastewater in a sewerage system should be applied wherever possible, because this will minimise the cost of operation. Natural stormwater drainage occurs in what is usually termed a catchment basin. In a catchment basin rainwater run-off flows to a common point of discharge, and in so doing form streams and rivers. Crossing a catchment boundary may mean that the water has to be unnecessarily pumped, requiring an energy source. A wastewater sewerage system should therefore be within a stormwater catchment basin. Figure 2.10 shows an example of wastewater collection in a catchment basin.

Figure 2.10. Plan of London's sewerage, showing the main sewers and drainage areas of Beckton and Crossness wastewater treatment plants.

Sewerage systems can be classified into combined sewerage and separate sewerage. Combined sewerage carries both stormwater and wastewater, while separate sewerage carries stormwater or wastewater separately. Recent trends have been for the development of separate sewerage systems. The main reason for this is that stormwater is generally less polluted than wastewater, and that treatment of combined wastewater and stormwater is difficult during heavy rainfalls, resulting in untreated overflows (commonly termed combined sewer overflow, CSO). In practice there is usually ingress of stormwater into wastewater sewerage pipes, because of unsealed pipe joints, and unintentional or illegal connections of rainwater run-off. Conversely there may be unintentional or illegal wastewater connections to stormwater sewerage.

Wastewater sewerage systems can be classified into three major types: 1. Conventional sewerage, 2. Simplified sewerage and 3. Settled sewerage

3.1 Conventional sewerage

Conventional sewerage is also termed deep sewerage. This term results from the fact that in actual practice the sewerage pipes are laid deep beneath the ground. There are a number of reasons for the relatively great depth of the pipes. A minimum velocity is needed to ensure that self-cleansing conditions occur at least once daily (usually 0.75 m/s). Combined with a minimum specified diameter (usually 150 mm internal diameter), the outcome is the requirement of steep gradients for the pipes. Added to this is the specification for a minimum depth of buried pipes to avoid interference with road traffic and other services (minimum of 0.9 to 1.2 m). Main sewerage trunks are therefore generally quite deep if gravity is relied upon as the driving force for flow. Figure 2.11 shows a typical layout for a deep sewerage system.

Figure 2.11 Sewerage system for the city of Osaka

Pumping is generally required at various stages of the sewer pipe network, especially if the landscape is fairly flat. The larger the population served by the sewerage system, and the longer the planning horizon is to cope with future population increases, the larger the diameter of the final pipes becomes. The costs of the pipes, inspection manholes, pumps and pumping stations and their construction/installation are therefore high. The costs of operation and maintenance are correspondingly high.

The design procedure for conventional sewerage is well developed from its early beginnings in the provision of sewerage in the city of London and other European cities. It is now acknowledged that the design procedure for the conventional sewerage is based on very conservative assumptions.

3.2 Simplified sewerage

Simplified sewerage is also known as shallow sewerage. Again the term reflects the nature of the shallower placement of the pipes in contrast to the conventional or deep sewerage. The purpose of simplified sewerage is to reduce the cost of construction and the corresponding cost of operation and maintenance. Simplified sewerage is designed based on hydraulic theory in the same manner as for conventional sewerage. Its design assumptions are, however, less conservative. Smaller diameter pipes are used when water use per person is known to be less. Minimum depth of cover of pipes can be as low as 0.2 m when there is only light traffic. Manholes can be replaced by inspection cleanouts because of the shallow pipes. Design planning horizon can be 20 instead of 30 years, because population projection may be uncertain. In a variation of the simplified sewerage the pipe layout passes through property lots (condominial) rather than on both sides of a street (conventional). Figure 2.12 shows a comparison between sewerage layout in conventional sewerage and in condominial sewerage, while Table 2.3 shows a comparison of length of pipes required. Cost of construction can be 30 to 50 % less than conventional sewerage depending on local conditions.

Figure 2.12. Pipe layout for (a) conventional and (b) condominium sewerage

Table 2.3. Comparison of length of pipes required for conventional and condominium sewerage

Shallow sewerage is also conducive to local community participation. This is because of sewer pipes having to cross property boundaries and hence the need for the community to agree to this arrangement. This arrangement needs to be in place not only during construction, but also for maintenance (e.g. unblocking of sewer pipes). The shallow pipe, and hence the shallow trenches, also allow members of the community to participate by for example providing labour for digging the trenches. This is in contrast to conventional sewerage where specialised machinery is required for the deep trenches. Figure 2.13 contrasts the two approaches.

Figure 2.13 Contrast in community participation between conventional and condominial swerage

There has been considerable experience with simplified sewerage (Refer to Regional Overviews of Central & South America) and manuals have been produced to assist engineers with its design. Developed initially in Brazil it has been used in many parts of the world.

3.3 Settled sewerage

Settled sewerage refers to sewerage for conveying wastewater that has been settled, for example in a septic tank. The origin of settled sewerage is to convey overflow from septic tanks where the soil cannot cope or absorbed the overflow. This usually occurs when the groundwater table is high, or where the soil permeability is low, or where there are rock outcrops. It can also be used when effluent from septic tanks pollutes groundwater and it is necessary to convey the effluent off-site and treat it. Because there are no solids that can potentially sediment in the sewerage pipes, there is no requirement for the self-cleansing velocity. Smaller pipes and lower gradients can be used. The cost of settled sewerage is between a third and a half of conventional sewerage. Originally developed in South Australia to overcome problems with failing septic tanks, it has been used quite widely worldwide to upgrade septic tank systems.

Where there is no existing septic tank, an interceptor box or tank can be used. It functions like a septic tank and designed in the same way (Figure 2.14). To reduce cost the wastewater from a group of houses can be connected to one interceptor tank. Just like in a septic tank, accumulation of sludge has to be removed regularly from an interceptor tank.

Figure 2.14. Interceptor tank in settled sewerage

3.4 Stormwater collection

As mentioned in the introduction to this section (2 (3)), stormwater naturally flow through the landscape's natural drains. Piped stormwater collection was a development in European cities to overcome odour and improve asthetic appearance of wastewater disposed with stormwater. The covering of ditches used for combined sewerage was an intermediate step in using natural drainage to construct sewerage for combined wastewater and stormwater. Piped sewerage also allows more land area for road and footpath. With separate collection of wastewater there is an attempt to return some stormwater flow path to its more natural state to improve urban amenity value.

4 Wastewater and stormwater treatment (Topic c)

Treatment of wastewater and stormwater means the removal of pollutants from the water. The first principle to bear in mind therefore is to prevent pollutants from entering the water in the first place. Reference to preventing litter entering stormwater drains has been made above. In the case of stormwater we need to ensure that surfaces through which stormwater run-off passes over should as far as possible be free from solids and other wastes. Thus collection of solid wastes is an important part of stormwater treatment or its prevention. Separately collecting of wastewater and stormwater also belongs to this principle. Treatment of industrial wastewaters before discharge to the sewer is highly important in this regard.

In the case of wastewater, separating blackwater and greywater can mean less energy is required in treatment. This is because blackwater contains most of the solids, which during treatment have to be removed from the mixture. Further separating urine and faecal materials may also mean that the urine can be reused without much treatment and the faecal materials can be more simply treated. The use of water to convey toilet wastes may be questioned based on this principle, because treatment means separating these wastes from the water.

Besides preventing pollutants entering the water, water conservation means that less volume of water has to be treated. Since the size of treatment systems is primarily governed by the volume of water to be treated rather than the amount of pollutants in the water, less volume means smaller treatment plants and corresponding capital cost. Use of less water to flush toilets belongs to this principle.

A range of wastewater treatment technology options is presented below. Treatment of wastes on-site is considered first (4.1), followed by off-site treatment of the wastewater (4.2). Treatment principles are related to natural purification processes described in Section 2 (2.2). Each technology requires maintenance and proper operation. The demand of each technology for maintenance varies and this is also discussed, as well as public health and environmental impacts of the technology. Treatment options for stormwater are presented in section 4.3.

4.1 On-site wastewater treatment systems

On-site treatment relies on decomposition of the organic wastes in human excreta by bacteria (Section 2 (2.3)). 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 (see Section 2 (6) on Wastewater reuse), the overflow from the pit or tank is allowed to soak into the ground. Further bacteriological decomposition and soil filtration, adsorption and purification processes take place. Potential of 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 and two improved on-site treatment units are described below because they represent major types of on-site treatment systems. Variations of these exist and some are described in greater detail in the Regional Overviews for regions where these systems are used. The treatment principles are, however, covered under these major types.

4.1.1 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. As described in Section 2 (2.3) the anaerobic decomposition releases gases (carbon dioxide and methane) 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. Nutrients are generally not removed by bacteria under these conditions, so pollution of groundwater will occur.

Control of odour and insects are important with a pit latrine. This is achieved by having a vented pit (Figure 2.15). The vent acts to draw odour and insects into the pit and up the vent. Gases (methane and carbon dioxide) produced by the decomposition of the excreta also leave through the vent. Natural convection can be relied upon by ensuring that the vent protrudes well above the roof of the housing. Facing the vent towards the sun (southward in the Northern hemisphere and northward in the Southern hemisphere) and painting the vent black to maximise absorption of heat from the sun will help venting by heat convection. The heated air in the vent rises and draws air from the toilet. Ventilated improved pit (VIP) toilets are widely used in Africa (see Regional Overview for Africa).

Figure 2.15 Ventilated Improved Pit latrine

Pit latrines pose problems when groundwater is shallow and the pit is in groundwater or close to it. There is no soil barrier to protect the water quality of the groundwater, and mosquitoes may breed inside the pit. A pit is also difficult to dig when the ground is rocky. Pit latrines should not be used in these cases.

The pit will eventually fill with faecal sludge and needs to be emptied. The period between emptying depends on the size of the pit and its usage. It is desirable to design the pit to store at least one year of sludge production. Emptying requires mechanical suction of the sludge. The sludge requires treatment prior to re-use or disposal (see Section 2 (6)). Two adjoining pits can be used alternately. Further decomposition of sludge in a full pit takes place while the adjacent pit is in use. Its content after further decomposition can be manually removed.

An alternative way of dealing with a full pit is to dig another pit and relocate the sanitary platform and toilet housing to the new pit. The full old pit can then be covered with soil, preferably of greater than 15 cm depth to prevent disease vectors (rodents and insects) from burrowing into it.

4.1.2 Composting toilet

Rather than 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 (Figure 2.16). 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 wastes. Worms can also be added to assist with vermi-composting. Further details on handling and composting of sludge can be found in section 2 (5).

Figure 2.16 Composting toilet

4.1.3 Pour flush toilet

A pour flush toilet (Figure 2.17) has a water seal. The problems associated with odour and insects are avoided by having the water seal.

Figure 2.17 Pour flush latrine pan.

Excreta deposited in the latrine pan is flushed by pouring 2 to 3 L 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.

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 (see Section on Wastewater Reuse 2 (6)). Disposal of greywater on-site is by use of a leach pit or trench (See below under Septic tank). Limitations of disposal of greywater by leach pit or trench are similar to those applicable to septic tank.

4.1.4 Septic tank

A septic tank is a water tight tank, usually located just below ground, and receives both blackwater and greywater (Figure 2.18). 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 2.18 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 pit or trench. A leach pit (Figure 2.19) 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 (Figure 2.20). 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 2.19 Leach pit (Seepage pit)

Figure 2.20. Leach trench for disposal of septic tank effluent

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 evapotranspiration. An evapotranspiration trench 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 (Figure 2.21). The trench should be sized to store water during the rainy season or low evaporation periods.

Figure 2.21 Evapotranspiration trench

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 (Section 2 (3)). If the groundwater table is not too close, an inverted leach drain as described under Improved On-site Units below (4.1.5) can be used.

The organic solids in a septic tank undergoes 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 (Section 2 (6)).

The septic tank overflow undergoes further bacterial decomposition as it percolates through a leach pit or trench. The decomposition is undertaken by soil bacteria, usually under aerobic conditions. 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.

4.1.5 Improved on-site treatment units

Improved on-site treatment units refer to treatment units which improve the performance of one of the above on-site systems, for reducing BOD, SS and/or nutrients. Two designs are described to illustrate the main principles used. 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. A number of these are described in detail in the Regional Overviews, where these units are used.

