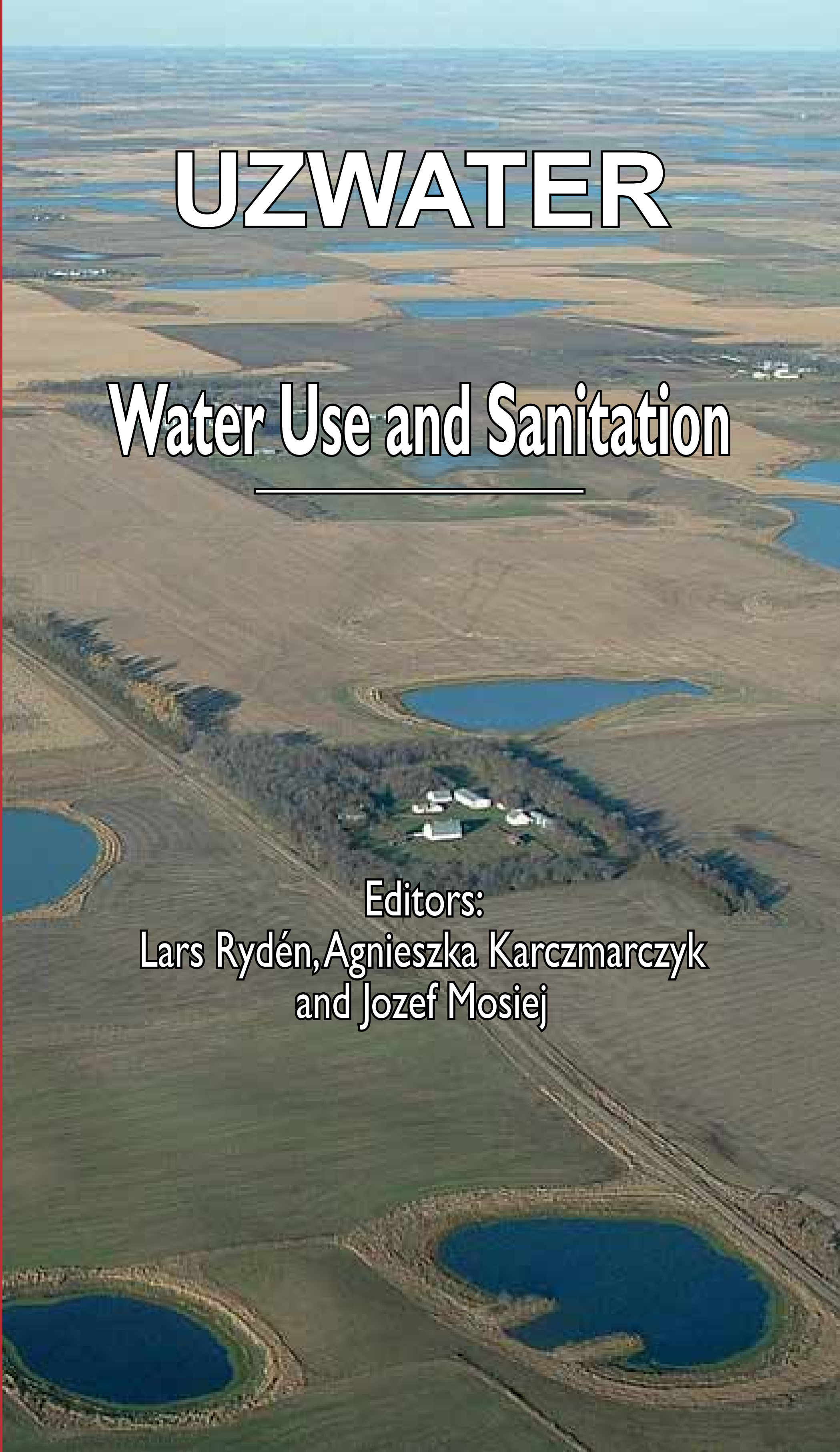

UZWATER

Water Use and Sanitation

Editors:
Lars Rydén, Agnieszka Karczmarczyk
and Jozef Mosiej

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Content Overview

Content

Chapter 1
Wastewater Management in Uzbekistan

1.1 Geography, climate and population

Uzbekistan is a landlocked country in Central Asia, with a total area of 447,400 km^2. Physiographically the country can be divided into three zones:

- *the desert* (Kyzylkum), steppe and semi-arid region covering 60% of the country, mainly the central and western parts;
- *the fertile valleys* (including the Fergana valley) that skirt the Amu Darya and Syr Darya rivers;
- *the mountainous areas* in the east with peaks of about 4,500 m above sea level (Tien Shan and Gissaro-Alay mountain ranges).

In 2009, the cultivated area was an estimated to be 4.65 million ha, of which 92.5% was under temporary crops and 7.5% under permanent crops (Table 1.1). Only 18% of the cultivable area, an estimated 25.4 million ha, is cultivated because of the water shortage.

The climate is continental; arid/deserts cover over 60% of the territory. Average annual rainfall is 264 mm, ranging from less than 97 mm in the northwest to 425 mm in the mountainous regions in the centre and south. In the Fergana valley, average annual rainfall varies between 98 and 502 mm, while in the Tashkent *vilayat*, it varies between 295 and 878 mm. Rainfall occurs during the winter, mainly between October and April. There are high temperatures 42-47 ^oC on the plains and 25-30 ^oC in the mountainous regions in July, and low temperatures in winter, minus 11 ^oC in the north and 2-3 ^oC in the south in January. Because of frequent frosts, between late September and April, only one crop a year can be grown. In favourable years, however, double-cropping of vegetables with a short growing period is possible.

The total population was an estimated 27.8 million inhabitants in 2011 (of which 64% rural) (Table 1.1). During the period 2001-2011 annual population growth rate was an estimated 1%. Population density is about 62 inhabitants/km^2, which is the highest of the five former Soviet Central Asian republics. Population ranges from more than 464 inhabitants/km^2 in Andijan province in the Fergana valley in the east to only eight inhabitants/km^2 in Karakalpakstan.

Table 1.1 Basic statistics and population (Source: Irrigation in Central Asia in figures).

Physical areas			
Area of the country	2009	48,810,000	ha
Cultivated area (arable land and area under permanent crops)	2009	1,910,000	ha
• as % of the total area of the country	2009	3.9	%
• arable land (temporary crops + temp fallow + temp meadows)	2009	1,850,000	ha
• area under permanent crops	2009	60,000	ha
Population			
Total population	2011	5,105,000	inhabitants
• of which rural	2011	50	%
Population density		10	inhabitants/km2
Economically active population	2011	2,431,000	inhabitants
• as % of total population	2011	48	%
• female	2011	47	%
• male	2011	53	%
Population economically active in agriculture		714,000	inhabitants
• as % of total economically active population	2011	29	%
• female	2011	53	%
• male	2011	47	%
Economy and development			
Gross Domestic Product (GDP) (current US$)	2010	20,001	million US$/yr
• value added in agriculture (% of GDP)	2010	12	%
• GDP per capita	2010	3,967	US$/yr
Human Development Index (highest = 1)	2011	0.686	
Access to improved drinking water sources			
Total population	2006	84	%
Urban population	2010	97	%
Rural population	2006	72	%

1.2 Water use

In 2005, total water withdrawal was 56.0 km^3, of which 50.4 km^3 (90%) was for agriculture, 4.1 km^3 (7%) for municipal and 1.5 km^3 (3%) for industry (Table 1.2). Total groundwater withdrawal was 5 km3 or 9% of total water withdrawal, of which 49% for urban and rural water supply, 34% for irrigation and 17% for industry. In 2010, 87% of the population had access to improved water sources (98 and 81% in urban and rural areas respectively).

In 2000 all UN member states signed the United Nations Millennium Declaration (UNMD) with eight Millennium Development Goals (MDGs). Goal num-

Table 1.2 Water: sources and use (Source: Irrigation in Central Asia in figures).

Renewable freshwater resources			
Precipitation (long-term average)	-	206	mm/yr
	-	92,200	Million m^3/yr
Internal renewable water resources (long-term average)	-	16,340	Million m^3/yr
Total actual renewable water resources	-	48,870	Million m^3/yr
Dependency ratio	-	80	%
Total actual renewable water resources per inhabitant	2011	1,760	m^3/yr
Total dam capacity	2010	22,162	Million m^3
Water withdrawal			
Total water withdrawal by sector	2005	56,000	Million m^3/yr
- agriculture	2005	50,400	Million m^3/yr
- municipalities	2005	4,100	Million m^3/yr
- industry	2005	1,500	Million m^3/yr
• per inhabitant	2005	2,158	m^3/yr
Surface water and groundwater withdrawal (primary and secondary)	2005	49,160	Million m^3/yr
• as % of total actual renewable water resources	2005	101	%
Produced municipal wastewater	2000	1,083	Million m^3/yr
Treated municipal wastewater		-	Million m^3/yr
Direct use of treated municipal wastewater		-	Million m^3/yr
Desalinated water produced		-	Million m^3/yr
Direct use of agricultural drainage water	2000	6,840	Million m^3/yr

ber 7 commits the states to ensure environmental sustainability by reducing the proportion of people without sustainable access to safe drinking water by half by 2015. This commitment was expressed again at the World Summit on Sustainable Development in Johannesburg in 2002, where basic sanitation was added to the above mentioned Millennium Development Goal, the reason being that 3 billion people lack safe sanitation services.

Actually, in 2007, the situation regarding drinking water in developing countries is even worse than it was a few years ago, mostly because of pollution, irrigation, lack of money, wars and progressive climate change. The World Health Organization has defined around 20 litres of water per capita per day as the minimum amount for life needs – although this amount still implies high health concerns – and 100 litres per capita per day as the optimal access, associated with low health concerns. Nevertheless, an adequate amount of water of adequate quality is essential for public health and hygiene. In addition to human needs for water, non-domesticated plants, animals, and other organisms need water as well.

In 2015 the MDG of 93% of improved drinking water sources for Caucasus and Central Asia had not been meet (Fig.1.1). Improved sanitation coverage was accounted for 96% of the population.

1.3 Wastewater treatment

The level of household connection to sewerage infrastructure is relatively low compared to many OECD countries. Even when households are actually connected to the sanitation infrastructure, the treatment of wastewater is not always assured.

While little consolidated information exists about the level of equipment with primary and secondary treatment facilities, it is clear that existing infrastructures often do not operate effectively. Following important reductions in water consumption as a consequence of the collapse of the ECECA (Eastern and Central Europe and Central Asia) economies in the early 1990's, the capacity of the existing wastewater treatment plants is often too large. Hence, many of them function below their design capacity, which causes treatment to be ineffective or impossible. The deteriorated condition of many wastewater treatment plants is another reason for their ineffectiveness. In Kazakhstan, for instance, between 26

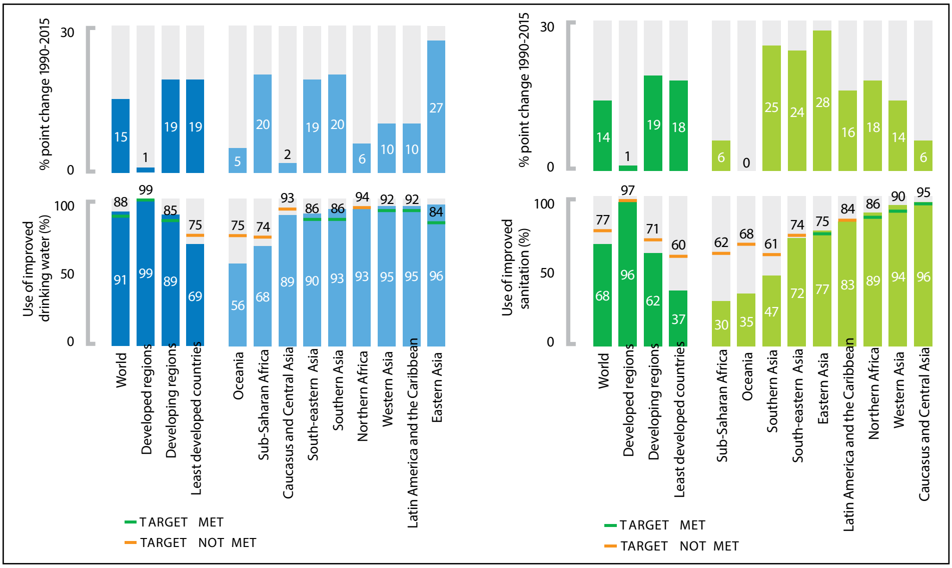


Figure 1.1. Use of improved drinking water sources, improved sanitation and MDG targets in 2015, and percentage point change from 1990 to 2015 (Source: 25 Years Progress on sanitation and drinking water).

and 33% of mechanical-biological treatment plants were found to be in need of rehabilitation. These problems are exacerbated by the chronicle lack of cash for simple operational purposes, the unreliability of key supplies such as electricity, and a frequent inadequacy of infrastructure design to local conditions.

As a result of this situation and the parallel collapse of industrial output many treatment plants have been shut-down in recent years and municipal water utilities have advanced to be the main polluters of surface water in many places in ECECA. This is the case in Georgia, where municipal sewage is the dominant polluter of rivers, lakes and the Black Sea coastal area, representing about 60% of all wastewater, with phosphates, nitrates and organic compounds being the main pollutants.