(a) Inverted trench

In the system illustrated in Figure 2.22 the trench of the septic tank is underlain by a plastic or impermeable liner. 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 2.22 Inverted trench (Ecomax)

(b) Aerated treatment unit

An aerated treatment unit consists of a tank similar to a septic tank. The tank is partitioned into four compartments (Figure 2.23). 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, chlorination is applied by inserting chlorine tablets in the pipe between the third and fourth compartments. Chlorination is required when the treated wastewater is irrigated by sprinklers. Sub-surface irrigation is preferable, because it does not require chlorination.

Figure 2.23 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 (4.2.1). 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.

4.2 Off-site wastewater treatment systems

Off-site treatment is the treatment of wastewater that has been conveyed using a sewerage system (Section 2 (3)). Activated sludge treatment is now considered the conventional means of large-scale off-site treatment of sewage, and is described first. Trickling filtration is an alternative that was developed earlier than the activated sludge process, and this is described next. There have traditionally been other more simple, but as effective methods of treating sewage. These include the use of ponds or lagoons, land based treatment (sewage farming), and aquaculture. The first two are described in this section, while aquaculture is described under wastewater reuse (Section 2 (6)), because wastewater is generally treated first prior to aquaculture.

Several general principles common to treatment systems will be discussed first. The main aim of treatment is to reduce biochemical oxygen demand (BOD) and suspended solids (SS) to acceptable levels. This is achieved by removing solids and aerating the wastewater to satisfy the oxygen demand of the wastewater. The different treatment systems achieve the removal of solids and in providing oxygen in different ways. It should be noted that if the systems are properly designed, constructed, operated and maintained, they should all achieve the required standard of treatment. The latter is generally a reduction of BOD to less than 20 mg/L, and SS to less than 30 mg/L.

Nutrients (nitrogen and phosphorus) may need removal if the wastewater is discharged to water environments sensitive to enrichment by nutrients. The North America and Western Europe Regional Overviews contain details of methods for removing nutrients, because nutrients have been found to be a problem in many receiving waters. Heavy metals and other pollutants are not generally a problem unless the sewerage system receives industrial discharges. In this case treatment of industrial wastes prior to discharge to the sewerage system is the solution of this problem.

Removal of SS and BOD produces sludge, and the sludge has to be treated prior to reuse or disposal (Section 2 (5)). Anaerobic treatment has recently been suggested for wastewater. The main reason for the use of an anaerobic process is the recovery of energy (in the form of methane) from the wastewater (see Section 2 (2.3)) for explanation of the anaerobic process). The upflow anaerobic sludge blanket process is described at the end of this section.

4.2.1 Activated sludge treatment

The term 'activated sludge' refers to sludge in the aeration tank of an activated sludge treatment process. It consists of flocs of bacteria, which consume the biodegradable organic substances in the wastewater. Because of its usefulness in removing organic substances from wastewater, the sludge is kept in the process by separating it from the treated wastewater and re-circulating it. A typical arrangement of an activated sludge process is schematically shown in Figure 2.24.

Figure 2.24 Schematic diagram of an activated sludge wastewater treatment process

Wastewater entering an activated sludge treatment plant is usually passed through a bar screen to remove gross materials such as napkins, rags and other materials which may damage mechanical equipment further down the treatment plant. The bar screen consists of vertical bars separated by a distance of about 1 cm. Screened solids are continually scraped off the bars. The screenings can be landfilled or incinerated.

Sand and similar heavy particles are removed next in a grit chamber. This chamber can be aerated to separate these particles from other suspended solids. The wastewater spends a relatively short period in the grit chamber (in the order of minutes). The sedimented sand and grit is usually landfilled.

The finer solids are removed in a settling or sedimentation tank, where the wastewater spends of the order of an hour to allow the solids to settle or float. The mechanical removal of solids as described above is usually called 'primary treatment', the sedimentation tank as primary sedimentation tank, the overflow from the sedimentation tank as primary-treated wastewater (primary effluent) and the sludge produced as primary sludge.

The primary-treated wastewater is then passed to an aeration chamber. Aeration provides oxygen to the activated sludge and at the same time thoroughly mixes the sludge and the wastewater. Aeration is by either bubbling air through diffusers at the bottom of the aeration tank, or by mechanically agitating the surface of the water.

In the aeration tank the bacteria in the activated sludge consume the organic substances in the wastewater as described in Section 2 (2.3). The organic substances are utilised by the bacteria for energy, growth and reproduction. The wastewater spends in the order of a few hours in the aeration chamber before entering a second sedimentation tank to separate the activated sludge from the treated wastewater. The activated sludge is returned to the aeration tank. There is an increase in the amount of activated sludge because of growth and reproduction of the bacteria. The excess sludge is wasted to maintain a desired amount of sludge in the system. This part of the treatment process is called 'secondary treatment', the sedimentation tank as secondary sedimentation tank, the overflow from the sedimentation tank as secondary-treated wastewater (secondary effluent) and the excess activated sludge as secondary sludge.

Depending on the flow rate of wastewater, several parallel trains of primary and secondary stages can be employed. There are several ways to operate an activated sludge process. In a 'high rate' process a relatively high volume of wastewater is treated per unit volume of activated sludge. The high amount of organic waste consumed by the activated sludge produces a high amount of excess sludge. In an 'extended aeration' mode of operation the opposite condition takes place. A relatively low amount of organic waste is treated per unit volume of sludge with little excess sludge to be removed. Removal of BOD is higher in the extended aeration mode compared to the high rate mode, but more wastewater can be treated with the latter mode.

An activated sludge treatment plant is a highly mechanised plant, and is suited to automated operation. The capital cost for building such a plant is relatively high. The energy requirement, particularly for providing air to the aeration tank, is also relatively high. There is a need for regular maintenance of the mechanical equipment, which requires skilled technical personnel and suitable spare parts. The operation and maintenance costs of an activated sludge treatment plant are therefore relatively high.

An activated sludge treatment process can be operated in batches rather than continuously. One tank is allowed to fill with wastewater. It is then aerated to satisfy the oxygen demand of the wastewater, following which the activated sludge is allowed to settle. The treated wastewater is then decanted, and the tank is filled with a new batch of wastewater. At least two tanks are needed for the batch mode of operation, constituting what is called a 'sequential batch reactor (SBR)'. SBRs are suited to smaller flows, because the size of each tank is determined by the volume of wastewater produced during the treatment period in the other tank.

4.2.2 Trickling filtration

A trickling filter is a bed of solid media for bacteria to attach on its surfaces. Wastewater is irrigated on the solid media (Figure 2.25). It is also called a biological filter to emphasise that the filtration process is not mechanical straining of solids, but removal of organic substances by use of bacterial action.

Figure 2.25 Schematic diagram of a trickling or biological filter

The solid media can be stones, waste coal gravel or specially manufactured plastic media. The latter can be corrugated plastic sheets or hollow plastic cylinders, with the main aim being to provide a large surface area for bacteria to attach to, while at the same time allowing free movement of air. Typically the solid media is placed in a tank on a support with openings to allow air to move up by natural convection and for treated wastewater to be collected in the under-drain.

Wastewater has to undergo primary treatment (See Activated Sludge Treatment above, 4.2.1) before trickling filtration, otherwise solids will block the filter. As wastewater trickles over the surfaces of the solid media organic substances are trapped in the layer of bacterial slime. The organic substances are consumed by the bacteria in the same manner as in the activated sludge process, while air diffuses into the slime layer from the air spaces in the bed of the trickling filter. Growth and reproduction of the bacteria take place and result in an increase of thickness of the slime layer, particularly at the top of the biological filter. Periodically bacterial slime sloughs off the surfaces of the filter media and leaves with the treated wastewater.

Solids derived from the sloughing off of bacterial slime are separated from the treated wastewater in a sedimentation tank. Sludge from this sedimentation tank is not returned to the trickling filter, but treated prior to reuse or disposal (Section 2 (6)). Treated wastewater can however be returned to the trickling filter, if this will assist with either treating the wastewater further (second pass) or more generally for a more uniform distribution of water over the trickling filter bed. The trickling filter and associated sedimentation tank is also termed 'secondary treatment'.

The energy requirement for operating a trickling filter is less than for an activated sludge process, because oxygen supply to the bacteria is provided by natural diffusion of air. The area requirement of a biological filter is, however, larger than for an activated sludge process to achieve the same quality of treated wastewater.

4.2.3 Lagoons

Ponding or lagooning is effective in treating wastewater and can reduce BOD and SS to the same levels as mechanical treatment plants (e.g. Activated Sludge Treatment). In addition because of the longer residence time of wastewater in the lagoon (in the order of days), removal of pathogenic bacteria and viruses by natural die-off is greater than in an activated sludge treatment plant (residence time of the order of hours). Cysts of parasites and helminth eggs are also usually removed through sedimentation in the lagoons.

A lagoon is a shallow excavation in the ground (1 to 2 m deep). It is generally unlined and percolation of wastewater into the soil and groundwater takes place. With time the percolation rate will reduce, because of formation of a sediment layer. Evaporation loss of water can be significant in arid climate regions. The soil itself is, however, not involved in the physical and biochemical wastewater treatment processes taking place in the lagoon. A lagoon can therefore be lined with a layer of clay or with an impermeable plastic membrane if protection of groundwater is desired, without affecting the performance of the lagoon. Wastewater lagoons are also called 'waste stabilisation lagoons', because the organic substances in the wastewater are converted to more stable (less degradable) forms.

The following processes take place in a lagoon. As wastewater enters a lagoon sedimentation of solids occurs. Because of the long residence time of the wastewater in the lagoon system, much of the solids in the original wastewater are removed. Aeration of the water from the atmosphere occurs by a process of diffusion aided by turbulence caused by wind movement on the surface of the water. This process is the same as the natural process of aeration of a lake described in Section 2 (2.2).

Oxygen is also supplied by algae in the lagoon which thrive on the nutrients (nitrogen and phosphorus) released by the decomposition of the organic wastes. The photosynthetic activity of algae, however, only takes place when there is sunlight. Thus oxygen produced by photosynthesis is only available during this period. A symbiotic relationship exists between the bacteria and the algae. Bacteria take up oxygen and release carbondioxide, while algae take up carbondioxide released by the bacteria and produce oxygen for the bacteria (Figure 2.26).

Figure 2.26 Symbiotic relationship between bacteria and algae in a wastewater lagoon

Depending on the oxygen demand of the bacteria in the lagoon, the following conditions occur:

Anaerobic lagoon	The oxygen demand of the bacteria exceeds oxygen supply by surface aeration and algal photosynthesis. Biodegradation of the organic wastes is by anaerobic bacteria. Methane gas is a by-product (Section 2 (2.3)). Odorous gases are produced, but impact is reduced when a layer of scum forms at the water surface.
Facultative lagoon	The oxygen demand of the bacteria is met by surface aeration and algal photosynthesis, but is not met when the latter is not active. The water environment is aerobic during the day, but turns anaerobic at night. Biodegradation of organic wastes is by facultative bacteria, which can operate under both aerobic and anaerobic conditions.
Aerobic lagoon	The oxygen demand of the bacteria is met by surface aeration and algal

	photosynthesis.

It is common to have a series of lagoons with the first one or two being anaerobic lagoons, the middle ones facultative lagoons and the last few aerobic lagoons. The sediment at the bottom of lagoons is anaerobic, and undergoes anaerobic bacterial decomposition. The first lagoon in a series will eventually be filled with solids. The sludge produced can be removed and treated for re-use or disposal (Section 2 (6)) or allowed to undergo further biodegradation in the lagoon prior to re-use. Anaerobic lagoons can be made deeper so that more sludge can be accommodated and the need to remove sludge made less frequent.

Lagoon performance is affected by temperature. At a higher ambient temperature (e.g. in the tropics) a shorter residence time of wastewater in the lagoon is required to achieve the same level of treatment compared to when the temperature is lower. Because algae are present in treatment lagoons, they leave with the treated effluent. One way of harvesting the algae is through aquaculture (see Section 2 (6)).

Oxygen transfer from the atmosphere into lagoons can be increased by mechanically agitating the surface of the water. This can be done by using a vertically mounted impeller, and the lagoon becomes more like the aeration tank of an activated sludge process. The agitation can also be provided using a horizontally mounted rotor. A configuration that can be used to apply this is a circular ditch (Figure 2.27), and the water is continuously circulated around the ditch so that its movement is like that in a river.

Figure 2.27. Oxidation ditch

4.2.4 Land based treatment

Land based treatment of wastewater relies on the action of soil bacteria to degrade the organic wastes in the wastewater. In what is termed 'Soil Aquifer Treatment' wastewater is applied to unlined basins in cycles of flooding and drying of approximately one weak each (Figure 2.28). During flooding wastewater percolates through the soil beneath the basin to the unconfined groundwater aquifer. Organic substances are consumed by soil bacteria. Suspended solids are trapped at the bottom of the basin, and the percolation rate decreases. During drying the layer of solids accumulating at the bottom of the basin are degraded by bacteria and also undergo drying, The percolation capacity for wastewater is therefore rejuvenated.

Figure 2.28 Soil aquifer treatment or rapid-rate land application system

Soil aquifer treatment is also known as rapid-rate land application. It works well when the soil permeability is high (> 1 m/day), and the highest groundwater table is at least 2 m below the bottom of the basin. Upon reaching the groundwater the SS and BOD of the water is generally low. Furthermore if the soil beneath the basin contains clay minerals, pollutants like heavy metals may be adsorbed by the clay minerals. The groundwater aquifer acts as a storage for the treated wastewater, which is usually withdrawn for reuse.

In what is termed 'slow-rate land application system' wastewater is applied to land through channels in the upper part of the gradient and treated wastewater is collected in channels in the lower part of the gradient of a slightly inclined ground (Figure 2.29). The application is intermittent and its rate is dependent on the permeability of the soil and the loss of water due to evaporation. The organic substances in the wastewater are biodegraded by soil bacteria at the surface of the soil and during percolation through the soil. Vegetation is usually part of the treatment process. It takes up nutrients (nitrogen and phosphorus) released from the degradation of the organic substances. The vegetation (usually grasses) is harvested by grazing animals (cattle or sheep).

Figure 2.29 Slow-rate land application system

When the soil is saturated with water (e.g. during the rainy season), 'overland flow' or 'grass filtration' mode of operation is used. In this case wastewater flows over the soil surface and the organic substances are removed by bacteria attached to the vegetation and soil surface (Figure 2.30).

Figure 2.30 Grass filtration

Raw wastewater can be used in any of the above land based treatment system provided that the application rate is small. Settled wastewater needs to be used for higher rates of application. Land application treatment systems work well in arid or semi-arid regions, where the soil is generally not saturated with water over much of the year, and reuse of wastewater for agriculture is attractive. Particular attention has to be given to public health requirements (see Section 2 (6)).

4.2.5 Constructed wetlands

Constructed wetlands are in-between lagoons (4.2.3) and land based treatment systems (4.2.4). A constructed wetland consists of a gravel bed in which wetland species, such as reeds, are planted (Figure 2.31). Wastewater (usually after settling of solids) passes through the gravel bed, and organic substances are degraded by bacteria attached to the surfaces of the bed and plant roots. The removal of BOD and SS in beds with and without plants does not appear to differ by very much. Wetland plants take up nutrients (nitrogen and phosphorus) when water residence time is long. Long-term nutrient removal requires harvesting of the plants. Constructed wetlands need to be designed to minimise problems with insects (mosquitoes and midges).

Figure 2.31 Constructed wetland

4.2.6 Anaerobic treatment of wastewater

Anaerobic treatment is more suited to wastewater high in BOD. It is used to treat the sludge from an activated sludge treatment or biological filtration process (see Section 2 (5)). In households where there is cottage industry (such as food processing to supply restaurants or food market) the wastewater may be high in BOD. Wastewater high in BOD may also be generated when water conservation measures result in less water being used. A simple method to treat blackwater and kitchen waste is shown in Figure 2.32. The biogas produced can be combusted for use in cooking.

Figure 2.32 A simple anaerobic treatment of blackwater and kitchen waste

In the Upflow Anaerobic Sludge Blanket (UASB) process settled wastewater is passed upward through a sludge blanket. The sludge blanket consists of anaerobic bacteria, which have developed into granules. Because of the high settling velocity of the granules, the granules are not carried over in the upflowing wastewater. A high concentration of bacteria is therefore retained in the tank. The tank itself has no internal moving parts (Figure 2.33). If wastewater is distributed evenly at the base of the tank, mixing between the wastewater and the granules of bacteria is promoted by the carbondioxide and methane gases produced by the anaerobic treatment process and the upward moving flow of the wastewater.

Figure 2.33. Upflow anaerobic sludge blanket (UASB) reactor

Although the reactor itself has a simple configuration with no moving parts, pumping of the feed is still required. Methane gas is produced which needs special handling procedures to prevent leakage and explosion. Wastewater treated anaerobically requires further aerobic treatment to reduce its BOD and odour. Excess granules need to be treated prior to reuse or disposal, although currently there is a demand for the granules to start up UASB reactors. The mixture of methane and carbon dioxide (termed 'biogas') can be combusted and used for heating the content of the anaerobic reactor or for other purposes.

4.3 Stormwater treatment

Stormwater can be polluted as discussed in Section 2 (2.1). When collected in a combined sewerage system it is treated with the wastewater, though treatment is not effective during peak heavy stormwater run-off periods resulting in combined sewer overflow (CSO) that is not treated. Storage basins or tanks can be used to accommodate moderate peak flows of combined stormwater and wastewater, and treating the stored water at night when wastewater flow is a minimum.

Separately collected stormwater is generally treated by passing it through a settling basin to remove solids (Figure 2.34). The retention time in the settling basin is designed so that solids can settle in say 20 minutes for a one in five year storm-event. For storm-events less than the design value removal efficiency is greater, while for storm-events greater than the design value removal efficiency is lower. Mechanical devices have been developed that can trap gross solids (see North American RO). Both settling basins and mechanical traps need to be cleaned regularly to maintain solids removal efficiency.

Figure 2.34. Stormwater treatment by settling

Naturally landscaped stormwater drains can help filter out fine sediments through the action of vegetation slowing down the flow and trapping solids. Permeable surfaces allow rainwater to percolate into the soil, thus treating the water in much the same manner as land based treatment of wastewater (4.2.4.) and at the same time reduce the amount of run-off. Pavements have been designed and manufactured for this purpose. Directing run-off to vegetated area (rainwater harvesting) can reduce down-stream flow and reuse the water for maintaining plant growth. This is especially beneficial in arid climates. Four techniques for stormwater treatment are described below. Used judiciously these can treat stormwater locally (at source, Figure 2.35). Applying these on a sub-catchment scale (site), or whole catchment scale (region) can reduce flooding and the undesirable impacts of stormwater described in Section 2 (2.1), while at the same time improve the amenity value of the landscape through creation of, for example, passive recreation water bodies.

Figure 2.35. Management train for stormwater at the local, sub-catchment and catchment levels

4.3.1 Filter strips and swales

Filter strips and swales are vegetated surface features that drain water evenly off impermeable areas (Figure 2.36). Swales are long shallow channels, while filter strips are gently sloping areas of ground. They allow run-off to flow in sheets through vegetation, slowing and filtering the flow. Swales also act to temporarily store and infiltrate the run-off into the ground. Sediments are removed from the water, and vegetation can take up any nutrients in the water. Swales and filter strips can be integrated into the surrounding land use, for example road verges. Local grasses and flower species can be introduced for visual effect and to provide a wildlife habitat. Maintenance consists of regular mowing, clearing litter and periodic removal of excess silt.

Figure 2.36 Filter strip and swale in an urban landscape

4.3.2 Filter drains and permeable surfaces

Filter drains consist of permeable materials located below ground to store run-off. Run-off flows to the storage area via a permeable surface (Figure 2.37). The permeable surface can be in the form of grassed or gravelled areas, paving blocks with gaps between individual units or paving blocks with vertical voids built in. Water is therefore collected from a large surface area, stored in the filter drains and allowed to infiltrate through the soil. The permeable fill traps sediments and thereby clean the run-off. Filter drains and permeable surfaces are currently used for road verges and car parks. The surfaces should be kept clear of silt and cleaned regularly to keep the voids clear. Weed control may be necessary.

Figure 2.37 Permeable pavements

4.3.3. Infiltration devices

Infiltration devices drain water directly into the ground. They include soakways and infiltration trenches, which are located below ground, and into which stormwater run-off is directed. They function by storing water and allowing the water to infiltrate into the ground. Figure 2.38 shows a cross-section through a traditional soakway and a chamber soakway. They work well when the soil is permeable and the groundwater table is not close to the surface. Maintenance consists of regular inspection to ensure the infiltration capacity is maintained. Areas draining to an infiltration device should be kept clear of silt, as this will get washed into the device and reduce its permeability as well as filling up space that should be used for storage.

Figure 2.38 Cross-section through a traditional soakway and a chamber soakway.

4.3.4 Basins and ponds

Basins are areas for storage of run-off that are dry during dry weather, whereas ponds have permanent water (Figure 2.39). Both act to store water and therefore attenuate the flow of water during a storm. Flow downstream of the basins or ponds can therefore be controlled. Basins and ponds also act as infiltration devices (Section 4.3.3). Basins and ponds are usually used at the end of a train of treatment for stormwater, and provide additional step if source control (Sections 4.3.1 to 4.3.3) does not have an adequate capacity to control run-off. Detention time is of the order of two to three weeks. Both basins and ponds can be vegetated, so that we can have a range of features, including wetlands, that have amenity values for passive recreation or wildlife habitat. Run-off water quality is improved upon storage in basins or ponds because of sedimentation of solids, bacterial action and nutrient uptake by vegetation. Water stored in ponds can also be used for irrigation of parks and gardens or for fire-fighting and other purposes. Basins and ponds need to be maintained to control vegetation and removal of accumulated silt.

Figure 2.39 Constructed wetland for stormwater treatment

5 Sludge treatment, reuse and disposal

Sludge is produced from the treatment of wastewater in on-site (e.g. septic tank) and off-site (e.g. activated sludge) systems. This is inherently so because a primary aim of wastewater treatment is removing solids from the wastewater. Additionally soluble organic substances are converted to bacterial cells, and we remove the latter from the wastewater. Sludge is also produced from the treatment of stormwater (Section 4.3), although it is likely to be less organic in nature compared to wastewater sludge.

Bucket latrine and vault latrine store faecal sludge, which needs to be collected and treated. These two types of latrine are not discussed in Section 2 (4), because no treatment is involved at the latrines. In the former case human excreta is deposited in a bucket and the content of the bucket is emptied daily, usually at night giving the term ‘night soil’ to the faecal sludge. In the latter the excreta is stored in a vault for a longer period of up to two weeks before removal. The content of the vault should preferably be removed mechanically.

The characteristics of sludge vary widely from relatively fresh faecal materials generated in bucket latrines to sludge which has undergone bacterial decomposition for over a year in a double pit latrine. The treatment required is therefore dependent on the characteristics of the sludge. The former may contain large numbers of pathogens, whereas the latter will contain much less due to pathogen die-off. Sludge should, however, always be handled with care to avoid contact with pathogens.

Sludge may be contaminated with heavy metals and other pollutants, especially when industrial wastes are disposed into the sewer. Pre-treatment of industrial wastes is therefore essential before discharge to the sewer. Treatment of sludge contaminated with high concentrations of heavy metals or toxic chemicals will be more difficult and the potential for re-use of the sludge will be limited.

Faecal sludge contains essential nutrients (nitrogen and phosphorus, Section 2 (2)) and is potentially beneficial as fertilisers for plants. The organic carbon in the sludge, once stabilised, is also desirable as a soil conditioner, because it provides improved soil structure for plant roots.

Options for sludge treatment include stabilisation, thickening, dewatering, drying and incineration. The latter is most costly, because fuel is needed and air pollution control requires extensive treatment of the combustion gases. It can be used when the sludge is heavily contaminated with heavy metals or other undesirable pollutants. Prevention of contamination of the sludge by industrial wastes is preferable to incineration. A conversion process to produce oil from sludge has been developed, which can be suitable for heavily contaminated sludge.

The costs of treatment of sludge are generally of the same order as the costs of removing the sludge from the wastewater.