1.4 Water consumption

Municipal water utilities in ECECA account for 1-15% of the total water consumption in the region. It varies from 1% in Turkmenistan (Turkmenistan water note, World Bank, 2000) to about 5% in Kazakhstan and in the Russian Federation and up to 15% in Ukraine (UNEP/GRID-Arendal). During the last five years, the water demand from water utilities substantially declined in ECECA (e.g., in Ukraine it dropped by 1.7 times during the period from 1990 to 2001). In some places it declined by half due to the reduction of industrial water consumption, cancelling of hot water services, and demand management through metering. Also, high rates of cross-subsidy between industrial and household consumers in some ECECA resulted in some industries and commerce to construct their own intakes and treatment facilities, thereby reducing their demand for water through vodokanals (water works).

Nevertheless, domestic water use in ECECA remains at relatively high levels at between 200 litres per capita a day (lpcd) in small towns and 500 litres in large cities, even though some significant decrease has been observed in some countries (e.g. Moldova). In some locations consumption levels may be even higher, such as for instance in Tbilisi, Georgia (up to 900 lpcd) as well as in Ashgabat, Turkmenistan (700 lpcd).

One of the reasons for excessive water consumption is that the use of domestic water metering is not yet widely developed in ECECA, which does not encourage more efficient use of water. Consumption figures should be treated carefully, however, since domestic and production metering are not well developed yet. Hence, it is possible that consumption figures include a substantial part of water that is actually lost in the distribution network.

Country, area or territory	Year	Population (x1,000)	Percentage urban population	Use of sanitation facilities (percentage of population)												Progress towards MDG target	Proportion of the 2015 population that gained access since 1990 (%)
				Urban				Rural				Total					
					Unimproved				Unimproved				Unimproved				
				Improved	Shared	Other Unimproved	Open Defecation	Improved	Shared	Other Unimproved	Open Defecation	Improved	Shared	Other Unimproved	Open Defecation		
Turkey	1990 2015	53 995 76 691	59 73	96 98	1 1	3 1	0 0	64 86	2 2	30 12	4 0	83 95	1 1	14 4	2 0	Met target	36
Turkmenistan	1990 2015	3 668 5 373	45 50	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	NA	-
Turks and Caicos Islands	1990 2015	12 41	74 95	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	- -	NA	-
Tuvalu	1990 2015	9 10	41 52	75 86	8 9	15 3	2 2	71 -	4 -	18 -	7 -	73 -	6 -	16 -	5 -	NA	-
Uganda	1990 2015	17 535 40 141	11 16	28 29	43 44	27 25	2 2	11 17	6 9	61 66	22 8	13 19	10 14	57 60	20 7	Limited or no progress	13
Ukraine	1990 2015	51 659 44 646	67 70	97 97	2 2	1 1	0 0	- 93	- 4	- 3	- -	- 96	- 3	- 1	- -	Met target	NA
United Arab Emirates	1990 2015	1 806 9 577	79 86	98 98	2 2	0 0	0 0	95 95	5 5	0 0	0 0	97 98	2 2	1 0	0 0	Met target	79
United Kingdom	1990 2015	57 214 63 844	78 83	99 99	1 1	0 0	0 0	100 100	0 0	0 0	0 0	99 99	1 1	0 0	0 0	Met target	10
United Republic of Tanzania	1990 2015	25 485 52 291	19 32	6 31	6 31	86 36	2 2	7 8	3 4	80 71	10 17	7 16	4 12	80 60	9 12	Limited or no progress	12
United States Virgin Islands	1990 2015	103 107	88 95	- -	- -	- -	- -	- -	- -	- -	- -	96 96	- -	4 4	- -	Limited or no progress	3
United States of America	1990 2015	254 507 325 128	75 82	100 100	- 0	0 0	0 0	99 100	- 0	1 0	- 0	100 100	- 0	0 0	0 0	Met target	22
Uruguay	1990 2015	3 110 3 430	89 95	93 97	3 3	0 0	4 0	81 93	2 2	4 5	13 0	92 96	2 3	1 1	5 0	Met target	13
Uzbekistan	1990 2015	20 555 29 710	40 36	95 100	- -	5 0	0 0	76 100	- -	24 0	0 0	84 100	- -	16 0	0 0	Met target	42
Vanuatu	1990 2015	147 264	19 26	- 65	- 33	- 1	- 1	- 55	- 15	- 28	- 2	- 58	- 20	- 20	- 2	Good progress	-
Venezuela (Bolivarian Republic of)	1990 2015	19 741 31 293	84 89	89 97	- -	6 0	5 3	45 70	- -	11 1	44 29	82 94	- -	7 1	11 5	Met target	43
Viet Nam	1990 2015	68 910 93 387	20 34	65 94	4 5	7 1	24 0	29 70	2 4	26 25	43 1	36 78	2 5	23 16	39 1	Met target	51
West Bank and Gaza Strip	1990 2015	2 081 4 549	68 75	96 93	- 7	3 0	1 0	- 90	- 10	- 0	- 0	- 92	- 8	- 0	- 0	Limited or no progress	-
Yemen	1990 2015	11 790 25 535	21 35	70 -	1 -	23 -	6 -	12 -	1 -	33 -	54 -	24 -	1 -	31 -	44 -	NA	-
Zambia	1990 2015	7 845 15 520	39 41	59 56	27 25	11 18	3 1	29 36	7 8	23 34	41 22	41 44	15 15	18 27	26 14	Limited or no progress	23
Zimbabwe	1990 2015	10 462 15 046	29 32	52 49	47 45	0 4	1 2	35 31	19 16	0 13	46 40	40 37	27 26	0 9	33 28	Limited or no progress	9

Figure 1.2 Country, Regional and Global Estimates on Water and Sanitation (Source: 25 Years Progress on sanitation and drinking water).

Internal water metering and especially metering within multi-apartment buildings are only gradually being implemented. In Moldova, the Russian Federation and Ukraine less than 30% of connections are metered, while this figure can be as high as 100% in some OECD and Baltic countries. Even when installed, internal water meters are not always used for billing purposes. Such practices were reported in Almaty, Chisinau, and many other relatively large cities where utilities sign contracts not with individual consumers but with condominiums or housing maintenance companies. The situation with excessive water consumption is only likely to change in the event of significantly increased water tariffs and more accurate billing according to consumption (e.g. through metering).

1.5 The Water network

Traditionally in the Soviet Union, insufficient attention and resources were dedicated to the maintenance of water infrastructure. The general economic decline, financial constraints of industrial consumers, and reduced water consumption further exacerbated these problems. Hence, the replacement of corroded pipes and other rehabilitation work has been neglected for many years which has resulted in extremely high accident rates. There are now between two and ten accidents per kilometre of pipe a year in most places in ECECA, while 0.2-0.3 accidents are considered reasonable in OECD countries.

While such accident rates should lead to significant levels of water losses (more than 50%), the figures seem to show only moderate losses (30-40%). In fact figures of unaccounted-for-water have even been decreasing over the last years in those ECECA countries where they have been surveyed. This apparent contradiction is due to the fact that ECECA utilities lack the equipment and willingness to measure losses effectively. Production and internal metering are not a standard practice in ECECA utilities, and the introduction of such meters is frequently considered to be an excessive cost. The fact that under the existing tariff system, water utilities have little or no incentives for providing transparent information (as consumers are billed according to calculated average consumption) further complicates the matter.

1.6 Water service and public health

Another consequence of the deterioration of the water infrastructure is that water utilities in many ECECA countries find it difficult to provide service continuity. In Moldova, for example, water supply outside the capital city of Chisinau was available only for several hours a day. Nowhere in Moldova is water supplied 24 hours a day. Hot water services have often been discontinued definitely especially in small towns. Similar trends can be observed in Ukraine, Tajikistan, Kazakhstan and some other ECECA. Besides posing a problem to consumers in terms of water quality (when the network is down infiltration into supply mains takes place) and access, this practice contributes to further accelerate the deterioration of the network (due to the shockwave or “hydraulic hammer” that is generated when the supply is re-established).

The deterioration of water quality that goes along with an infrastructure that is slowly falling apart is resulting in levels of water borne diseases at significantly higher levels than in the EU. In some countries, essentially in Central Asia more than one-third of the population is using drinking water that does not meet hygiene standards, and in some sub-regions this proportion can exceed 50%. Pathogenic micro-organisms remain the most important danger to drinking water in the region, with gastro-intestinal diseases an important cause of child morbidity and mortality in some countries.

Incidences of water related diseases, e.g. hepatitis A, are high in many ECECA countries. These figures are supported by the perception in the population. For instance, among Baku's residents in Azerbaijan, 87% perceive piped water to be unsafe. This is causing significant costs to public health systems and the economy. In Moldova, for instance, the NEAP calculated the social and economic impact of water pollution and reached the conclusion that polluted drinking water leads to 950 to 1850 premature deaths annually, as well as 2 to 4 million days of illness annually. The monetary cost to the economy was assessed to be as high as 5 to 10% of GDP.

The treatment rate of raw water to achieve potable quality declined due to a lack of the water treatment chemicals, dilapidation of treatment equipment, and financial constraints. As has been stated earlier, wastewater treatment plants are now becoming the main polluters of surface water in a number of ECECA countries and regions. Also, there are numerous cases when decaying sewerage pipes cause secondary cross-contamination of drinking water. Almost everywhere in

ECECA, the strict potable water quality standard (legacy of the USSR Sanitary Standard for the water quality, SanPin) is being replaced by temporary water quality permits that allow utilities to sometimes significantly exceed SanPin standards. The cost reduction strategy in Turkmenistan, for example, involved a change in chlorination method from liquid chlorine to calcium hypochloride, which substantially increased the rigidity of potable water (with the calcium content up to 2 g/l) and reduced its taste and sanitary parameters.

Consequently, demand for clean potable water from alternative sources is growing rapidly. Water vending, where an entrepreneur delivers water from a "clean underground spring" in mobile tanks, is a profitable business in some large cities in ECECA (including Moscow, Kharkiv, Kiev, Yerevan, and several large cities in Central Asia). Bottled water business is also growing in all ECECA countries, reflecting the decline in tap water quality. In fact, the Russian Ministry of Health recommended wider use of bottled water in its Order in 2000. In the wider Baku area in Azerbaijan 97% of the population reported that they systematically

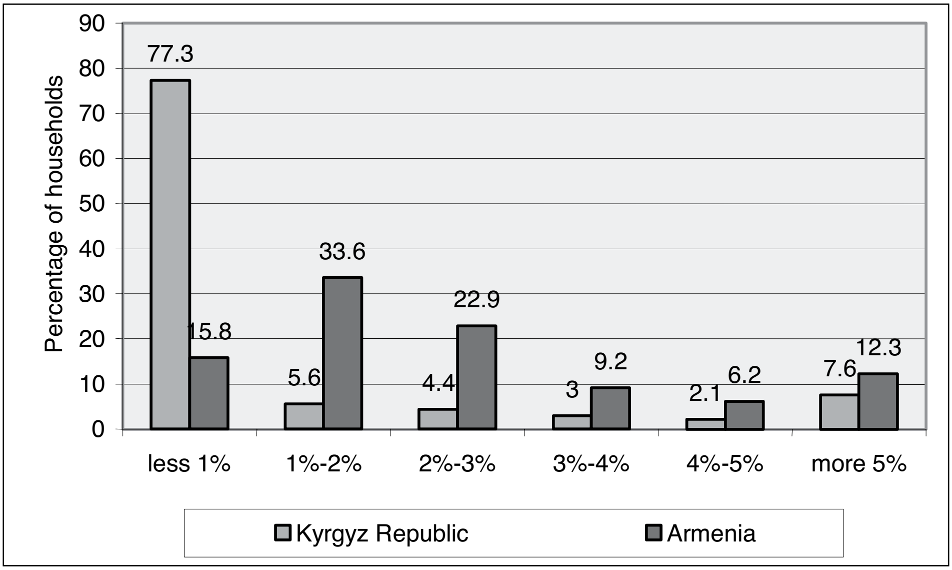
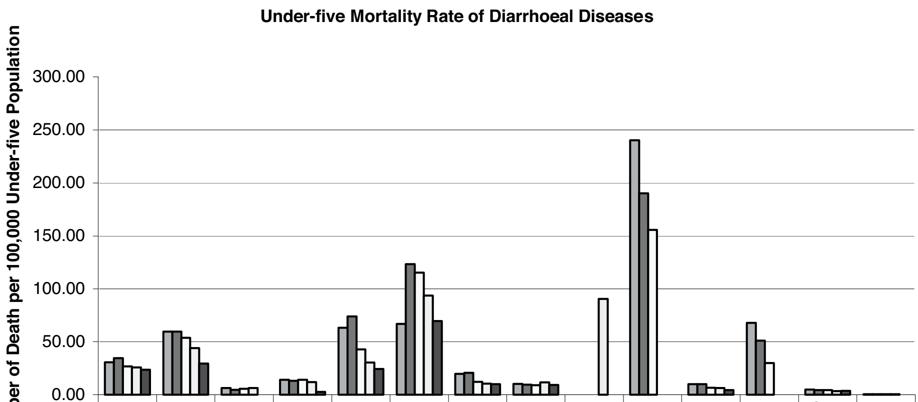


Figure 1.3 Price of water supply and sanitation as a share of household expenses (percentage of households according to the share of water bill in their total expenses), Kyrgyzstan and Armenia, 2001, (Source: OECD EAP Task Force, (2002), Key issues and recommendations: Affordability, Social Protection and Public Participation in Urban Water Sector Reform in EECCA, Paris).