5.1 Stabilisation

Faecal sludge collected from bucket or vault latrines has a very high biochemical oxygen demand (BOD) and is generally putrid and odorous. Primary and secondary sludges from an activated sludge treatment plant also have a high BOD and may be difficult to dewater. Even sludge from a septic tank, which has undergone bacterial decomposition over at least a year, still has a high BOD. Stabilisation is the term used to denote the process of BOD reduction. The stabilisation process can be carried out under aerobic or anaerobic conditions. The corresponding bacterial processes are described in Section 2 (2.3).

Aerobic stabilisation of primary and secondary sludges can be carried out in an aeration tank in the same manner as in an activated sludge process. Because of the high oxygen requirement this process is energy intensive and costs are high. Aerobic stabilisation requires less energy when carried out as part of a composting process. For composting of sludge, its solids content should be increased to at least 15 % so that it can be handled as a solid. Thickening and dewatering (see below) of primary and secondary sludges are required to achieve the required solids content. Faecal sludge may contain high enough solids. Mixing with dry materials such as dry saw dust may assist with achieving the required solids content as well attaining the required carbon to nitrogen ratio for composting.

5.2 Composting

Composting is an aerobic bacterial decomposition process to stabilise organic wastes and produce humus (compost). Compost contains nutrients and organic carbon which are excellent soil conditioners. Composting takes place naturally on a forest floor where organic materials (leaf litter, animal wastes) are converted to more stable organic materials (humus) and the nutrients are released and made available for plant uptake (Section 2 (2.2)). The process is slow on a forest floor, but can be accelerated under optimum conditions.

The optimum conditions for composting are a moisture content of about 50 %, a carbon to nitrogen ratio of about 25 to 30, and temperature of 55 ^{o}C. Because wastewater sludge is rich in nutrients its carbon to nitrogen ratio is low (5 to 10). It is also high in moisture. Addition of dry saw dust, which is very high in carbon to nitrogen ratio (500) can adjust both the moisture and carbon to nitrogen ratio. Other waste materials that can be used for this purpose are mulched garden wastes, forest wastes and shredded newspaper.

Composting can be carried in specially built composter, such as an inclined rotating cylinder, fed on one end with the raw materials, and the aerated product collected at the other end. As the materials are slowly tumbled over a period of about one week, they are mixed and aerated. Because bacterial decomposition produces heat, temperatures in the insulated composter can easily reach 55 ^{o}C. The immature compost is then windrowed for at least 12 weeks to allow the composting process to complete, with occasional turning of the windrow.

Composting can be more simply carried out in windrows (Figure 2.40). Regular turning of the windrows assists with mixing of the materials and more importantly supply the oxygen to the bacteria. Temperatures can reach 55 ^{o}C, because compost has a good heat insulating property. Turning of the compost also ensures that all parts of the windrow reach the required 55 ^{o}C essential for pathogen destruction. Turning is required every two to three days in the first two weeks when temperature is 55 ^{o}C or above. After this period frequent turning of the compost windrow is not required as less heat is generated and less oxygen is required while the compost undergoes maturation.

Figure 2.40 Windrow composting

5.3 Anaerobic digestion

Anaerobic digestion is a bacterial decomposition process which stabilises organic wastes and produces a mixture of methane and carbon dioxide gas (biogas). The heat value of methane is the same as natural petroleum gas, and so biogas is valuable as an energy source.

Anaerobic digestion is usually carried out in a specially built digestor, where the content is mixed and the digestor maintained at 35 ^{o}C by combusting the biogas produced. After digestion the sludge is passed to a sedimentation tank where the sludge is thickened. Biogas is collected from both the digestor and the sedimentation tank (Figure 2.41). The thickened sludge requires further treatment prior to reuse or disposal.

Figure 2.41 Simple anaerobic digestion process

Anaerobic digestion can also be carried out at a slower rate in an unmixed tank or pond. Covering is usually by a UV resistant plastic sheet, because of the large area needed to be covered, and biogas is collected from the top of the sheet.

Storage of biogas can be in a cylindrical tank with a floating roof. The cylindrical roof floats on water and its position is determined by the volume of the gas stored under the pressure of the roof. Biogas can also be stored in a balloon, but only under low pressure.

5.4 Thickening

Sludge contains a high concentration of solids, but its water content is still high. Combined primary and secondary sludge from an activated sludge treatment plant contains about 2 % solids and hence 98 % water. One kg of dry sludge is associated with 49 L of water. Thickening to 5 % solids means one kg of dry solids is associated with 19 L of water, thus 30 L of water has to be removed.

Thickening is carried out in a sedimentation tank or in a sedimentation pond (Figure 2.42). The latter is advantageous if land area is available, because the sludge can be allowed to settle over a much longer period and a higher solids content of the thickened sludge is achieved. The water removed from thickening needs treatment. It can be returned to the inlet of an off-site wastewater treatment plant, or in the case of sludge from on-site units by an aerobic treatment process such as lagooning

Figure 2.42 Sludge thickening pond (Ghana)

5.5 Dewatering and drying

Dewatering aims to reduce the water content further so that the solids content of the sludge is about 20 % (equivalent to 1 kg dry sludge with 4 L of water). The sludge can then be handled like a solid. Dewatering can be done mechanically using a filter press (employing pressure or vacuum), or a centrifuge. It can also be done using drying beds. A drying bed consists of a 30 cm bed of sand with an under-drainage (Figure 2.43). Sludge is applied on the sand bed and is allowed to dry by evaporation and drainage of excess water over a period of several weeks depending on climatic conditions. Bacterial decomposition of the sludge takes place during the drying process while moisture content is sufficiently high. During the rainy season the process may take a longer time to complete, and sizing the area of the drying beds should take this into account.

Figure 2.43 Sludge drying bed

5.6 Sludge reuse

Raw sludge from activated sludge treatment plants has been applied directly onto agricultural land particularly in the United Kingdom. This practice is considered unsatisfactory because of the presence of pathogens in the sludge in high numbers. There has been no thorough study, however, which has shown that there is an increase in the risk of acquiring illnesses associated with pathogens in the raw sludge when proper handling procedure and non-entry to the land following application is observed.

Reuse of composted sludge as a soil conditioner in agriculture and horticulture returns carbon, nitrogen, phosphorus and elements essential for plant growth back to the soil (Section 2 (2.4)). Less chemical fertilisers are required and the organic carbon helps to improve soil structure for soil aeration, water percolation and root growth. The nitrogen and phosphorus are also released gradually for plant uptake compared to the more soluble chemical fertilisers. The potential of leaching of the nutrients to ground or surface water by rainfall run-off is much reduced. Pathogens and heavy metals can, however, limit the reuse of sludge.

Pathogens should be reduced to levels that do not pose health hazards to workers handling the sludge, potential health hazards from the spreading of helminth eggs and from horticultural produce contaminated by pathogens. Composting of the sludge to attain a temperature of 55 ^{o}C for two weeks followed by windrow maturation produces sludge that meet these conditions. Stabilised sludge which has been dewatered and dried on sand beds to attain a low moisture content can meet the same conditions.

Heavy metals and toxic chemicals are difficult to remove from sludge. Preventing these chemicals from entering the wastewater or sludge should be the aim of wastewater management for sludge intended for reuse in agriculture or horticulture. Reuse may still be possible for purposes such as mine site rehabilitation, highway landscaping or for landfill cover. Sludge which has been conditioned for reuse is also called ‘biosolids’

Conversion of sludge, which is heavily contaminated by heavy metals or toxic chemicals, to oil is technically feasible (Enersludge process). A full scale plant is operating in Perth, Western Australia. The conversion is by a pyrolysis process, heating dried sludge to a high temperature in the absence of oxygen or with a controlled amount of oxygen. Capital and running costs of an oil from sludge process are high.

5.7 Sludge disposal

Final or ultimate disposal of sludge, which cannot be reused, is by landfilling or incineration. Since sludge for landfilling usually contains heavy metals or toxic chemicals, lining of the landfill with clay or plastic liner may be required to prevent contamination of groundwater. Incineration of sludge is by a multiple hearth furnace or fluidized bed furnace. Energy input is required to dry the sludge before combustion is self-sustaining. Combustion flue gases usually need treatment to meet air pollution control standards. Investment and operating costs are high.

6 Wastewater and stormwater reuse (Topic d)

Human excreta and wastewater contains useful materials. These are water, organic carbon and nutrients. They should be regarded as a resource. In their natural cycles they are broken down by micro-organisms and become useful to plants and animals (Section 2 (2.2)), thus sustaining natural ecosystems. When improperly disposed these substances can cause pollution, because the organic materials exert oxygen demand, and the nutrients promote algal growth in lakes, rivers and near-shore marine environments.

Human excreta and wastewater contain pathogens. Reuse of the wastes must ensure that public health is maintained. Planned reuse is the key to wastewater reuse. Planning for reuse ensures that public health and protection of the environment are taken into account. Reuse of treated wastewater for irrigation of crops, for example, will need to meet (i) standards for indicator pathogens, and (ii) plant requirement for water, nitrogen and phosphorus. Standards for reuse of wastewater for various purposes have been developed by WHO and many states (see Regional Overviews). Plant requirements for water and nutrients is plant-specific and site-specific (dependent on soil type and climate) and information on these requirements need to be obtained from local sources of information.

Unplanned or unintentional wastewater reuse is already taking place widely when we have human settlements along a major river (e.g. the Mississippi River). Water is withdrawn from the river by a community, treated for water supply and distributed. After its use the water is collected, treated and discharged to the river. This process is repeated many times along the river. The only documented 'intended reuse' of this nature is in Windhoek, Namibia where treated wastewater is returned to the water reservoir supplying water to the town. This was initiated during a severe drought (See Regional Overview for Africa).

While reuse of wastewater for public water supply of drinking water quality standard is the exception, the technology exists to process wastewater to drinking water. A pilot plant at Denver demonstrated that 1 million US gallons per day (3.78 million L/day) of secondary effluent could be treated to produce water that is better in quality than water supplied to the city of Denver.

All water used for drinking purposes has in a sense been used, because in the water cycle (Section 2 (2.2)) water is continuously cycled.

6.1 Wastewater reuse from off-site treatment plants

6.1.1 Wastewater reuse for agriculture

Treated wastewater from off-site treatment plants can be reused for irrigation of parks and gardens, agriculture and horticulture, tree plantation and aquaculture, if these exist or can be established not far from the wastewater treatment plants. For these purposes the wastewater should generally be treated to secondary wastewater standard (< 20 mg/L BOD and < 30 mg/L SS). Total coliforms should be < 1000 organisms per 100 mL for irrigation by spraying. When sub-surface irrigation is used this requirement may not be necessary. A period of non-entry to irrigated sites may need to be observed, particularly for wastewater-irrigated parks and gardens. Irrigation of vegetables for direct human consumption requires a much stricter guideline.

Because requirement of wastewater for plant growth is governed by climatic conditions, soil and plant type, there may be a need for storage of the wastewater. An alternative to storage, if land area is not available for this purpose, is to dispose of wastewater that is excess to requirement. A combination of wastewater for irrigation and aquaculture (see below) is also an option that can be considered.

Land application for treatment of wastewater described in Section 2 (4.2.4) (Slow rate land application and grass filtration) when combined with growing of grasses for grazing by sheep or cattle can properly be considered as treatment and reuse of wastewater.

6.1.2 Wastewater reuse for aquaculture

Wastewater reuse for aquaculture has been practised in many countries for a considerable period of time. It has the potential of wider application in the tropics. A special section in this Source Book is devoted to this important topic.

<Insert Aquaculture section>

6.1.3 Wastewater reuse for industry

Treated wastewater can also be used for industrial purposes, if suitable industries are not far from the treatment plants. Industry's requirement for water quality ranges widely, from very pure water for boilers of electricity generation to lower water quality for cooling towers. Treated wastewater can fulfil the lower range of this requirement, e.g. water for cooling towers. Secondary-treated wastewater after chlorination may be adequate for this purpose.

With off-site treatment plants reuse of wastewater may be limited by the need to pipe treated wastewater to where it is needed. To implement wastewater reuse in houses for toilet flushing, watering of gardens and other purposes which do not need drinking quality water, a third pipe-reticulation system is required, that is in addition to the reticulation to provide drinking water and the sewer to collect the wastewater. Care is also needed to prevent cross-connection between drinking water and treated wastewater.