	ARM	AZE	BLR	GEO	KAZ	KGZ	MDA	RUS	TJK	TKM	UKR	UZB	CEE average	EU average
1996	30.55	59.45	6.26	13.99	63.42	66.97	19.72	10.19		240.30	9.85	68.13	4.84	0.42
1997	34.40	59.49	4.65	13.06	74.03	123.32	20.61	9.47		190.31	9.93	51.09	4.48	0.47
1998	26.64	53.68	5.51	14.02	42.82	115.31	12.03	8.94		155.82	6.62	29.91	4.49	0.56
1999	25.83	43.98	6.28	11.96	30.39	93.67	10.47	11.64	90.59		6.33		3.34	0.52
2000	23.60	29.50		2.63	24.39	69.81	9.92	9.34			4.36		3.75	

Figure 1.4 Under-five Mortality Rate of Diarrhoeal Diseases. (Source: OECD EAP Task Force, (2002), Key issues and recommendations: Affordability, Social Protection and Public Participation in Urban Water Sector Reform in EECCA, Paris).

were boiling water for nutritional purposes, and about 20% said they were buying bottled water or water from vendors. It is probable that the wide recognition in the ECECA population that tap water is no longer safe, and the fact that many seem to resort to purification or substitution with water from other sources, has helped to avoid more serious public health impacts.

It is in towns and cities with a population of less than 100,000 that the water infrastructure has been deteriorating most dramatically and that the economic problems of the sector are most severe. Small and medium cities and towns suffer from a number of "handicaps", which are: a smaller potential for economies of scale, significantly lower average revenues in the population, and lack of capacity and access to capital markets. Medium sized towns with a population between 25,000 and 100,000 are in a particularly difficult situation as they cannot resort to low cost solutions as is possible in small municipalities: high-rise apartment complexes dominate instead of private housing that is prevalent in smaller cities; community driven approaches are not viable due to the complexity of the water systems requiring special skills and knowledge.

Hence, all the problems that have been discussed in previous sections are exacerbated. Unit operational costs in small and medium sized cities of the Russian Federation and Moldova are about 50 to 100% higher than in the largest cities. In the same time the ability to pay for water services is significantly lower than in large cities, due to lower average revenues per capita. This and the fact that water tariffs in small, medium and large cities are roughly the same, explains why the non-payment problem appears to be much more widespread in small and medium sized cities. Data from the Russian Federation and Moldova indicates that average collection periods are roughly twice as long in small cities (20 months in Moldova, 7 in Russia) than in large cities (10 months in Moldova, 2.5 in Russia).

This situation is reflected in systematically better average working ratios in large cities (about 85% in Russia), than in small cities where operational expenses may dramatically exceed operational revenues (about 150% in Russia, and about 121% for small towns in Moldova in 2001). As a consequence of this situation, towns with a population of less than 100,000 frequently have higher accident rates, sometimes twice as high as in large cities. It is also in medium and small towns that accident rates have been increasing more rapidly, indicating an accelerated deterioration of infrastructure. At the same time the continuity of services is lower with an average of 10-12 hours per day in Moldova (compared to close to 24h in large cities). Given this situation it is likely that the impacts on public health are most severely felt in small and medium sized cities, even though there is no data to sustain this suspicion.

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Chapter 2
Sanitation and Sustainable Sanitation

2.1 Sanitation

Sanitation potentially delivers benefits at three levels; to the user, to society and to the wider community through the environment. At the user level, sanitation potentially delivers health improvements, but often expectations focus more on the utility of the service provided - measured in terms of comfort, privacy and convenience. At the level of society we expect sanitation to deliver public health improvements – but the available evidence suggest that for this, the service may have to include both safe collection of faeces as well as hand washing and disposal of sullage (grey) water and solid waste. To deliver wider environmental benefits, the service has to deal with the life-cycle management of wastes - including collection, appropriate treatment and safe re-use or disposal.

In generally we may have improved or unimproved sanitation facilities (Figure 2.1). An improved sanitation facility is defined as one that hygienically separates human excreta from human contact. It can be achieved by connection to a public sewer, septic system or even latrine. Following that an improved drinking-water source is defined as one that, by nature of its construction or through active intervention, is protected from outside contamination, in particular from contamination with faecal matter. Unimproved and improved drinking-water and sanitation facilities are presented on Figure 2.2. Use of drinking-water sources and sanitation facilities in Uzbekistan with the focus on rural areas is set at Figure 2.3.

As seen throughout history, the common targets for sanitation and wastewater treatment are protection of public health, recycling of nutrients and protection against environmental degradation. These targets are hereafter called primary functions. For the system to be sustainable, the primary functions have to be balanced against economical, socio-cultural (among them the private goals) and technical considerations. This balance is illustrated in Figure 2.4.

2.2 Sustainable sanitation

The term sustainable sanitation is used in an effort to mainstream sanitation into the concept of sustainable development as agreed upon between the countries at

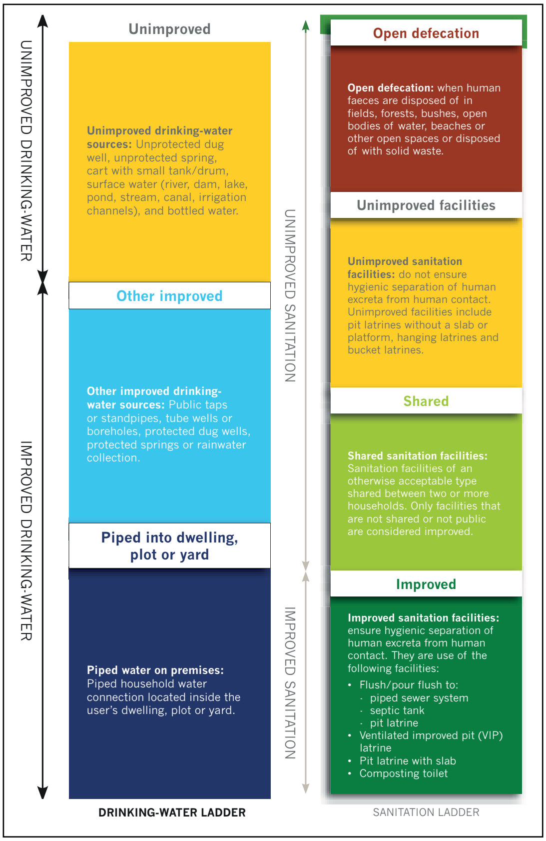

Figure 2.1 Unimproved and improved drinking-water and sanitation. Source: Progress on Sanitation and Drinking Water. 2010 UPDATE. http://www.unicef.org/eapro/JMP-2010Final.pdf

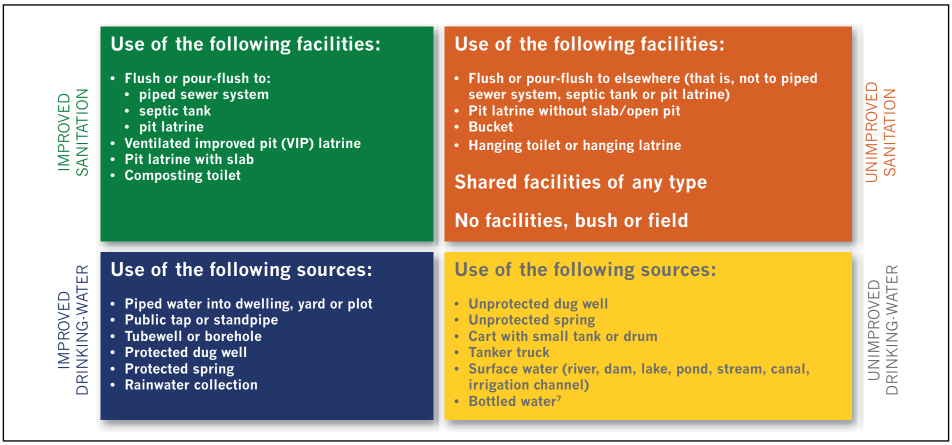

Figure 2.2 Unimproved and improved drinking-water and sanitation facilities. Source: Progress on Sanitation and Drinking Water. 2010 UPDATE. http://www.unicef.org/eapro/JMP-2010Final.pdf

the 1992 UN Conference on Environment and Development in Rio de Janeiro. This means that sanitation solutions should be assessed and be feasible in terms of economic, equity and environmental criteria. Sustainable sanitation can be defined as sanitation that protects and promotes human health, does not contribute to environmental degradation or depletion of the resource base, is technically and institutionally appropriate, economically viable and socially acceptable. This definition is used for example, for ecological sanitation in Sweden and Germany.

A similar definition is used in the Swedish Research program Urban Water where five aspects of sustainability are considered; health, environment, economy, socio-cultural and technical function.

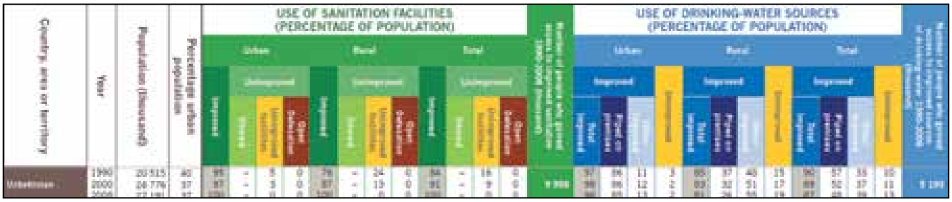

Figure 2.3 Use of drinking-water sources and sanitation facilities in Uzbekistan with the focus on rural areas.

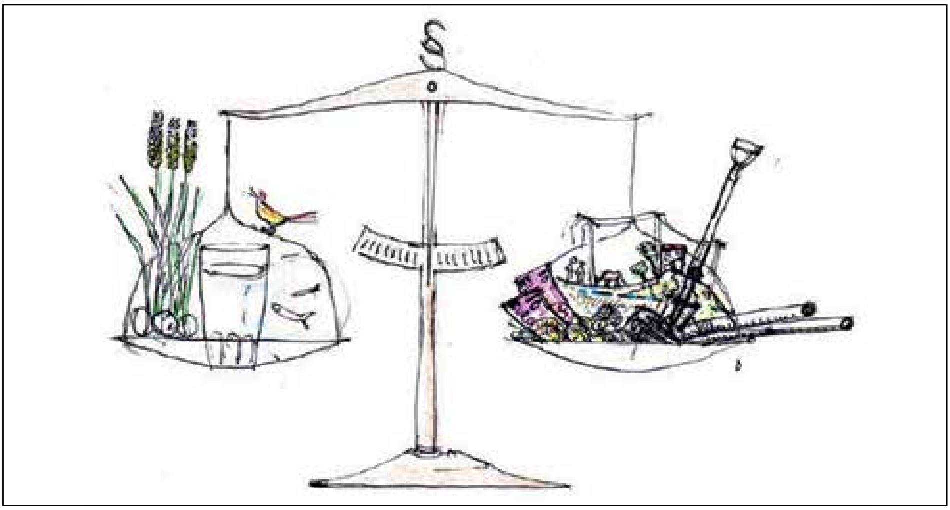

Figure 2.4 The primary functions of sanitation balanced against practical considerations.

2.3. The sanitation system

When planning and comparing different sanitation systems, the boundaries of the systems must be defined. In research and in long-term strategic planning, the sanitation system might be broad and include agriculture and sometimes the users.

Agricultural systems relate closely to sanitation since agriculture produces food that, after consumption, is managed in the sanitation system. In a well connected socio-agricultural system, products from sanitation systems are brought back to agriculture, thus closing the loop for nutrients. In practical planning and design, it is more useful to define the sanitation system as a technical system only. Thus, the more pragmatic definition of sanitation includes all components, from the sources (e.g., toilet, kitchen sink, and so on.) to the end of the pipe before discharge into the recipient system. In practical planning it is also imperative to consider the interactions between the technical sanitation system and surrounding systems and stakeholders. When designing and assessing the impact of a technical system on users, people living nearby and people yet not born, economy, institutional capacity, as well as agriculture and the recipients must be considered. A conceptual sketch of the sanitation system is given in Figure 2.5.

The technical system does not necessarily mean a facility "of steel and concrete". Natural systems (outdoor systems) can also be used for treatment. Espe-

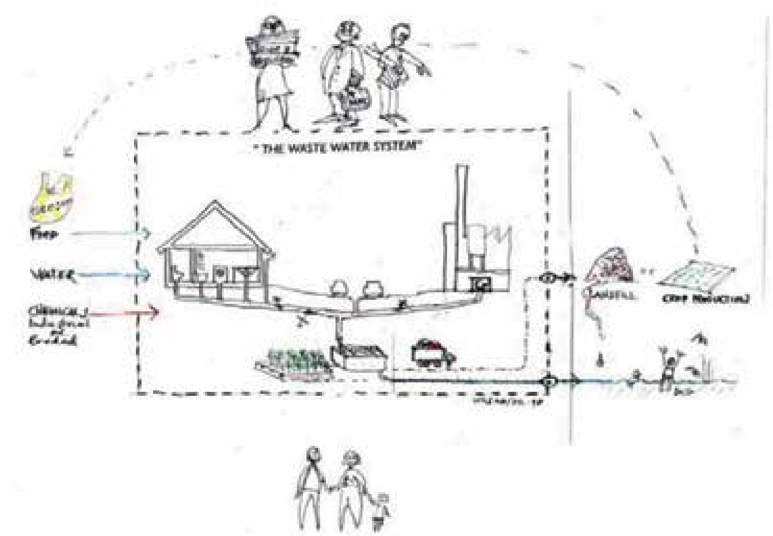

Figure 2.5 A conceptual sketch of the sanitation system.

cially in rural areas, irrigation systems, soil and sand filters systems or constructed wetland systems are appropriate for wastewater treatment. The requirements set up for the sanitation system can be achieved by measures all the way from the point of origin to the recipient. Therefore, it is important to be aware of the inlet point as well as the outlet point of the system. In the planning process it is necessary to decide for example, if the system starts inside the house or at the garden edge, how many houses that should be included into the system and if the end of the system must be at a point where all treated water can be measured or if the system can be extended to include for example, part of a field for crop production. In the latter case the performance of system cannot be measured by traditional water sampling. Clearly defined system boundaries are necessary for making comparisons of different sanitation solutions, and to assess sustainability of the system.

It is important to be aware of the whole system and to consider that what "goes in goes out". Thus the quality of treated wastewater and rest products (such as faeces, urine or sludge) depends very much on the inputs. For example, if toxic compounds and heavy metals are outgoing water or in the rest products. A "system approach" on sanitation thus means that precautionary actions (source control) should always be considered, for example, separation of toilet waste and grey water or reduction of phosphorous in household detergents. To facilitate treatment and recycling, storm water and industrial wastewater should always be kept separate from the household sanitation system.

2.4 Ecological sanitation

Ecological sanitation is a philosophy of dealing with what is presently regarded as waste and wastewater for disposal. Ecological sanitation applies the basic natural principal of closing the loop by using modern and safe sanitation and reuse technologies. It employs up a wide range of sanitation options. Two principles are often applied in eco-sanitation systems: (1) flow streams with different characteristics are often collected separately, (2) the unnecessary dilution of the flow streams is usually avoided. Comparison of basic sanitation, ecological sanitation and environmental sanitation is graphically explained on Figure 2.6

Sanitation systems have to deal with the management of urine, faeces (toilet waste) and grey water (water used for bathing, washing, and so on), either separately or mixed (Figure 2.7). These different fractions have different characteristics, both in terms of content of pollutants and in terms of volumes. The main characteristics of urine, faeces and grey water; the impacts of different pollutants and possible remediation measures are given on Figure 2.8 and Table 2.1.

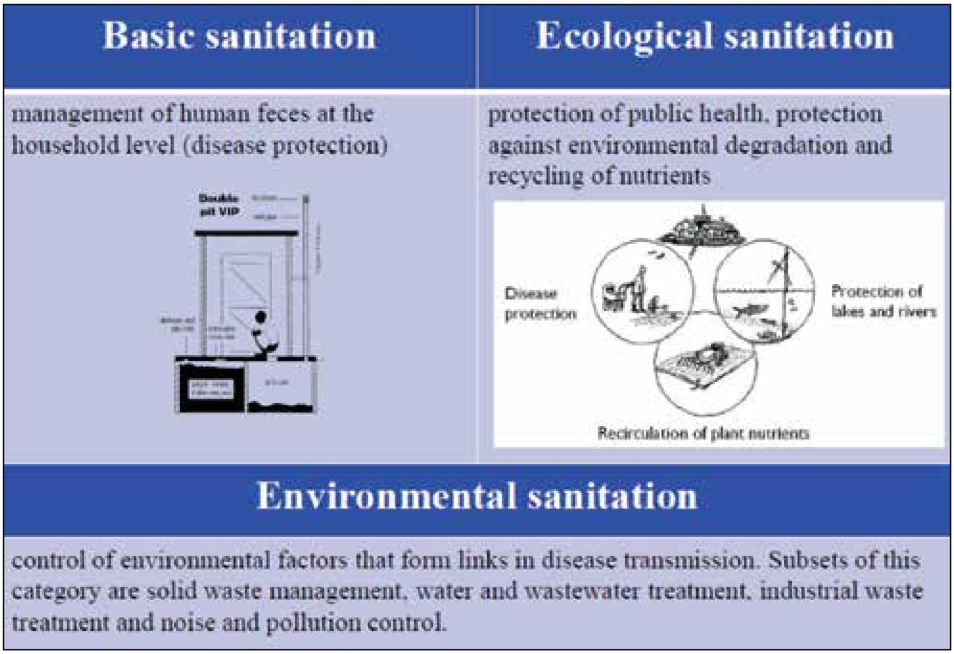

Figure 2.6 Basic, ecological and environmental sanitation.

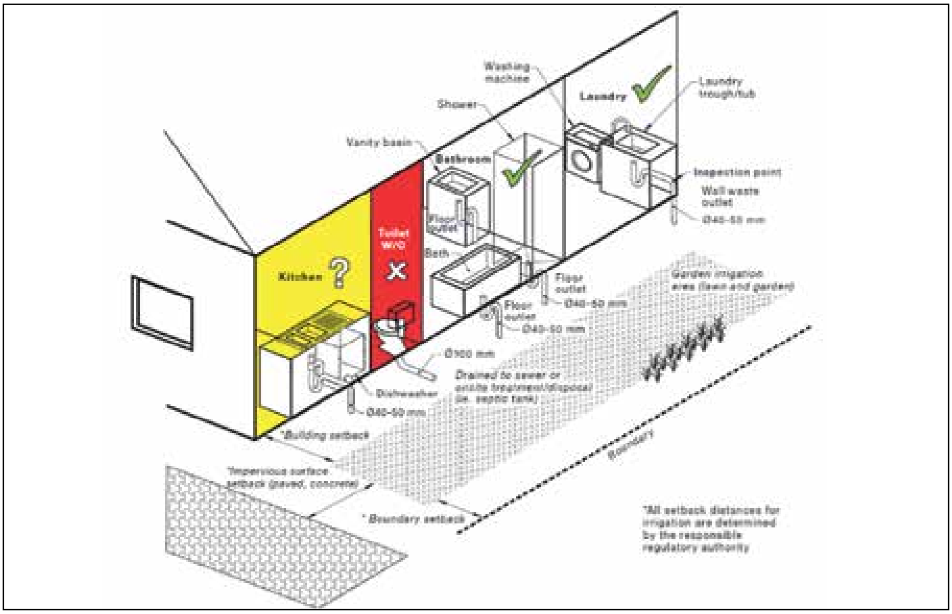

Figure 2.7 Potential greywater drainage access points for a single household [http://www.ironbarkarchitecture.com.au/blog/2015/6/11/water-talk-part-ii\]

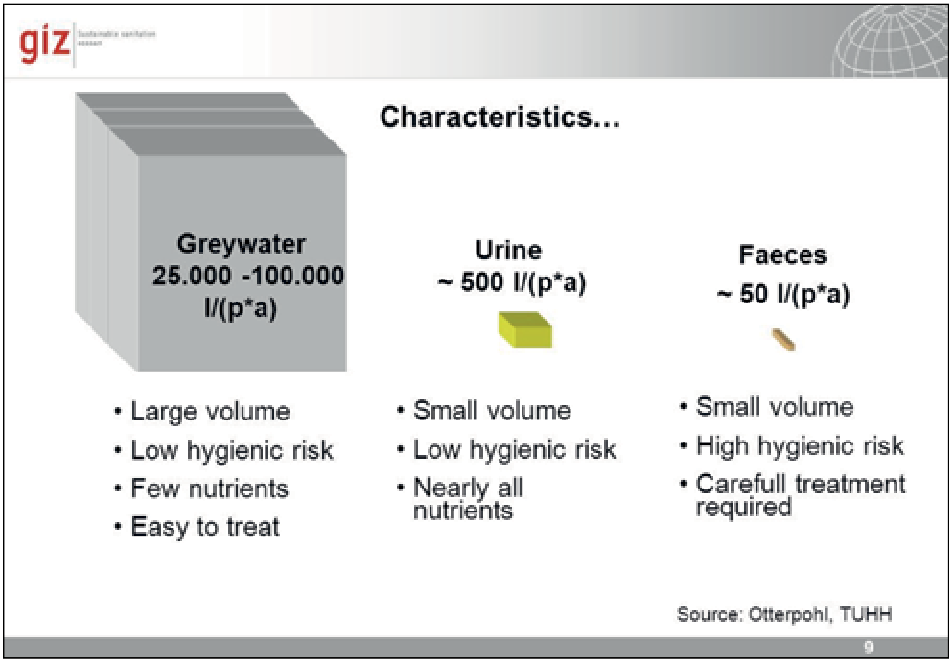

Figure 2.8. Greywater, urine and faeces characteristics [http://slideplayer.com/slide/1189/]

As Table 2.1 shows, there are many ways of achieving the primary functions when considering the whole technical system from the source to the discharge into the recipient. The figures in the table can be used for approximate calculations of nutrient and water loads for initial planning purposes. (For design and dimensioning of technical components, more accurate calculations should be made).

2.5 Protection of public health

Wastewater is a main pathway for spreading diseases in the world. The health risk depends mainly on the content of pathogens (disease-transmitting organisms) and is a function of faecal contamination. Urine and grey water usually does not contain high concentrations of pathogens, but may have small amounts as a result of faecal cross-contamination. Thus, to prevent the spreading of diseases it is necessary to prevent the exposure of faeces to humans. All exposure routes have to be considered, from the user of the system to the handling of the rest of the products and the discharge of treated wastewater. Possible exposure routes are given in Table 2.2.

Table 2.1 Content in different household wastewater fractions, the environmental impact and means for pollution/impact control

Substance	Content in different fractions			Impact	Means for control
	Faeces	Urine	Greywater		
Water, l/pers,d (flush water incl.)	4-10	20-40	80-200	• Scarcity in some places • Heat losses when discharged • Investment in treatment • Logging of ground and building	Behaviour Fee system Water saving equipment
	Mean all together: New houses: 150 Old houses: 180				
Pathogens	High	Very Low	Low	Infections	• Do not mix faeces in water. • Hygienic handling of faeces, e. g by disinfecting by composting • Treatment of water in aerobic biological filters, e.g. trickling filters or vertical sandfilters • Minimise risk for exposure
Organic matter (BOD) kg/pers.year	5,5	2	10	Oxygen depletion may cause Odour and Toxic water Fat, oil and growth of bacteria's may cause blockage in pipes, soil pores etc.	• Removal by flotation and sedimentation • Aerobic mineralization, e.g. vertical sandfilter • Anaerobic mineralization, e.g. Imhoff tank or constructed wetland
	Feaces + urine = 7,5				
Phosphorous kg/pers.year	0,2	0,4	0,05-0,3*	Eutrophication Limited resource	• Reduce P in detergents • Separate treatment of urine or blackwater • Chemical precipitation • Sorption in soil or reactive filter • Uptake in bacteria, green plants
	Mean all together: 0,8				
Nitrogen kg/pers.year	0,5	4	0,5	• Eutrophication (in sea) • Oxygen consuming in water • Energy consuming when produced	• Separate handling of urine or blackwater • Treatment in aerobic/ anaerobic biological filters • Uptake in bacteria or green plants
	Mean all together: 5,0				
Heavy metals	present	negligible	present	Toxic for humans treatment system and for the ecosystem	Prevention at source e.g by information and prohibition
Organic toxic compounds	negligible	negligible	present	Toxic for humans, treatment system and for the ecosystem	Prevention at source e.g by information and prohibition Treatment in aerobic biological filters
Pharmaceutical residues/ hormones	present	present	negligible	Toxic for aquatic organisms	Microbial degradation in the topsoil

Table 2.2 Possible exposure of faeces in different parts of the sanitation system and when using end-products in agriculture.

Part of system	Possible exposure
Toilet	• during and after use • during cleaning
Treatment system	• during maintenance • in case of process failure • direct contact with treatment process
Discharge	• contact with treated water • using contaminated groundwater as drinkingwater source • contact with contaminated insects or wild animals
Handling of rest products	• emptying of collected restproducts
Use of end-products	• application on arable land • consumption of e.g. vegetables fertilised with wastewater

Although infectious diseases are the main health risks associated with sanitation, other compounds present in wastewater can also be hazardous for the health. Nitrates, for example, if leaked into groundwater that is used as drinking water, can cause health problems for small children (sometimes referred to as the Blue Baby Syndrome). Wastewater may also contain toxic compounds that pose health risks, for example, heavy metals, antibiotics (medicines) phthalates and phenols. Treatment processes generally are not designed to remove these compounds and the best way to reduce the content in wastewater is to reduce them at the source, for example, by reducing the amount of chemicals used in households.

2.6 Recycling

In principal, all nutrients we consume are excreted. Beside the macro-nutrients like phosphorous, nitrogen, potassium and sulphur there are also about twenty other micro-nutrients present in toilet waste essential for plant growth (Figure 2.9). Crop production usually benefits by adding nitrogen but also other elements may limit production, especially in soils cultivated for long time. Aquatic plant growth life is normally regulated by phosphorous and sometimes nitrogen. If these nutrients are discharged into water bodies they cause eutrophication and therefore, the traditional wastewater strategy has been to remove nutrients that fertilise water. However, a sustainable solution means that removed nutrients must be reused. Simply dumping removed nutrients in sludge is an expensive way of moving the eutrophication problem to the future and to other places. To make both wastewater treatment and agriculture long-term sustainable, all the nutrients in toilet waste should be reused in agriculture. Unfortunately the mod-

Figure 2.9. It is necessary to circulate the plant nutrients back to agricultural land. Sustainability is crucial, and reuse of phosphorus, nitrogen and organic matter is an important step in right direction (http://www.slideshare.net/SIANIAgri/blackwater-treatment-and-reuse-in-practice-in-sdertlje-sweden)

ern agro-society system is a more like linear nutrient flow system from fossil recourses to deposits in recipients (Figure 2.10).