'Sewer mining' is the term given to the withdrawal of wastewater from a sewer for reuse near to the point of withdrawal. This provides an opportunity for reuse without having to pipe treated wastewater from the centralised treatment plant. Wastewater needs to be treated to the standard required for the reuse, and may duplicate the function of the centralised treatment plant.

6.2 Reuse of wastewater from on-site systems

Many options are open to a householder who wishes to reuse wastes on-site. One option is separation of all wastes (Figure 2.44). Urine can be separately collected and stored for later use as a liquid fertiliser, rich in nitrogen, phosphorus and potassium. Toilet wastes can be composted and used as a soil conditioner, rich in organic carbon, nitrogen and phosphorus. Greywater can be treated in a constructed wetland and used for sub-surface irrigation of the garden beds. This option may be suitable for a householder who is interested in managing wastes for beneficial uses in the garden, being a keen gardener. Sufficient garden area needs to be available for this purpose.

Figure 2.44 Separation of household wastewater for on-site reuse

Another option is the use of an evapotranspiration system for growing shrubs and trees (see Section 2 (4.1.4)). This is a passive system, not requiring household attention on a regular basis, except desludging of the septic tank every 3 to 5 years. There is a fairly wide choice of shrubs and trees to choose from depending on local soil and climatic conditions.

6.3 Stormwater reuse

Stormwater is generally of a higher water quality than wastewater. Reuse (or strictly 'use') of stormwater can take place at two levels (household and municipal) or even at a larger (regional) scale if desired. Use at the household and municipal levels is described below.

6.3.1 Household level

Householders can use stormwater by collecting roof run-off in a tank for use as drinking water (common in arid regions), flushing toilets or for irrigation of the garden. The first flush of roof run-off can be contaminated by dust particles, leaf litter and animal droppings. The first flush can be simply diverted using a simple diverter (Figure 2.45). A screen can placed at the inlet to the tank to filter gross particles. Water for drinking will still need to be boiled to denature pathogens.

Figure 2.45 Diverter for the first flush from roof run-off

Water from the roof can be directed to the garden beds directly rather than through soakways, and in this way shallow rooted vegetation can benefit from the water, especially in arid regions.

6.3.2 Municipal level

At the municipal level stormwater can be stored in ponds for use for irrigation of parks and gardens and for fire-fighting purposes. This is in addition to employing the ponds for flood control and for improving the amenity value of the water as described in Section 2 (4.3). Other uses are for groundwater recharge, either as a means of storing water, e.g. during the rainy season, for withdrawal in the dry season. Groundwater recharge can also be used to prevent encroachment of sea water near the coast where there is heavy groundwater withdrawal in excess of natural replenishment by precipitation.

7 Wastewater and stormwater disposal (Topic e)

Disposal of wastewater and stormwater should preferably be considered only when reuse options are not feasible. Ultimate disposal of wastewater is either onto land or water (river, lake, ocean).

7.1 Land-based disposal of wastewater

Disposal onto land takes the form of effluent from on-site and off-site treatment systems being allowed to percolate through the ground. For a septic tank, for example, this occurs through the soakage of overflow from the septic tank in a leach drain (Section 2 (4.1.4)). Disposal onto land generally pollutes groundwater, and may reach surface water when groundwater eventually discharges into surface water. The impact of BOD and nutrients in the wastewater on the surface water has been attenuated by soil processes and is therefore not as severe as direct disposal into surface water. Disposal from an off-site treatment plant for groundwater recharge to control encroachment of sea water in coastal areas is a form of reuse.

Injection of wastewater into a deep confined aquifer via a borehole is a possibility. Only treated wastewater with very low content of suspended and colloidal solids can be injected into a deep aquifer to prevent blockage of the pore spaces surrounding the borehole. The long-term effect of deep well injection is still unclear and the method is not generally recommended.

7.2 Wastewater disposal to water environments

Disposal into a lake, stream or ocean needs to take into account the ability of the receiving water to assimilate wastewater. The natural purification capacity of the environment is limited (Section 2 (2.2)). Even when wastewater is disposed to the ocean, the area surrounding the outfall can be sufficiently polluted and the pollutants (including pathogens) can be washed towards the beaches. The minimum water quality standard for disposal to a water environment is BOD < 20 mg/L and SS < 30 mg/L. This standard is generally achieved by secondary treatment processes (lagooning or activated sludge treatment). This standard was initially developed for wastewater discharge into rivers, assuming that an eight fold dilution by river water takes place. A class 1 river therefore can maintain a BOD of less than < 3 mg/L (Section 1). Such dilution is not always achieved in arid or semi arid areas.

Nutrients (nitrogen and phosphorus) promote the growth of algae in the receiving water. In lakes and sensitive water environments the removal of nutrients may be required. Furthermore if the wastewater contains high levels of heavy metals and toxic chemicals, these may have to be removed before wastewater disposal. Over the years the requirement for disposal into water environments have become stricter as the impact of pollutants is better appreciated. It can be expected that this trend towards more stringent discharge requirements will continue (See Western Europe and North America Regional Overviews).

7.3 Stormwater disposal

Ultimate disposal for stormwater is onto land (by infiltration to groundwater) and to water environments (river, lake, ocean). These have been covered as part of stormwater treatment (4.3) and reuse (6.3), because they utilise infiltration as a general technique. Techniques for reuse are those that delay its ultimate flow to water environments to improve flow management and hence reduce the frequency and extent of flooding. At the same time these techniques also generally remove pollutants (particulates and oils) prior to the water reaching a river, lake or the sea, while creating amenities such as wetlands, waterfowl habitats and water-based passive and active recreational facilities.

8 Sound Practices

8.1 Technology choice

Environmentally sound practices in wastewater and stormwater management are practices that ensure that public health and environmental quality are protected. A range of technologies exist that can achieve this objective (Section 2 (2) to (7)). A summary is shown in Table 2.5. Even though this table does not cover all available technologies, they represent major technologies for situations that are likely to be encountered. The Regional Overviews include technologies that are modifications or variations of the listed technologies or represent practices or advances in the regions.

Table 2.5. Technologies for wastewater and stormwater management (with relative costs, environmental impact and maintenance requirement)

Wastewater management technologies

Technology	Capital cost	Operation & maintenance cost	Environmental impact
On-site technology			
Pit latrine	Low	Low	Pollution of groundwater
Composting toilet	Low	Low	Reuse of nutrients
Pour flush toilet	Low	Low	Pollution of groundwater
Improved on site treatment unit	Medium to high	Low to medium	Reuse of water and nutrients
Off-site technology			
Collection technology			
Conventional sewerage	High	High	Dependent on treatment
Simplified sewerage	Medium to high	Medium	Dependent on treatment
Settled sewerage	Medium	Low	Dependent on treatment
Treatment technology			
Activated sludge	High	High	Nutrients may need removal
Trickling filtration	Medium	Medium	Nutrients may need

			removal
Lagoons	Low to medium (dependent on cost of land)	Low	Nutrients may need removal; aquaculture can be incorporated
Land-based treatment	Low to medium (dependent on cost of land)	Low to medium	Reuse of water and nutrients
Constructed wetland	Low to medium (dependent on cost of land)	Low	Amenity value
Anaerobic treatment	Medium	Medium	Produces biogas; further aerobic treatment needed

Stormwater management technologies

Technology	Source control	Site control	Regional control
Filter strips and swales	√		
Filter drains and permeable surfaces	√		
Infiltration devices		√	
Basins and ponds			√

Cost increases from source control to regional control technology

Common to all sound technologies is that there is a scientific basis for the physical, chemical and biological processes for the removal of pathogens and pollutants from the water. These processes are largely akin to the purification and recycling processes taking place in nature (Section 2 (2.2)). Properly designed, constructed, maintained and operated these technologies can achieve protection of public health and the environment, and can recycle water and nutrients, which are beneficial to sustaining ecosystems and life.

Associated with each technology hardware is a philosophical basis or approach, e.g. separation of waste components (dry conservancy), or conveying all wastes away with water (water based conveyance), minimising capital cost, minimising maintenance requirement; or maximising reuse) maintenance and operational requirements, which are the software associated with the technological hardware, and therefore level of skills required to operate the hardware and software, and consequently training requirements for personnel.

The choice of technology is determined by environmental, economic and social factors.

8.2 Environmental considerations

Achievement of protection of environmental quality is implicitly assumed when we consider technologies for wastewater and stormwater management. These considerations are (i) the need to protect the environment and (ii) the imperative of recycling/reusing the water and nutrients in the water. The first factor is usually taken into account by making sure that standards for discharge of wastewater are met. Standards alone should not be relied upon, because it is the capacity of the environment to assimilate the wastes that should not be exceeded. Each local environment has its own capacity depending amongst others on the natural throughflow of water, climatic, vegetation and soil conditions.

Reuse of the water and nutrients conserve these resources in a world where water will in the future be a precious resource for growing food and maintain ecosystems for the world's increasing population and standard of living. Reuse of water can in fact fulfil the objective of protecting the environment, because reuse has standards which have to be met prior to the water being able to be reused. A corollary to the above two factors is the need to exclude toxic and hazardous chemicals from being mixed and discharged with human excreta. Treatment, reuse or disposal of wastewater and stormwater containing toxic and hazardous chemicals will be considerably more difficult than treating the toxic and hazardous wastes separately.

Conservation of resources needs to consider water conservation at the point of its use. Less water used means less wastewater produced. The hierarchy of waste management discussed in Section 1 (4) emphasises this point.

8.3 Economic factors

Sound practices require that costs are optimised. Optimising the cost of technology for wastewater management needs to consider (1) availability of land, (2) labour costs, (3) land uses and (4) economy of scale. Land is required for wastewater and stormwater management either underground to lay pipes or on the ground for a treatment plant or for land-based disposal. If low cost land is available a lower cost technology utilising more land can be chosen rather than a higher cost technology using less land area. Lagoons, for example, can be installed rather than an Activated Sludge Treatment Plant, because both can achieve the same standard for final BOD and SS. Labour cost for construction and maintenance is an important consideration. On-site treatment systems are generally more conducive to the use of manual labour for construction and maintenance, whereas off-site treatment systems generally require specialised equipment and skilled labour.

Availability of land, when an on-site system is used, enables reuse of treated wastewater at the site. Similarly when an off-site system is used, nearby agriculture, horticulture, forestry or industrial activities can present an opportunity for reusing the wastewater.

Economy of scale may be taken advantage when total cost of treatment is considered. Individual on-site systems do not present an opportunity for economy of scale for cost reduction, unless they are constructed in standard sizes and prefabricated components are manufactured in large quantities. Off-site treatment of wastewater from many households provides an opportunity for cost-saving in treatment. The cost of treatment per unit volume of wastewater will decrease with an increase in population served. The cost of collection will, however, increase, because larger diameter pipes and additional pumps and pumping stations are required. This will counter the cost saving in centralised treatment. There will be an optimum size of population served by an off-site treatment system when the combined cost of collection and treatment are considered. When opportunities for water reuse are also considered (piping of reuse water, availability of land or opportunities for reuse) there seems to be an optimum to the size of population served (Figure 2.46).

Figure 2.46 Cost of treatment as a function of population served

The economics of wastewater management needs to consider the benefits of improvement to public health and long-term affordability of sanitation services to the community. The benefits of improved public health to the economy of a country is difficult to quantify, although estimates have been made on the cost to the economy as a result of people suffering from illnesses from waterborne diseases. Similarly the economic benefits of the protection of the environment from improper disposal of wastewater and stormwater is difficult to estimate. A case for subsidy to communities to install wastewater treatment facilities has been put forward (The all beneficiaries contribute (abc) principle).

From a community's point of view the affordability of a wastewater collection and treatment system is an important factor. A percentage of the average person's income in a community, or of the average value of housing appears to be a figure that can be used as a measure of what a community can afford. What the percentage figure should be is determined by the importance given by community members to having the wastewater system in their community. The priority given to wastewater management in turn is dependent on the community having the information that will help them decide on its importance relative to other household and community needs. Hygiene promotion and education is the needed to provide this information. An example of an excellent hygiene promotion is a publication by WHO (Reference needed).