In areas with water scarcity, the recycling of water may also be an important function of the sanitation system. Agriculture consumes very large amounts of freshwater, and the recycling of wastewater through irrigation reduces the pressure on drinking water sources. Solving one problem should not create new problems, and therefore, nutrient recycling should be performed in an appropriate way. There are some risks associated with recycling of toilet waste and wastewater, including faecal contamination (transmission of infectious diseases), increased salinity of soils (for wastewater irrigation, in semi-arid or arid climates) and increased content of heavy metals or other toxic compounds in soils and on crops. However, the risks can be very well managed.

Hygienically safe and efficient methods for the application of toilet waste to arable land have been developed. The World Health Organization has published guidelines for the safe use of wastewater, excreta and grey water. According to the World Health Organization, “the direct use of excreta and grey water on arable land tends to minimize the environmental impact in both the local and global context”.

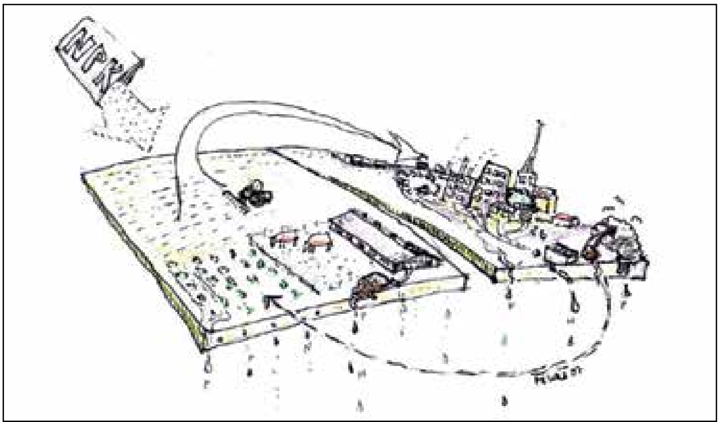

Figure 2.10. Closing the loop between agriculture and the city

Step 1: Problem identification

This step focuses on the causes of the problem and recommends a participatory approach to problem identification . Hence, also the identification of stakeholder groups and their roles. The process can then be performed using participatory methods such as the Logical Framework Approach (LFA) or Participatory Hygiene and Sanitation Transformation (PHAST).

Step 2: Identification of boundary conditions

Step two delineates the scope of the problem and hence the range of action for solutions. Identification of the boundary conditions should define the technical limits of the sanitation system (community served, water supply, recycling to agriculture), but also potentially limiting socio-economic patterns, natural environments, and political conditions. An analysis of SWOT (Strengths, Weaknesses, Opportunities and Threats) is here a useful exercise.

Step 3: Terms of requirement (TOR)

The TOR for assessing sanitation alternatives are usually set through a participatory process with stakeholders and local governments. The requirements can be divided into two groups: primary functions and practical considerations. The primary functions include regulation compliance for health, water, and natural resource protection. The practical considerations are more geared towards user concerns and include costs, technical reliability, user satisfaction, and management issues.

Step 4: Analysis of possible solutions

The analysis of possible solutions is based on how well potential technologies meet the Terms of Requirement (TOR). Options should be evaluated against the TOR and at least three possible options should be selected for the presentation to the community in the following step. A matrix scoring exercise can be useful here.

Step 5: Choice of most appropriate solution

The results of the analysis in step 4 are presented to the stakeholders. The differences how each system fulfils the TOR are clearly explained. The final selection of the most appropriate solution is done by the future users of the sanitation system.

Figure 2.11 Steps of open planning of sanitation systems

Table 2.3 Technical options for different functions of wastewater treatment

	"Conventional" treatment technology (intensive/indoor)	Natural treatment technology (extensive/outdoor)
Pretreatment – removal of suspended solids	Screens Grids Sieves Pre-sedimentation tanks	Sedimentation ponds Septic tanks Mulch filter (a living soil)
Removal of BOD (secondary treatment)	Trickling filters Biorotors Activated sludge	Stabilization ponds (Dry) wetlands Vertical soil filters (infiltration, sandfilters) Irrigation
Removal of phosphorous (tertiary treament)	Chemical precipitation in wastewater treatmebntplants. Bio-P Osmotic filters	Precipitation ponds Infiltration Reactive filters (horisontal filters) Irrigation
Removal of nitrogen (advanced treatment)	Nitrification + denitrification in wastewater treatment plant. Struvite precipitation Ammoniac stripping	Nitrification + denitrification in dry+ wet wetlands, or sandfilter + wet wetland
Sludge management (dewatering, stabilisation, hygienisation)	"Thickeners" Sieves Centrifuges Fermentation (composting, lime-stabilisation	Drainage beds Biological drainage beds (Reed beds) Long time storage Composting Lime-stabilisation Nitrogen-hygienisation

2.7 Screening of technical options and planning the sanitation systems

When choosing a sanitation system, the focus should be on the function of the system, that is, performance regarding primary functions as well as practical considerations (Figure 2.11). Technology is a means of achieving these goals and not a goal in itself. It is important that user and institutional capacity is compatible with the technical system. The technical solution for the sanitation system is chosen from desired performance and from local conditions. Thus, technology used in different situations will differ. Both conventional and ecological technologies may be relevant and should be considered and evaluated in a planning situation. An overview of different technologies for sanitation/wastewater management is given in Table 2.3.

Chapter 2 sources:

Sustainable Sanitation in Central and Eastern Europe – addressing the needs of small and medium-size settlements edited by Igor Bodík and Peter Ridderstolpe Global Water Partnership contribution to International

Year of Sanitation 2008, Global Water Partnership Central and Eastern Europe, 2007 ISBN 978-80-969745-0-4

Investing in Water and Sanitation: Increasing Access, Reducing Inequalities. GLAAS 2014 Report. UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water. Progress on Sanitation and Drinking Water. 2010 UPDATE

The Challenge of Extending and Sustaining Services. GLAAS 2012 Report. UN-Water Global Analysis and Assessment of Sanitation and Drinking-Water

Sustainable Sanitation in Cities. A framework for action targeting the Poor – Facilities and Improved Services by Barbara Evans and Sophie Tremolet. Session 2 in KfW

Water Symposium 2009 Financing Sanitation "Improving Hygiene awareness and sanitation" Frankfurt, 8-9 October 2009 Edited by Doris Kohn and Dr. Verena Pleiffer. 2010 KfW Development Bank

Recommended reading:

Guidelines for the safe use of wastewater, excreta and grey water
www.who.int/water_sanitation_health/wastewater/gsuww/en

Recommended watching:

Construction of Ecosan urine diverting toilet: www.youtube.com/watch?v=zwmt6pB3lcs
Urban Ecological Sanitation with Nik Bertulis https://www.youtube.com/watch?v=IHiM7QK2G0Y
Terra Preta Sanitation series:

1. Overview https://www.youtube.com/watch?v=E-iO6Tw3UUM
2. Terra Preta toilet development https://www.youtube.com/watch?v=AWIGQ3r4vUw
3. Fermentation https://www.youtube.com/watch?v=fTrR-ZWVGBQ
4. Composting https://www.youtube.com/watch?v=n2zKvvI2Gak
5. Charcoal production in woodgas stoves https://www.youtube.com/watch?v=i13_kzJU4qg
6. Highly productive organic farming https://www.youtube.com/watch?v=pSShndKiA3g
7. Pit latrines and sanitation in Ethiopia https://www.youtube.com/watch?v=wN1GN5Iahuc
8. Problems with artificial fertilizer https://www.youtube.com/watch?v=vb9P-8b1SvI
9. Conventional cooking https://www.youtube.com/watch?v=xRHvRKKIci8
10. Ecosan and urine diversion toilets https://www.youtube.com/watch?v=JwCMOtHHT5M
11. Building an arbor loo https://www.youtube.com/watch?v=jUSiiXPVYaw
12. Bamboo for grey water treatment https://www.youtube.com/watch?v=HNJUyTbCNjI
13. Seminar lecture https://www.youtube.com/watch?v=d0AIKsKXys0
14. Who is who https://www.youtube.com/watch?v=WohruCV-zoI

Chapter 3
Local (Household level) Sanitation Systems

3.1 The Single Pit system

A system template defines a suite of compatible and proven technology combinations from which a sanitation system can be designed. The system templates can be used to identify and display complete systems which take into account the management of all product flows between user interface and use or disposal, and to compare the different options that are available in specific contexts.

The single pit is one of the most widely used sanitation technologies. This system is based on the use of a single pit technology to collect and store excreta. The system can be used with or without flush water. Inputs to the system can include urine, faeces, anal cleansing water, flush water and dry cleansing materials. The use of flush water and/or anal cleansing water will depend on water availability and local habit.

When the pit is full there are several options. If there is space, the pit can be filled with soil and a fruit or ornamental tree can be planted, which will thrive in the nutrient rich environment, and a new pit built. Alternatively, the faecal sludge that is generated from the collection and storage/treatment technology has to be removed and transported for further treatment. As the untreated faecal sludge is highly pathogenic, human contact and direct agricultural application should be

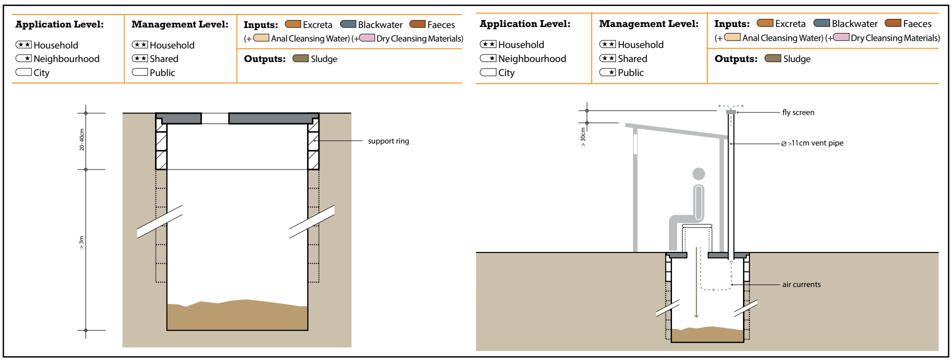

Figure 3.1. Single pit (left) and single ventilated improved pit (right). Source: Tilley et al.

avoided. The sludge that is removed should be transported to a dedicated faecal sludge treatment facility.

Appropriateness: treatment processes in a single pit (aerobic, anaerobic, dehydration, composting or otherwise) are limited and, therefore, pathogen reduction and organic degradation is not significant. However, since the excreta are contained, pathogen transmission to the user is limited. Single pits are appropriate for rural and peri-urban (surrounding the city) areas; in densely populated areas they are often difficult to empty and/or have insufficient space for infiltration. Single pits are especially appropriate when water is scarce and where there is a low groundwater table. They are not suited for rocky or compacted soils (which are difficult to dig), or for areas that flood frequently.

Considerations: this system should be chosen only where there is either enough space to continuously dig new pits or when there is an appropriate way to empty, treat and dispose of the faecal Sludge. In dense urban settlements, there may not be sufficient space to access a pit for desludging or to make a new pit. This system is, therefore, best suited to rural and peri-urban areas where the soil is appropriate for digging pits and absorbing the leachate. It is not recommended for areas prone to heavy rains or flooding, which may cause pits to overflow.

Some grey water in the pit may help degradation, but excessive amounts of grey water may lead to quick filling of the pit and/or excessive leaching. All types of dry cleansing materials can be discarded into the pit, although they may shorten the pit life and make it more difficult to empty. Whenever possible, dry cleansing materials should be disposed of separately. This system is one of the least expensive to construct in terms of capital cost. However, the maintenance costs may be considerable, depending on the frequency and method of pit emptying.

If the ground is appropriate and has good absorptive capacity, the pit may be dug very deep (> 5m) and can be used for several years without emptying (up to 20 or more years). However, the groundwater level and use should be taken into consideration when digging pits in order to avoid contaminating it. Although different types of pits are common in most parts of the world, a well-designed pit-based system with appropriate transport, treatment and use or disposal is rare.

Design Considerations: on average, solids accumulate at a rate of 40 to 60 L per person/year and up to 90 L per person/year if dry cleansing materials such as leaves or paper are used. The volume of the pit should be designed to contain at least 1,000 L. Typically, the pit is at least 3 m deep and 1 m in diameter. If the pit diameter exceeds 1.5 m, there is an increased risk of collapse. Depending on how deep they are dug, some pits may last 20 or more years without emptying.

To prevent groundwater contamination, the bottom of the pit should be at least 2 m above groundwater level (rule of thumb). If the pit is to be reused, it should be lined. Pit lining materials can include brick, rot-resistant timber, concrete, stones, or mortar plastered onto the soil. If the soil is stable (i.e., no presence of sand or gravel deposits or loose organic materials), the whole pit need not be lined. The bottom of the pit should remain unlined to allow for the infiltration of liquids out of the pit. As liquid leaches from the pit and migrates through the unsaturated soil matrix, pathogenic germs are adsorbed to the soil surface. In this way, pathogens can be removed prior to contact with groundwater. The degree of removal varies with soil type, distance travelled, moisture and other environmental factors and, thus, it is difficult to estimate the distance necessary between a pit and a water source. A minimum horizontal distance of 30 m is normally recommended to limit exposure to microbial contamination.

When it is not possible to dig a deep pit or the groundwater level is too high, a raised pit can be a viable alternative: the shallow pit can be extended by building the pit upwards with the use of concrete rings or blocks. A raised pit can also be constructed in an area where flooding is frequent in order to keep water from flowing into the pit during heavy rain.

Another variation is the unlined shallow pit that may be appropriate for areas where digging is difficult. When the shallow pit is full, it can be covered with leaves and soil, and a small tree can be planted. A ventilated improved pit is slightly more expensive than a single pit, but greatly reduces the nuisance of flies and odours, while increasing comfort. If a urine-diverting user interface is used, only faeces are collected in the pit and leaching can be minimized.

Operation & Maintenance: there is no daily maintenance associated with a single pit apart from keeping the facility clean. However, when the pit is full it can be a) pumped out and reused or b) the superstructure and squatting plate can be moved to a new pit and the previous pit covered and decommissioned, which is only advisable if plenty of land area is available.

Pros & Cons

+ Can be built and repaired with locally available materials
+ Low (but variable) capital costs depending on material and pit depth
+ Small land area required
- Flies and odours are normally noticeable
- Low reduction in BOD and pathogens with possible contamination of groundwater
- Costs to empty may be significant compared to capital costs
- Sludge requires secondary treatment and/or appropriate discharge

Application Level:	Management Level:	Inputs: Excreta, Faeces (+ Anal Cleansing Water) (+ Dry Cleansing Materials)
★★ Household	★★ Household	**Outputs:** Pit Humus
★ Neighbourhood	★★ Shared	
City	★ Public	

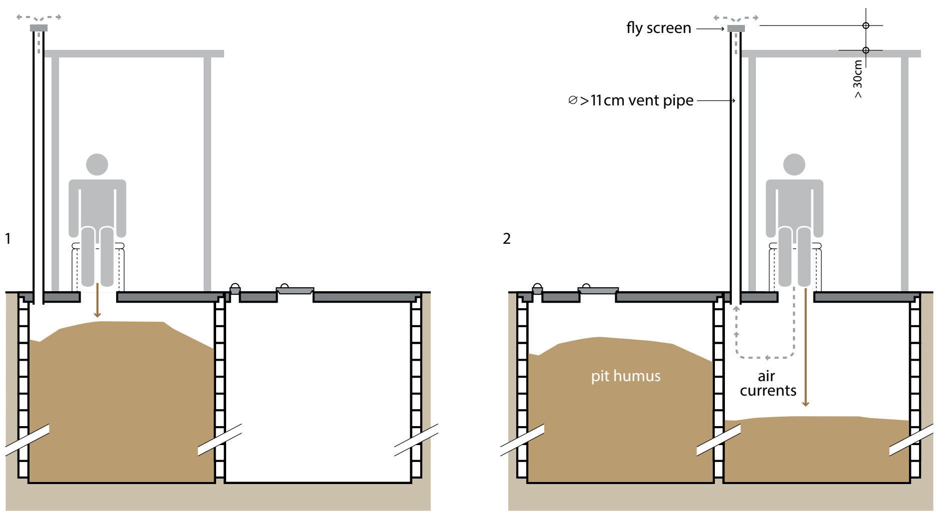

Figure 3.2. Double ventilated improved pit (Source: Tilley et al).

3.2 Waterless pit system without sludge production

This system is designed to produce a solid, soil-like material by using alternating pits or a composting chamber. Inputs to the system can include urine, faeces, organics, anal cleansing water, and dry cleansing materials. There is no use of flush water.

A dry toilet is recommended for this system, although a urine-diverting dry toilet or a urinal could also be used if the urine is highly valued for application. A dry toilet does not require water to function and in fact, water should not be put into this system; anal cleansing water should be kept at a minimum or even excluded if possible. Two alternating pits, give the material an opportunity to drain, degrade, and transform into pit humus (sometimes also called EcoHumus), a nutrient-rich, hygienically improved, humic material which is safe to excavate.

When the first pit is full, it is covered and temporarily taken out of service. While the other pit is filling with excreta (and potentially organics), the content of the first pit is allowed to rest and degrade. Only when both pits are full is the first pit emptied and put back into service. This cycle can be indefinitely repeated.

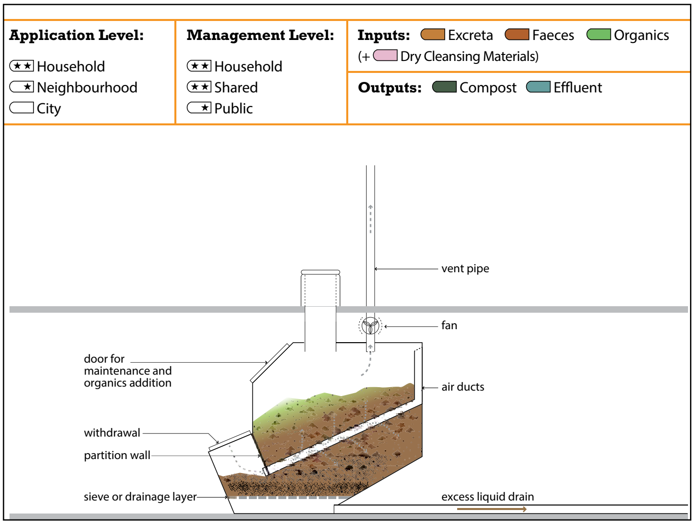

Figure 3.3. Composting Chamber (Source: Tilley et al).

As the excreta in the resting pit is draining and degrading for at least one year, the resulting pit humus needs to be manually removed using shovels, and vacuum truck access to the pits is not necessary.

A composting chamber is not strictly a pit technology, but it can also have alternating chambers and, if properly operated, produces safe, useable compost.

The pit humus or compost can be removed and transported for use and/or disposal manually. Since it has undergone significant degradation, the humic material is quite safe to handle and use as soil conditioner in agriculture. If there are concerns about the quality of the pit humus or compost, it can be further composted in a dedicated composting facility before it is used. This system is different from single pit system regarding the product generated at collection and storage/treatment level. In the previous system, the sludge required further treatment before it could be used, whereas the pit humus and compost produced in this system are ready for use and/or disposal.

Appropriateness: The double pit is more appropriate than the single pit for denser, peri-urban areas. After the resting time, the soil-like material is manually emptied (it is dug out, not pumped out), so vacuum truck access to the pits is not necessary. The double pit technology will only work properly if the two pits are used sequentially and not concurrently. Therefore, an adequate cover for the out of service pit is required. Double pits are especially appropriate when water is scarce and where there is a low groundwater table. They should be located in an area with a good breeze to allow for proper ventilation. They are not suited for rocky or compacted soils (that are difficult to dig) or for areas that flood frequently.

Considerations: because the system is permanent and can be indefinitely used it can be used where space is limited. Additionally, because the product must be manually removed, this system is suitable for dense areas that cannot be served by trucks for mechanical emptying. This system is especially appropriate for water-scarce areas and where there is an opportunity to use the humic product as soil conditioner. The material that is removed should be in a safe, useable form, although proper personal protection should be used during removal, transport and use.

The success of this system depends on proper operation and an extended storage period. If a suitable and continuous source of soil, ash or organics (leaves, grass clippings, coconut or rice husks, woodchips, etc.) is available, the decomposition process is enhanced and the storage period can be reduced. The required storage time can be minimized if the material in the pit remains well aerated and not too moist. Therefore, the grey water must be collected and treated separately. Too much moisture in the pit will fill the air voids and deprive the microorganisms of oxygen, which may impair the degradation process. Dry cleansing materials can usually be collected in the pit or chamber together with the excreta, especially if they are carbon-rich (e.g., toilet paper, newsprint, corncobs, etc.) as this may help degradation and air flow. Guidelines for the safe use of Excreta have been published by the World Health Organization (WHO) and are referenced on the relevant technology information sheets.

Design Considerations: The superstructure may either extend over both holes or it may be designed to move from one pit to the other. In either case, the pit that is not being filled should be fully covered and sealed to prevent water, garbage and animals, or people from falling into the pit. The ventilation of the two pits can be accomplished using one ventilation pipe moved back and forth between the pits, or each pit can be equipped with its own dedicated pipe. The two pits in the double pit are continually used and should be well lined and supported to ensure longevity.

A composting chamber can be designed in various configurations and constructed above or below ground, indoors or with a separate superstructure. A design value of 300 L/person/year can be used to calculate the required chamber volume. Ventilation channels (air ducts) under the heap can be beneficial for aeration.

More complex designs can include a small ventilation fan, a mechanical mixer, or multiple compartments to allow for increased storage and degradation time. A sloped bottom and a chamber for compost withdrawal facilitate access to the final product. A drainage system is important to ensure the removal of leachate. Excessive ammonia from urine inhibits the microbial processes in the chamber. The use of a urine-diverting dry toilet can, therefore, improve the quality of the compost.

Operation & Maintenance: to keep the double pit free of flies and odours, regular cleaning and maintenance is required. Dead flies, spider webs, dust and other debris should be removed from the ventilation screen to ensure a good flow of air. The out of service pit should be well sealed to reduce water infiltration and a proper alternating schedule must be maintained.

Although simple in theory, composting chambers are not that easy to operate. The moisture must be controlled, the C:N ratio must be well balanced and the volume of the unit must be such that the temperature of the compost pile remains high to achieve pathogen reduction. After each defecation, a small amount of bulking material is added to absorb excess liquid, improve the aeration of the pile and balance the carbon availability. Turning the material from time to time will boost the oxygen supply.

A squeeze test can be made to check the moisture level within the chamber. When squeezing a handful of compost, it should not crumble or feel dry, nor should it feel like a wet sponge. Rather, the compost should leave only a few drops of water in one's hand. If the material in the chamber becomes too compact and humid, additional bulking material should be added. If a UDDT is used, some water should be added to obtain the required humidity. Depending on the design, the composting chamber should be emptied every 2 to 10 years.

Only the mature compost should be removed. The material may require further treatment to become hygienically safe (e.g. co-composting). With time, salt or other solids may build up in the tank or drainage system. These can be dissolved with hot water and/or scraped out.

Pros & Cons Double ventilated improved pit

\+ Longer life than Single VIP (indefinite if maintained properly)
\+ Excavation of humus is easier than faecal sludge
\+ Significant reduction in pathogens
\+ Potential for use of stored faecal material as soil conditioner
\+ Flies and odours are significantly reduced (compared to non-ventilated pits)
\+ Can be built and repaired with locally available materials
\- Manual removal of humus is required
\- Possible contamination of groundwater
\- Higher capital costs than Single VIP; but reduced operating costs if self-emptied

Pros & Cons Composting Chamber

- \+ Significant reduction in pathogens
- \+ Compost can be used as a soil conditioner
- \+ No real problems with flies or odours if used and maintained correctly
- \+ Organic solid waste can be managed concurrently
- \+ Long service life
- \+ Low operating costs if self-emptied
- \- Requires well-trained user or service personnel for monitoring and main tenance
- \- Compost might require further treatment before use
- \- Leachate requires treatment and/or appropriate discharge
- \- Requires expert design and construction
- \- May require some specialized parts and electricity
- \- Requires constant source of organics
- \- Manual removal of compost is required

3.3 Pour flush pit system without sludge production

This is a water-based system utilizing the pour flush toilet and twin pits to produce a partially digested, humus-like product, which can be used as a soil amendment. Inputs to the system can include faeces, urine, flush water, anal cleansing water, dry cleansing materials and grey water. The black water output and possibly grey water is discharged into twin pits for pour flush for collection and storage/treatment. The Twin Pits are lined with a porous material, allowing the liquid to infiltrate into the ground while solids accumulate and degrade at the bottom of the pit. While one pit is filling with black water, the other pit remains out of service.

When the first pit is full, it is covered and temporarily taken out of service. It should take a minimum of two years to fill a pit. When the second pit is full, the first pit is re-opened and emptied. After a resting time of at least two years, the content is transformed into pit humus, a nutrient-rich, hygienically improved, humic material which is safe to excavate. Since it has undergone significant dewatering and degradation, pit humus is much more hygienic than raw, undigested sludge. Therefore, it does not require further treatment in a (semi-) centralized treatment facility. The pit humus is removed using a human-powered emptying and transport technology and transported for use and/or disposal. The emptied pit is then put back into operation. This cycle can be indefinitely repeated.