Procedures to consider economic and environmental factors in a systematic way have been developed. These range from a single decision-making flowsheet to a computer software package.

Figure 2.47 Simple decision making flowsheet for choosing wastewater treatment systems (Ref. Pickford)

Figure 2.48 Decision making flowsheet for choosing wastewater treatment technologies (Ref. Mara)

<Computer software of SANEX: Description of procedure and capability>

<Computer software of WAWTAR: Description of procedure and capability>

Figure 2.49 Stormwater decision making tree

8.4 Social and institutional factors

Social and institutional factors are most important in the delivery of any service including wastwater and stormwater services. These factors include the processes adopted by a community, region or country to plan, finance and implement the provision of sanitation services. Each community has developed their processes, and these may have been developed over a long period. The importance of involving the community in decision making to introduce wastewater and stormwater management has been reiterated as being important to ensure long term sustainability of the system.

Difficulty can be encountered with new communities developing in the fringes of large cities, where there may not have been the tradition of community decision making. The involvement of a community-based or non-government organisation may assist. Financing and cost recovery are important considerations for these communities, which generally are resource poor.

The management of ablution facilities illustrates the importance of ownership or sense of ownership. A private ablution facility is generally better maintained than a communal ablution facility. Hygiene maintenance of a private facility is usually the responsibility of a person in the household. This is usually the housewife, who cleans the facility or arranges its regular cleaning and also ensures that members of the household play their part. A communal hygiene facility can suffer from a lack of unclear responsibility for cleaning the facility or from abuse by irresponsible members of the community.

Requiring payment for use of a communal or public ablution facility, with an attendant for collection of payment and responsible for cleaning, appears to be a good model (Sulabh, India).

<Box: brief description of Sulabh, India>

There is an emerging trend for governments to privatise provision of wastewater and stormwater services. The private sector has developed considerable expertise in providing wastewater and stormwater services. These services range from developing master plans, community consultation, design, construction, operation & maintenance of collection, treatment and disposal facilities, to training of personnel. It is not clear whether the private sector achieves greater management efficiency when compared to a well operated government agency. The latter may not, however, operate in a particular locality, and capacity building within the government sector is required. Government's responsibility remains in providing policy direction, providing overall planning framework, and ensuring that public health and environmental objectives are achieved. Hygiene promotion should remain a high priority for governments, irrespective of public or private provision of services.

Communities with low incomes/resources require special attention with respect to achieving the wider public health and environmental objectives. The case of providing funding for wastewater and stormwater services is compelling from the overall public health and environmental benefits outside these communities.

8.5 Scenarios for Sound Practices

General scenarios can be sketched based on population density to illustrate integration of technology, environmental, economic and social factors. For a low population density and where land is available around dwellings, on-site systems with on-site reuse provide householders with options which are a function of water availability, toilet type and desired reuse of blackwater and greywater. Use of a double vault composting toilet (2 (4.1.2)) and greywater for subsurface irrigation is shown in Figure 2.50. Maintenance requirement will be emptying the vault (say, every 6 months), windrow-composting the content with garden waste and diverting blackwater from a full vault to the one just emptied. Irrigation system for greywater need to be checked weekly.

Figure 2.50 Composting toilet for blackwater and sub-surface irrigation of greywater

A system requiring less householder maintenance is a septic tank with an inverted leach drain or evapotranspiration trench (2 (4.1.5)). The septic tank needs to be de-sludged every 3 to 5 years. This is done by calling a sludge contractor. This service should be available in the community for this option to operate satisfactorily.

For a high population density, community ablutions blocks with payment for use can work well. The wastewater can be conveyed to a location where land is available for land-based treatment (2 (4.2.4)) and reuse through grazing grasses irrigated by treated wastewater. The operator of the ablutions facilities needs to ensure public health requirements for the wastewater reuse are met.

Toilet facilities in individual dwellings are an option with wastewater collected using simplified sewerage (2 (3.2)). This can be condominial sewers or with street connections depending on community choice. Collected wastewater is treated using a series of lagoons (2 (4.2.3.)), with the final lagoon employed for aquaculture (2 (6.1.2.)). Depending on land use downstream of the lagoons, wastewater can be reused further for agriculture, horticulture or tree plantation.

The requirement of planning a sewerage system within a catchment basin (to use gravity flow), the environmental requirement for reuse of wastewater nutrients (to prevent pollution), the economic requirement of balancing economy of scale of treatment and the cost of the sewer pipes, and the social requirement for community consultation point to planning for a community-scale collection, treatment and reuse of wastewater. The optimum size of the population served for a community-scale systems will depend on local conditions, which in turn are determined by local geographical (topography, climate, soil), environmental, economic and social/institutional considerations.

Bibliography

Construction Industry Research and Information Association (CIRIA) (1999) Sustainable urban drainage systems design manual for Scotland and Northern Ireland. CIRIA, London.

Depledge D (1997) Sanitation for Small Islands. Guidelines for Selection and Development. SOPAC Miscellaneous Report no. 250. SOPAC Secretariat, Suva, Fiji.

Esrey, S A, Gough, J, Rapoport, D, Sawyer, R, Simpson-Hebert, M, Vargas, J and Winblad, U (1998) Ecological Sanitation, Sida Swedish International Development Cooperation Agency, Stockholm.
(http://www.gwpforum.org/GWPEF/wfmain.nsf/7f929fc0912eb954852564ef006a6b85/a7c64dd72ea21b1ac12567af0042edd7!OpenDocument)

Finney B A and Gearheart R A (1998). A decision support model for prefeasibility Analysis of Water and Wastewater Treatment Technologies Appropriate for Reuse. The US Agency for International Development.

Heinss, U, Larmie, S A and Strauss, M (1999) Characteristics of Faecal Sludges and their Solids-Liquid Separation. EAWAG SANDEC (Swiss Federal Institute for Environmental Science and Technology, Department for Water and Sanitation in Developing Countries, Duebendorf.

Lange, J and Otterpohl, R (1997) Oekologie Aktuell ABWASSER Handbuch zu einer zukunftsfaehigen Wasserwirtschaft. MALLBETON GmbH, Donaueschingen-Pfohren.

Loetscher, T (1998) Appropriate Sanitation in Developing Countries: The development of a computerised decision aid (http://daisy.cheque.uq.edu.au/awm/manage/thomasl2.htm)

Lyonnaise des Eaux (1999) Lyonnaise des Eaux, Nanterre cedex

Mara, D (1996) Low cost sewerage. Wiley, Chichester.

Mara, D (1996) Low cost urban sanitation. Wiley, Chichester.

McGahey, C. (1998) WAWTTAR. In Ho, G. (Ed.) Proceedings of the Workshop on Adopting, Applying and Operating Environmentally Sound Technologies for Domestic and Industrial Wastewater Treatment for the Wider Caribbean Region. IETC Report no. 5, p. 68 - 74, UNEP IETC, Osaka/Shiga.

National Water Council, United Kingdom (1970) River Pollution Classification (refer to Tebbutt)

Novotny, V (1995) Nonpoint Pollution and Urban Stormwater Management, Technomic Publishing Co., Lancaster.

Novotny, V and Olem, H (1994) Water Quality: Prevention, Identification, and Management of Diffuse Pollution, van Nostrand Reinhold, New York.

Pickford, J (1995) Low-cost Sanitation: A survey of practical experience. Intermediate Technology Publications, London.

Rose, G D (1999) Community-based Technologies for Domestic Wastewater Treatment and Reuse: Options for urban agriculture, IRDC Research Program: Cities Feeding People, Report Series 27 (http://www.irdc.ca/cfp/rep27_e.html).

Sasse, L (1998) DEWATS Decentralised Wastewater Treatment in Developing Countries, BORDA Bremen Overseas Research and Development Association, Bremen.

Simpson-Hebert, M and Wood S (Eds.) (1998) Sanitation Promotion. World Health Organization (WHO) Water Supply and Sanitation Collaborating Council (Working Group on Promotion of Sanitation WHO/EOS/98.5), Geneva.

Smout I and Parry-Jones S (Eds.) Lessons learned from NGO experiences in the Water and Sanitation Sector. WELL, WEDC, Loughborough University, UK.

UNDP World Bank (1999) Resource Guide in Urban Environmental Sanitation. Prepared by Kalbermatten Associates, Inc. for United Nations Development Programme/ World Bank Water and Sanitation Program, Draft (August)

United Nations Environment Programme – International Environmental Technology Centre (UNEP IETC) (1995?) International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management. IETC Technical Publications Series No. 6, UNEP IETC, Osaka.

Water Supply and Sanitation Collaborative Council (1999a) Vision 21 Knowledge Synthesis (http://www.wsscc.org/vision21/docs/index.html)

Water Supply and Sanitation Collaborative Council (1999b) Vision 21 Water for People (http://www.wsscc.org/vision21/draft/index.html)

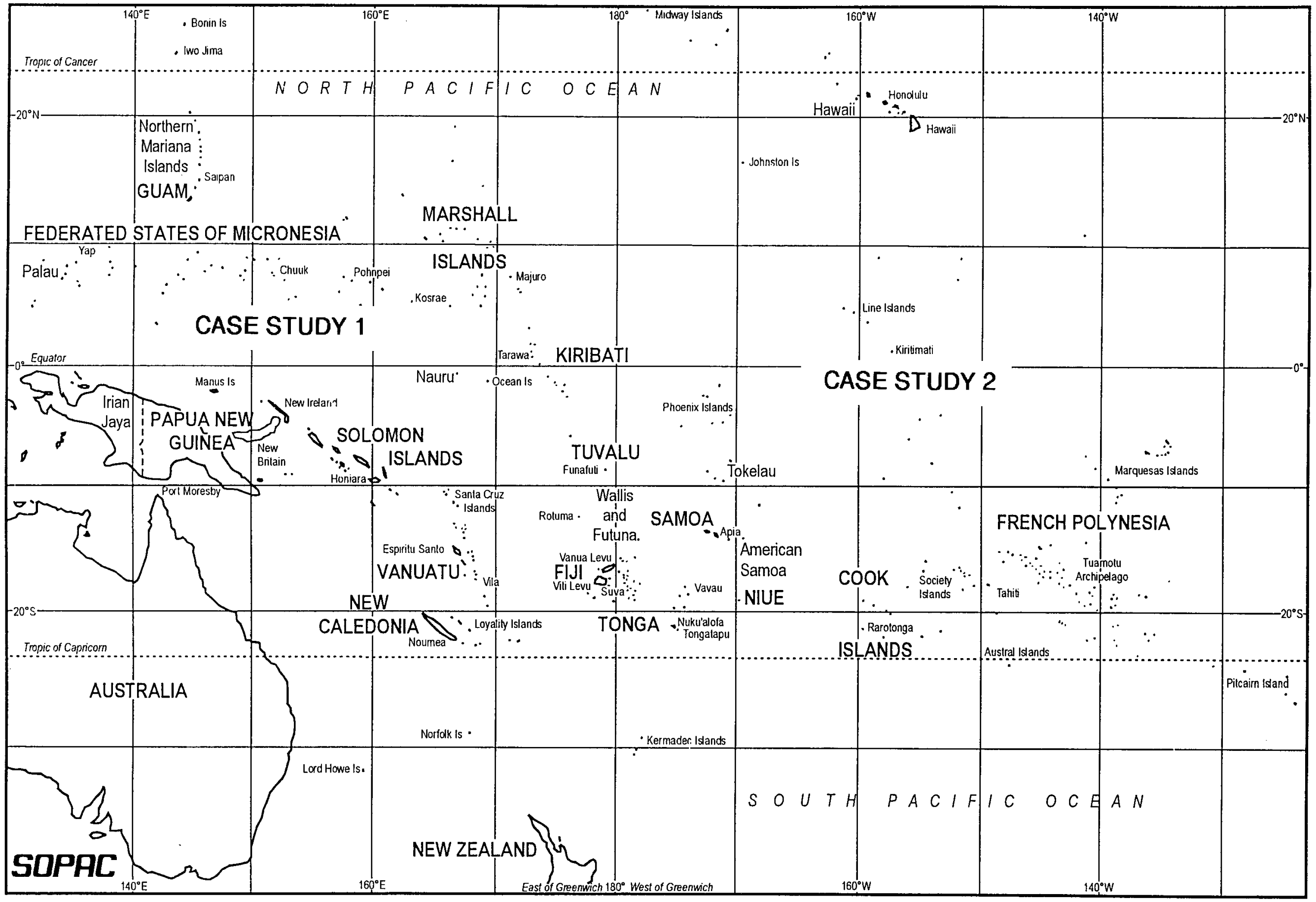
ACRONYMS

AusAID	Australian Aid
EPA	Environmental Protection Agency
FSM	Federated States of Micronesia
PNG	Papua New Guinea
PWA	Pacific Water Association
SIDS	Small Island Developing Country
SPC	South Pacific Community (formally South Pacific Commission)
SPREP	South Pacific Regional Environmental Programme
SOPAC	South Pacific Applied Geoscience Commission
USP	University of the South Pacific
VIP	Ventilated Improved Pit Latrine
WERI	Water and Environment Research Institute