Appropriateness: Twin pits for pour flush are a permanent technology appropriate for areas where it is not possible to continuously build new pit latrines. As

Application Level:	Management Level:	Inputs: Blackwater (Greywater)
★★ Household	★★ Household	Outputs: Pit Humus
★ Neighbourhood	★★ Shared	
City	★ Public	

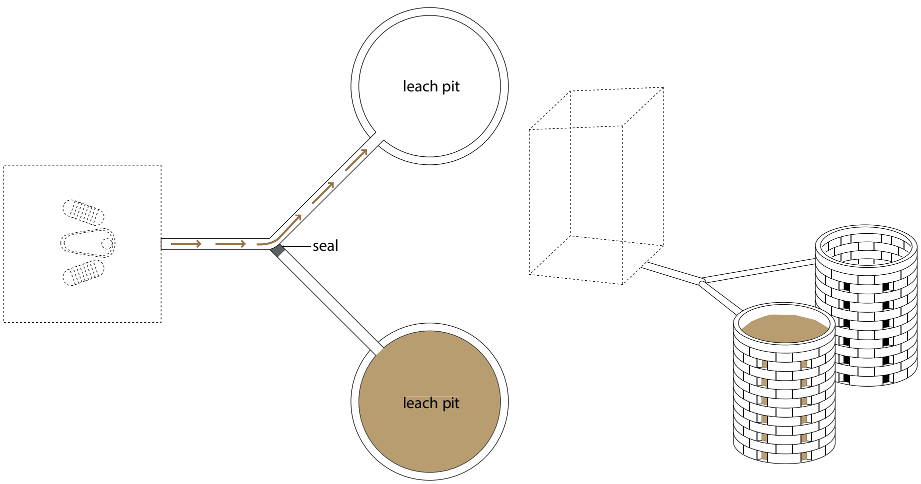

Figure 3.4. Twin Pits for Pour Flush (Source: Tilley et al).

long as water is available, this technology is appropriate for almost every type of housing density. However, too many wet pits in a small area is not recommended as the soil matrix may not be of sufficient capacity to absorb all the liquid and the ground could become water-logged (oversaturated). In order for the pits to drain properly, the soil must have a good absorptive capacity; clay, tightly packed or rocky soils are not appropriate. This technology is not suitable for areas with a high groundwater table or where there is frequent flooding. Grey water can be co-managed along with the black water in the twin pits, especially if the grey water quantities are relatively small, and no other management system is in place to control it. However, large quantities of flush water and/or grey water may result in excessive leaching from the pit and possibly groundwater contamination. The dewatered, solid material is manually emptied from the pits (it is dug, not pumped out), therefore, space is not required for vacuum trucks to access them.

Considerations: this system is suited to rural and peri-urban areas with appropriate soil that can continually and adequately absorb the leachate. It is not appropriate for areas with clayey or densely packed soil. As leachate from twin pits directly infiltrates the surrounding soil, this system should only be installed where there is a low groundwater table that is not at risk of being contaminated from the pits.

If there is frequent flooding or the groundwater table is too high and enters the twin pits, the dewatering process, particularly, in the resting pit, will be hindered. The material that is removed should be in a safe, useable form, although proper personal protection should be used during removal, transport and use. Grey water can be co-managed along with the black water in the twin pits, especially if the grey water quantities are relatively small, and no other management system is in place to control it. However, large quantities of flush water and/or grey water may result in excessive leaching from the pit and possibly groundwater contamination.

Grey water can be co-managed along with the black water in the twin pits, especially if the grey water quantities are relatively small, and no other management system is in place to control it. However, large quantities of flush water and/or grey water may result in excessive leaching from the pit and possibly groundwater contamination. This system is well-suited for anal cleansing with water. If possible, dry cleansing materials should be collected and disposed of separately because they may clog the pipe fittings and prevent the liquid inside the pit from infiltrating into the soil.

Design Considerations: The pits should be of an adequate size to accommodate a volume of waste generated over one or two years. This allows the contents of the full pit enough time to transform into a partially sanitized, soil-like material that can be manually excavated. It is recommended that the twin pits be constructed 1 m apart from each other to minimize cross-contamination between the maturing pit and the one in use. It is also recommended that the pits be constructed over 1 m from any structural foundation as leachate can negatively impact structural supports. Water within the pit can impact its stability. Therefore, the full depth of the pit walls should be lined to prevent collapse and the top 30 m should be fully mortared to prevent direct infiltration and to support the superstructure.

There is a risk of groundwater pollution when pits are located in areas with a high or variable water table, and/or fissures or cracks in the bedrock. As soil and groundwater properties are often unknown, it is difficult to estimate the distance necessary between a pit and a water source. It is normally recommended to have a minimum horizontal distance of 30 m between them to limit exposing the water source to microbial contamination. To ensure that only one of the two pits is used at any time, the idle pipe of the junction connecting to the out-of-use pit should be closed (e.g. with cement or bricks). Alternatively, the pour flush toilet could also be directly connected to the pit in use by a single straight pipe fixed in place with light mortar and covered with earth. The risk of failure and misuse is minimized by ensuring that the junction and pipes are not easily accessible.

Operation & Maintenance: The pits must be regularly emptied (after the recommended two year resting time), and care must be taken to ensure that they do not flood during rainy seasons. Emptying is done manually using long handled shovels and proper personal protection.

Pros & Cons

- \+ Because double pits are used alternately, their life is virtually unlimited
- \+ Excavation of humus is easier than faecal sludge
- \+ Significant reduction in pathogens
- \+ Potential for use of stored faecal material as soil conditioner
- \+ Flies and odours are significantly reduced (compared to pits without a water seal)
- \+ Can be built and repaired with locally available materials
- \+ Low (but variable) capital costs depending on materials; no or low oper ating costs if self-emptied
- \+ Small land area required
- \- Manual removal of humus is required
- \- Clogging is frequent when bulky cleansing materials are used
- \- Higher risk of groundwater contamination due to more leachate than with waterless systems

3.4 Waterless system with urine diversion

This system is designed to separate urine and faeces to allow the faeces to dehydrate and/or recover the urine for beneficial use. Inputs to the system can include faeces, urine, anal cleansing water and dry cleansing materials. The main inside technology for this system is the urine-diverting dry toilet, which allows urine and faeces to be separately collected.

Dehydration vaults are used for the collection and storage/treatment of faeces. When storing the faeces in vaults, they should be kept as dry as possible to encourage dehydration and pathogen reduction. Therefore, the chambers should be watertight and care should be taken to ensure that no water is introduced. Anal cleansing water should never be put into dehydration vaults, but it can be diverted and discharged into a soak pit. Also important is a constant supply of ash, lime, soil, or sawdust to cover the faeces. This helps to absorb humidity, minimize odours and provide a barrier between the faeces and potential vectors. If ash or lime are used, the related pH increase will also help to kill pathogenic organisms.

For the collection and storage/treatment of urine, storage tanks are used. Alternatively, urine can also be diverted directly to the ground through an irrigation system or infiltrated through a soak pit. Stored urine can be easily handled and poses little risk because it is nearly sterile. With its high nutrient content it can be used as a good liquid fertilizer. Stored Urine can be transported for application in agriculture. Human-powered emptying and transport is required for the removal and conveyance of the dried faeces generated from the dehydration vaults. The alternating use of double dehydration vaults allows for an extended dehydration period so that the dried faeces pose little human health risk when they are removed. A minimum storage time of 6 months is recommended when ash or lime are used as cover material. The dried faeces can then be applied as soil conditioner.

If there are concerns about the quality of the material, it can be further composted in a dedicated composting facility before it is used.

Appropriateness: dehydration vaults can be installed in almost every setting, from rural to dense urban areas, because of the small land area required, minimal odours and ease of use. If used in an urban context, this technology relies on a transport service for the dried faeces (and urine) since urban users normally do not have an interest and/or opportunity to use it locally. Dehydration vaults are especially appropriate for water-scarce and rocky areas or where the groundwater table is high. They are also suitable in areas that are frequently flooded because they are built to be watertight.

Considerations: this system can be used anywhere, but is especially appropriate for rocky areas where digging is difficult, where there is a high groundwater table, or in water-scarce regions. The success of this system depends on the efficient separation of urine and faeces, as well as the use of a suitable cover material. A dry, hot climate can also considerably contribute to the rapid dehydration of the faeces.

The material that is removed should be in a safe, useable form, although proper personal protection should be used during removal, transport and use. A separate grey water system is required since it should not be introduced into the dehydration vaults. If there is no agricultural need and/or no acceptance of using the urine, it can be directly infiltrated into the soil or into a soak pit. Anal cleansing water must be separated from the faeces, but it can be mixed with the urine if it is transferred to a soak pit. If urine is used in agriculture, anal cleansing water should be kept separate and infiltrated locally or treated along with grey water. Guidelines for the safe use of faeces and urine have been published by the

World Health Organization (WHO) and are referenced on the relevant technology information sheets.

Design Considerations: dehydration vaults can be constructed indoors or with a separate superstructure. A vent pipe is required to remove humidity from the vaults and control flies and odours. The chambers should be airtight for proper functioning of the ventilation. They should be made of sealed brickwork or concrete to ensure that surface runoff cannot enter. The WHO recommends a minimum storage time of 6 months if ash or lime are used as cover material (alkaline treatment), otherwise the storage should be for at least 1 year for warm climates (>20 °C average) and for 1.5 to 2 years for colder climates. In case of alkaline treatment, each vault is sized to accommodate at least 6 months of faeces accumulation. This results in a 6 month storage and dehydration time in the out-of-service vault. The vault dimensions should account for cover material, airflow, the non-even distribution of faeces, and possibly visitors and dry cleansing materials.

It can be assumed that one person will require around 50 L of storage volume every 6 months. A minimum chamber height of 60 to 80 cm is recommended for easy emptying and access to the urine pipes.

Operation & Maintenance: just like the faeces which are dried, but not degraded in the vaults, dry cleansing materials will not decompose in the chambers. Whenever the material is intended to be applied onto fields without further treatment, it is recommended to separately collect and dispose of the dry cleansing materials. Occasionally, the faeces that have accumulated beneath the toilet should be pushed to the sides of the chamber. Care should be taken to ensure that no water or urine gets into the dehydration vault. If this happens, extra ash, lime, soil or sawdust can be added to help absorb the liquid. To empty the vaults, a shovel, gloves and possibly a facemask (cloth) should be used to avoid contact with the dried faeces.

Pros & Cons

+ Because double vaults are used alternately, their life is virtually unlimited
+ Significant reduction in pathogens
+ Potential for use of dried faeces as soil conditioner
+ No real problems with flies or odours if used and maintained correctly (i.e., kept dry)
+ Can be built and repaired with locally available materials
+ Suitable for rocky and/or flood prone areas or where the groundwater table is high
+ Low (but variable) capital costs depending on materials; no or low oper ating costs if self-emptied

Application Level:	Management Level:	Inputs: Faeces (+ Dry Cleansing Materials)
★★ Household ★ Neighbourhood City	★★ Household ★★ Shared ★ Public	Outputs: Dried Faeces

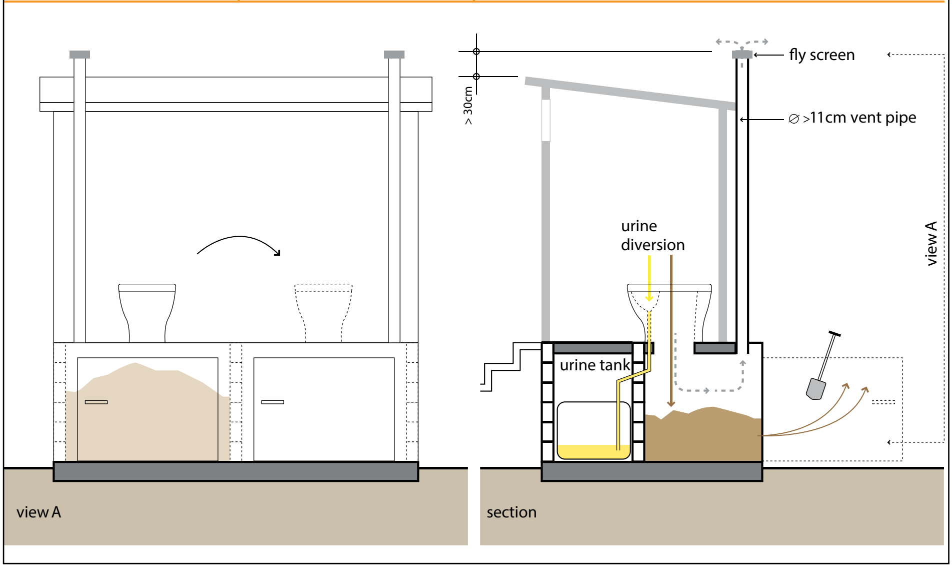

Figure 3.5. Dehydration Vaults (Source: Tilley et al).

- Requires training and acceptance to be used correctly
- Requires constant source of cover material
- Manual removal of dried faeces is required

3.5 Biogas systems

This system is based on the use of a biogas reactor to collect, store and treat the excreta. Additionally, the biogas reactor produces biogas which can be burned for cooking, lighting or electricity generation. Inputs to the system can include urine, faeces, flush water, anal cleansing water, dry cleansing materials, organics (e.g. market or kitchen waste) and, if available, animal waste. This system supports a pour flush toilet or, if there is a demand for the urine to be used in agriculture, a urine-diverting flush toilet. A urinal could additionally be used.

The user interface is directly connected to a biogas reactor (also known as an anaerobic digester) for collection and storage/treatment. If a urine-diverting flush toilet is installed (and/or a urinal), it will be connected to a storage tank for urine collection. Depending on the loading and design of the biogas reactor, a thin or thick digestate (sludge) will be continuously discharged. Because of the high volume and weight of the material generated, the sludge should be used onsite. Although the sludge has undergone anaerobic digestion, it is not pathogen free and should be used with caution, especially if there is no further treatment. Depending on how it is used, additional treatment (e.g., in planted drying beds) may be required before application.