REGIONAL MAP

Location of Case Studies

Map of the Region & SOPAC Member Countries



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PHOTOS

1. Stormwater disposal well in Guam
2. Community toilet in Tarawa, Kiribati that lacks daily maintenance
3. Disposal of septic tank solids into clarigester in American Samoa
4. Typical ocean outfall in Honiara, Solomon Islands
5. Septic tank discharge problems into unsuitable soil conditions
6. Construction of compost toilet in Fiji


SiP1
Stormwater disposal well in Guam
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Community toilet in Tarawa, Kiribati that lacks daily maintenance

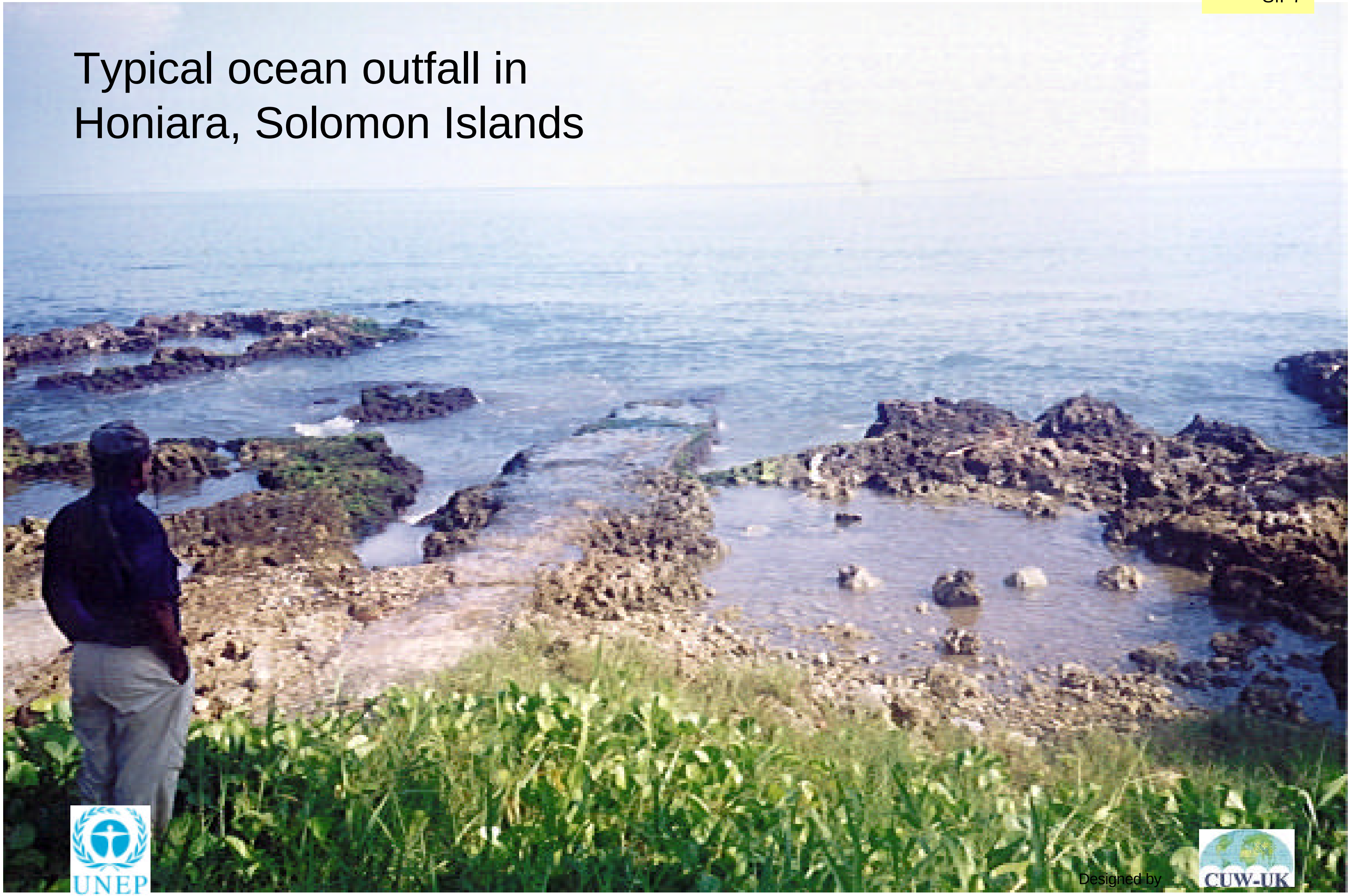
UNEP

Disposal of septic tank solids into Clarigester in American Samoa

UNEP

SiP7

Typical ocean outfall in Honiara, Solomon Islands



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Septic tank discharge problem into unsuitable soil conditions
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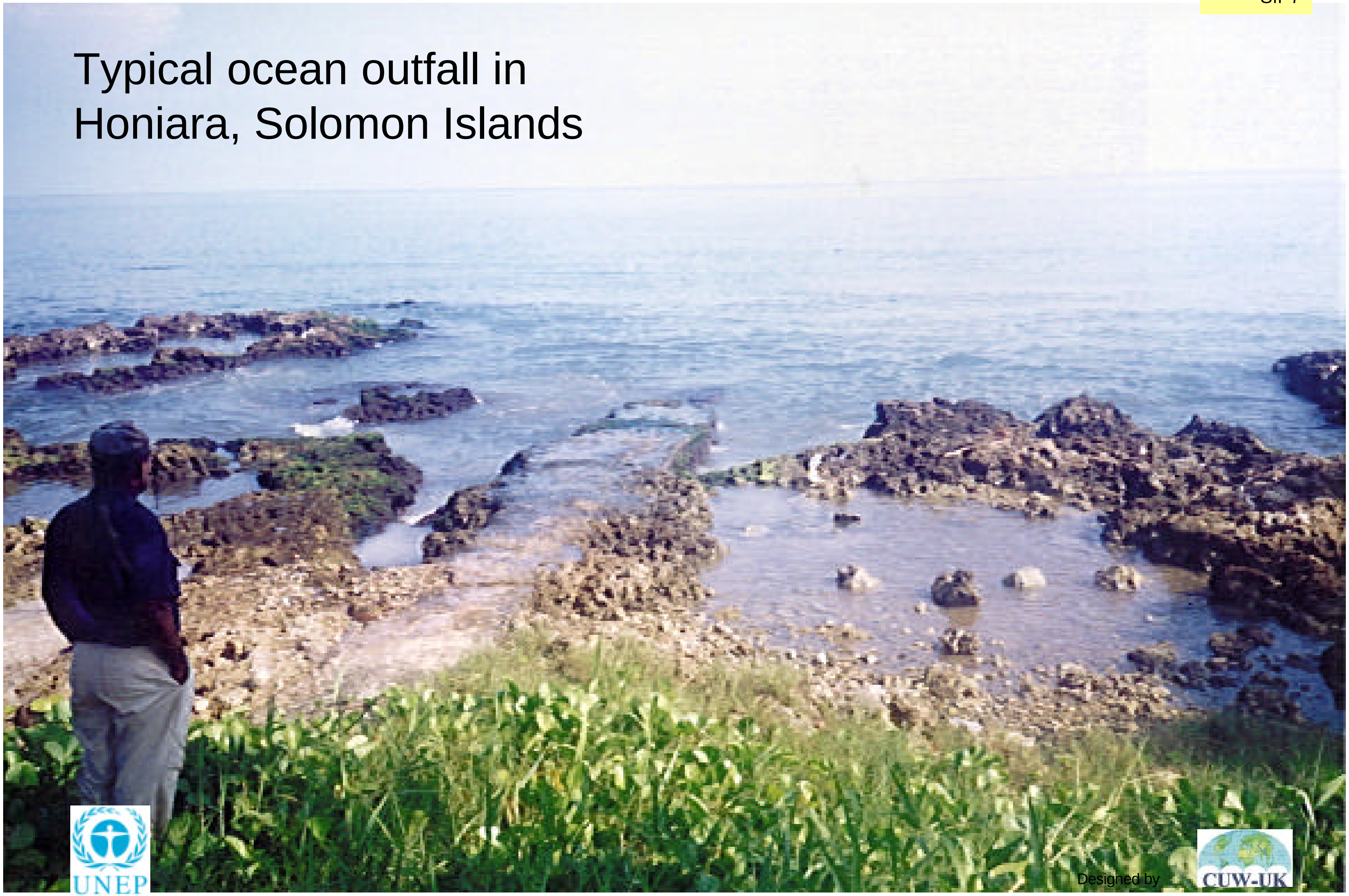
SiP7

Typical ocean outfall in Honiara, Solomon Islands




SiP8
Septic tank discharge problem into unsuitable soil conditions
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Construction of compost toilet in Fiji

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DIAGRAMS

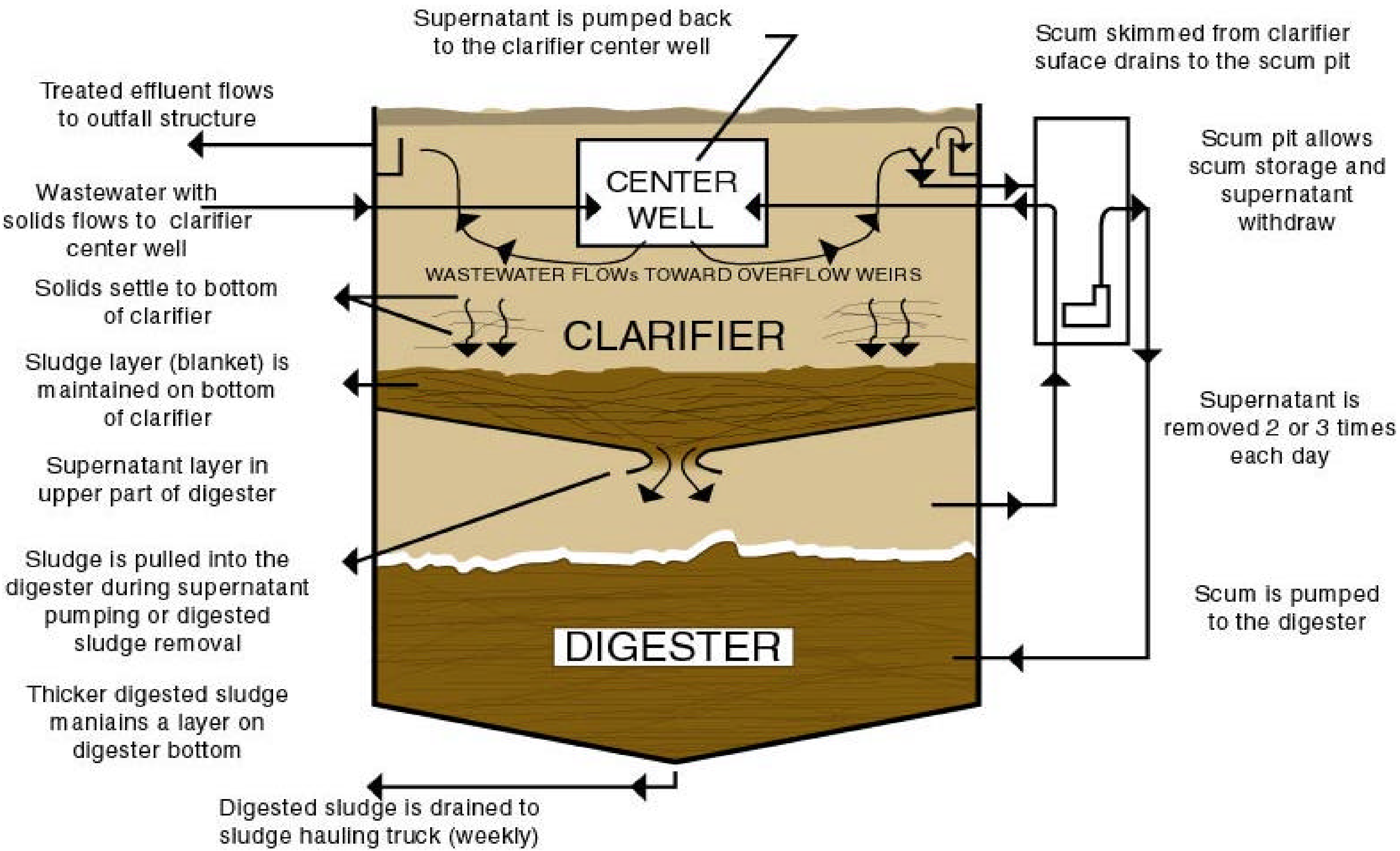
1. Open defecation
2. Clanigester operation
3. Overhang Latrine
4. Cornposting toilet sketch used in Kiritimati
5. Evapotranspiration trench sketch

Open Defecation

Source: Tearo, 1997

Where there are no latrines people resort to defecation in the open. This may be indiscriminate or in special places for defecation generally accepted by the community, such as defecation fields, rubbish and manure heaps, or under trees. Open defecation encourages flies, which spread faeces-related diseases.In moist ground the larvae of intestinal worms develop, and faeces and larvae may be carried by people and animals. Surface water run-off from places where people have defecated results in water pollution. In view of the health hazards created and the degradation of the environment, open defecation should not be tolerated in villages and other built-up areas. There are better options available that confine excreta in such a way that the cycle of re-infection from excreta-related diseases is broken.

Operation of the Clarigester



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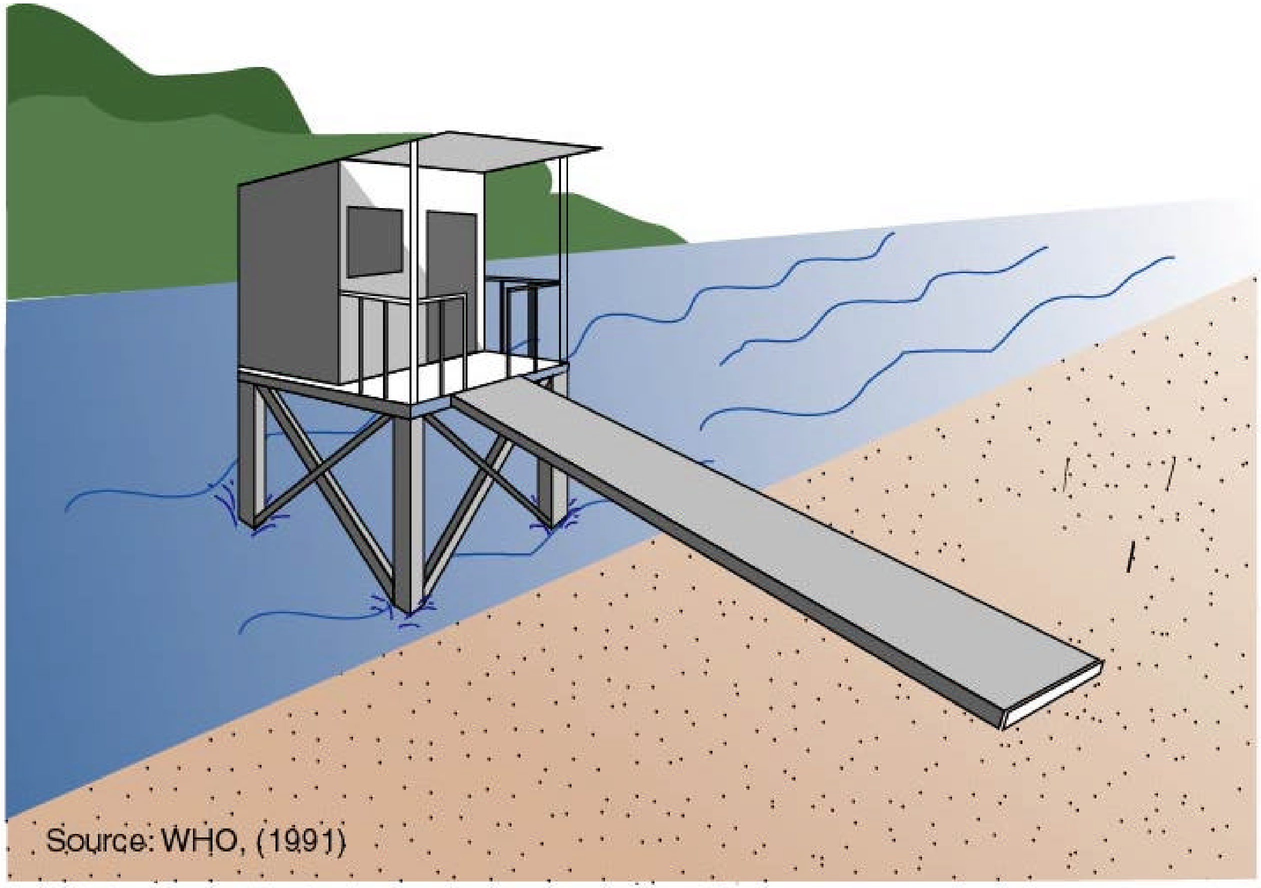
Overhung Latrine



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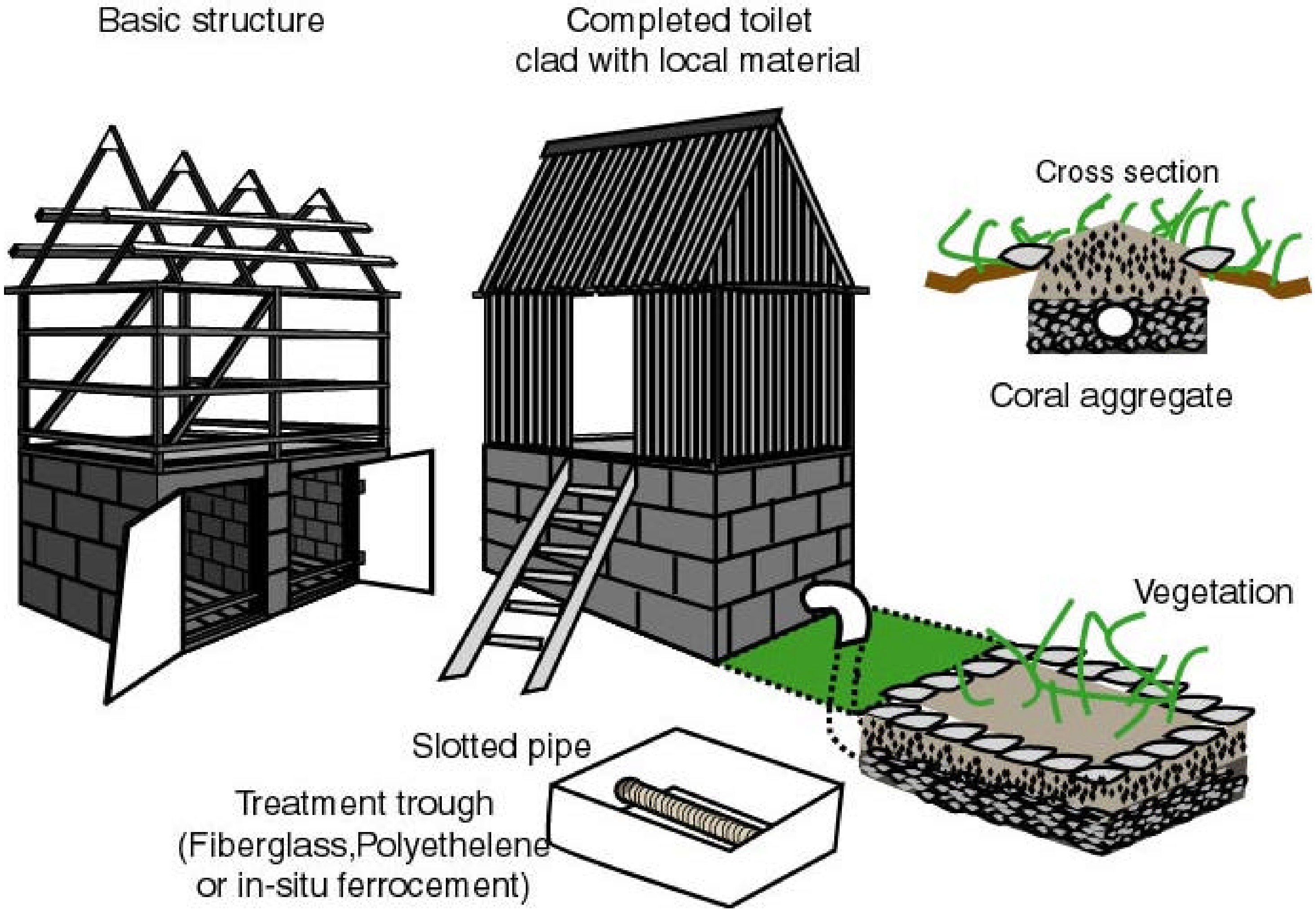
Composting Toilet used in Kiribati



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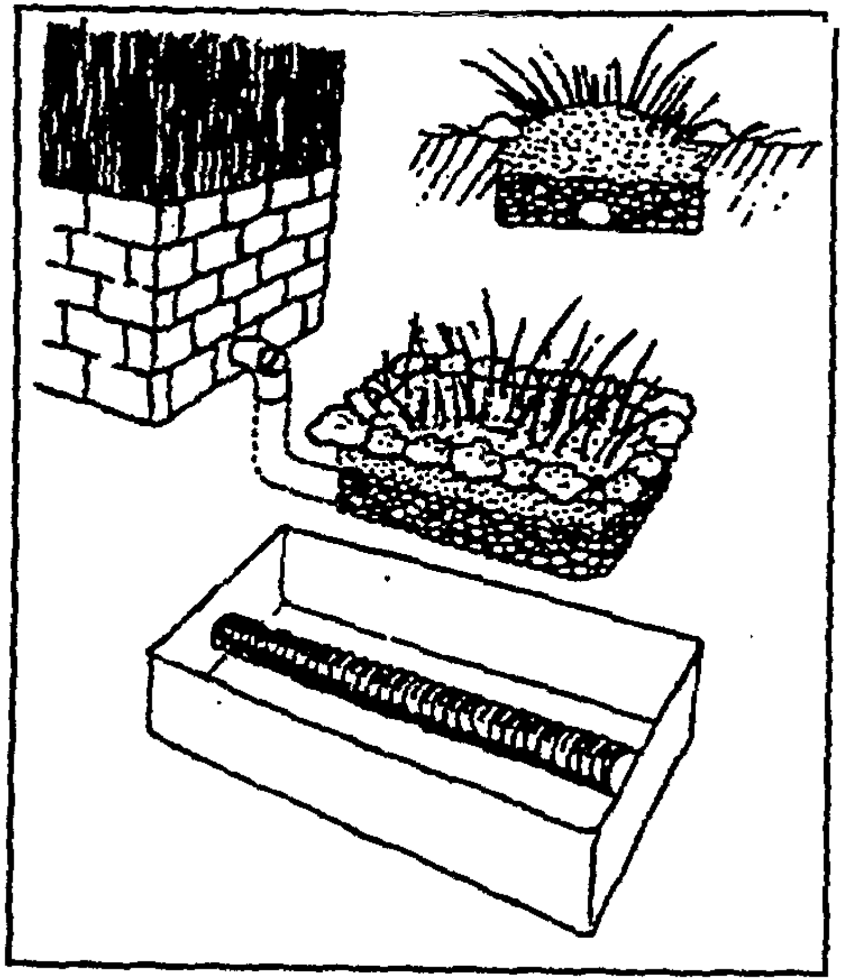
Evapotranspiration Trench



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