It is nutrient-rich and a good fertilizer that can be applied in agriculture or transported to a surface disposal or storage site. The biogas produced must be constantly used, for example as a clean fuel for cooking or for lighting. If the gas is not burned, it will accumulate in the tank and, with increasing pressure, will push out the digestate until the biogas escapes to the atmosphere through the digestate outlet. A biogas reactor can work with or without urine. The advantage of diverting urine from the reactor is that it can be used separately as a concentrated nutrient source without pathogen contamination. The urine collected in the storage tank is ideally applied on local fields.

Application Level:	**Management Level:**	**Inputs:** Sludge, Blackwater, Brownwater, Organics
★★ Household	★★ Household	**Outputs:** Sludge, Biogas
★★ Neighbourhood	★★ Shared	
★★ City	★★ Public	

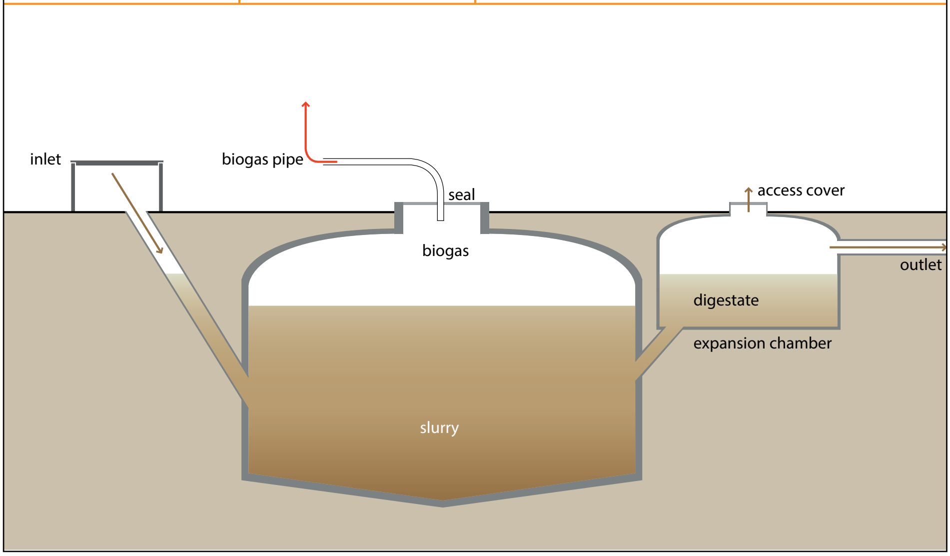

Figure 3.6. Biogas Reactor (Source: Tilley et al)

Appropriateness: this technology can be applied at the household level, in small neighbourhoods or for the stabilization of sludge at large wastewater treatment plants. It is best used where regular feeding is possible. Often, a biogas reactor is used as an alternative to a septic tank, since it offers a similar level of treatment, but with the added benefit of biogas. However, significant gas production cannot be achieved if black water is the only input. The highest levels of biogas production are obtained with concentrated substrates, which are rich in organic material, such as animal manure and organic market or household waste. It can be efficient to co-digest black water from a single household with manure if the latter is the main source of feedstock. Grey water should not be added as it substantially reduces the hydraulic retention time (HRT). Wood material and straw are difficult to degrade and should be avoided in the substrate.

Biogas reactors are less appropriate for colder climates as the rate of organic matter conversion into biogas is very low below 15 °C. Consequently, the HRT needs to be longer and the design volume substantially increased.

Considerations: this system is best suited to rural and peri-urban areas where there is appropriate space, a regular source of organic substrate for the biogas reactor and a use for the digestate and biogas. The reactor itself can be built underground (e.g. under agricultural land, and in some cases roads) and, therefore, does not require a lot of space. Although a reactor may be feasible in a dense urban area, proper sludge management is crucial and needs specific attention.

Because the digestate production is continuous, there must be provisions made for year-round use and/or transport away from the site.

The Biogas Reactor can function with a large range of inputs and is especially suitable where a constant source of animal manure is available, or where market and kitchen waste is abundant. On farms, for example, large quantities of biogas can be produced if animal manure is co-digested with the black water, whereas significant gas production would not be achieved from human excreta alone. Wood material or straw are difficult to degrade and should be avoided in the substrate.

Achieving a good balance between excreta (both human and animal), organics and water can take some time, though the system is generally forgiving. However, care should be taken not to overload the system with either too many solids or too much liquid (e.g., grey water should not be added into the biogas reactor as it substantially reduces the hydraulic retention time).

Most types of dry cleansing materials and organics can be discharged into the biogas reactor, although to accelerate digestion and ensure even reactions within the tank, large items should be broken or cut into small pieces. Guidelines for the safe use of sludge have been published by the World Health Organization (WHO) and are referenced on the relevant technology information sheets.

Design Considerations: biogas reactors can be brick-constructed domes or prefabricated tanks, installed above or below ground, depending on space, soil characteristics, available resources and the volume of waste generated. They can be built as fixed dome or floating dome digesters. In the fixed dome, the volume of the reactor is constant. As gas is generated it exerts a pressure and displaces the slurry upward into an expansion chamber. When the gas is removed, the slurry flows back into the reactor. The pressure can be used to transport the biogas through pipes. In a floating dome reactor, the dome rises and falls with the production and withdrawal of gas. Alternatively, it can expand (like a balloon). To minimize distribution losses, the reactors should be installed close to where the gas can be used.

The hydraulic retention time (HRT) in the reactor should be at least 15 days in hot climates and 25 days in temperate climates. For highly pathogenic inputs, a HRT of 60 days should be considered. Normally, biogas reactors are operated in the mesophilic temperature range of 30 to 38 °C. A thermophilic temperature of 50 to 57 °C would ensure the pathogens destruction, but can only be achieved by heating the reactor (although in practice, this is only found in industrialized countries).

Often, biogas reactors are directly connected to private or public toilets with an additional access point for organic materials. At the household level, reactors can be made out of plastic containers or bricks. Sizes can vary from 1,000 L for a single family up to 100,000 L for institutional or public toilet applications. Because the digestate production is continuous, there must be provisions made for its storage, use and/or transport away from the site.

Operation & Maintenance: if the reactor is properly designed and built, repairs should be minimal. To start the reactor, it should be inoculated with anaerobic bacteria, e.g., by adding cow dung or septic tank sludge. Organic waste used as substrate should be shredded and mixed with water or digestate prior to feeding.

Gas equipment should be carefully and regularly cleaned so that corrosion and leaks are prevented. Grit and sand that have settled to the bottom should be removed. Depending on the design and the inputs, the reactor should be emptied once every 5 to 10 years.

Pros & Cons

\+ Generation of renewable energy

\+ Small land area required (most of the structure can be built underground)

- \+ No electrical energy required
- \+ Conservation of nutrients
- \+ Long service life
- \+ Low operating costs
- \- Requires expert design and skilled construction
- \- Incomplete pathogen removal, the digestate might require further treat§ ment
- \- Limited gas production below 15 °C

3.6 Black water treatment system with infiltration

This is a water-based system that requires a flush toilet and a collection and storage/treatment technology that is appropriate for receiving large quantities of water. Inputs to the system can include faeces, urine, flush water, anal cleansing water, dry cleansing materials and grey water. There are two user interface technologies that can be used for this system: a pour flush toilet or a cistern flush toilet. A urinal could additionally be used.

The user interface is directly connected to a collection and storage/treatment technology for the black water that is generated: either a septic tank, an anaerobic baffled reactor (ABR), or an anaerobic filter may be used. The anaerobic processes reduce the organic and pathogen load, but the effluent is still not suitable for direct use. Grey water should be treated along with black water in the same collection and storage/treatment technology, but if there is a need for water recovery, it can be treated separately (this is not shown on the system template). Effluent generated from the collection and storage/treatment can be directly diverted to the ground for use and/or disposal through a soak pit or a leach field.

The sludge that is generated from the collection and storage/treatment technology must be removed and transported for further treatment. As the sludge is highly pathogenic prior to treatment, human contact and direct agricultural application should be avoided. The sludge that is removed should be transported to a dedicated sludge treatment facility.

Appropriateness: this technology is most commonly applied at the household level. Larger, multi-chamber septic tanks can be designed for groups of houses and/or public buildings (e.g., schools). A septic tank is appropriate where there is a way of dispersing or transporting the effluent. If septic tanks are used in densely populated areas, onsite infiltration should not be used, otherwise, the ground will become oversaturated and contaminated, and wastewater may rise up to the surface, posing a serious health risk. Instead, the septic tanks should be connected to some type of conveyance technology, through which the effluent is transported to a subsequent treatment or disposal site. Even though septic tanks are watertight, it is not recommended to construct them in areas with high groundwater tables or where there is frequent flooding. Because the septic tank must be regularly desludged, a vacuum truck should be able to access the location. Often, septic tanks are installed in the home, under the kitchen or bathroom, which makes emptying difficult. Septic tanks can be installed in every type of climate, although the efficiency will be lower in colder climates. They are not efficient at removing nutrients and pathogens.

Considerations: this system is only appropriate in areas where desludging services are available and affordable and where there is an appropriate way to dispose of the sludge. For the infiltration technologies to work there must be sufficient available space and the soil must have a suitable capacity to absorb the effluent. This system can be adapted for use in colder climates, even where there is ground frost. The system requires a constant source of water. This water-based system is suitable for anal cleansing water inputs, and, since the solids are settled and digested onsite, easily degradable dry cleansing materials can also be used. However, rigid or non-degradable materials (e.g., leaves, rags) could clog the system and cause problems with emptying and, therefore, should not be used. In cases when dry cleansing materials are collected separately from the flush toilets, they should be disposed of in an appropriate way. The capital investment for this system is considerable (excavation and installation of an onsite storage and infiltration technology), but the costs can be shared by several households if the system is designed for a larger number of users. Guidelines for the safe use of effluent and sludge have been published by the World Health Organization (WHO) and are referenced on the relevant technology information sheets.

Design Considerations: a septic tank should have at least two chambers. The first chamber should be at least 50% of the total length, and when there are only two chambers, it should be two thirds of the total length. Most of the solids settle out in the first chamber. The baffle, or the separation between the chambers, is to prevent scum and solids from escaping with the effluent. A T-shaped outlet pipe further reduces the scum and solids that are discharged. Accessibility to all chambers (through access ports) is necessary for maintenance. Septic tanks should be vented for controlled release of odorous and potentially harmful gases. The design of a septic tank depends on the number of users, the amount of water used per capita, the average annual temperature, the desludging frequency and the characteristics of the wastewater. The retention time should be 48 hours to achieve moderate treatment. A variation of the septic tank is called an Aquaprivy.

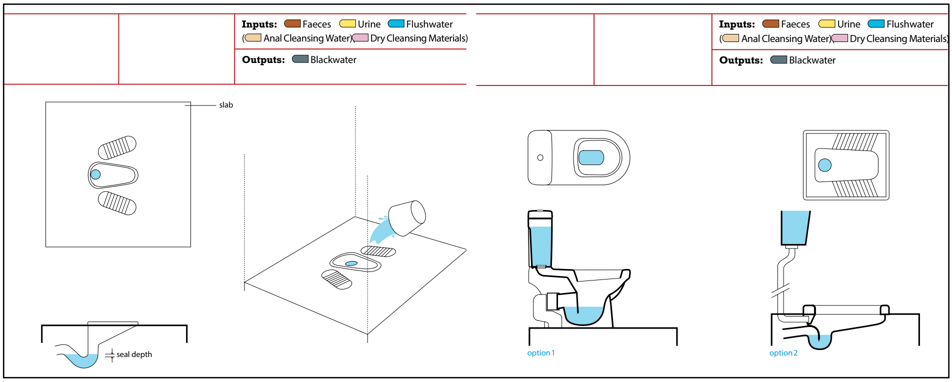

Figure 3.7. Pour Flush Toilet (left) and Cistern Flush Toilet (right) (Source: Tilley et al).

This is a simple storage and settling tank that is located directly below the toilet so that the excreta fall into it. The Aquaprivy has a low treatment efficiency.

Operation & Maintenance: because of the delicate ecology, care should be taken not to discharge harsh chemicals into the septic tank. Scum and sludge levels need to be monitored to ensure that the tank is functioning well. Generally, septic tanks should be emptied every 2 to 5 years. This is best done by using a motorized emptying and transport technology. Septic tanks should be checked from time to time to ensure that they are watertight.

Pros & Cons

- \+ Simple and robust technology
- \+ No electrical energy is required
- \+ Low operating costs
- \+ Long service life
- \+ Small land area required (can be built underground)
- \- Low reduction in pathogens, solids and organics
- \- Regular desludging must be ensured
- \- Effluent and sludge require further treatment and/or appropriate dis charge

Chapter 3 sources:

Based on:
Elizabeth Tilley, Lukas Ulrich, Christoph Lüthi, Philippe Reymond and Christian Zurbrügg Compendium of Sanitation Systems and Technologies. IWA & eawag aquatic research, 2014?

Chapter 4
Wastewater Treatment – Conventional, Natural and Ecological

4.1 Centralized versus decentralized wastewater treatment systems

The current concept of wastewater collection, treatment and discharge is based on centralized sewer systems (Figure 4.1), which have been regarded as the optimal solution for water pollution control and have prevailed in many industrial countries.

The basic idea behind the use of centralized water treatment is that wastewater is transported out of the city and far away from residential sites as quickly as possible in order to reduce public health risks. However, centralized approaches are often plagued by high capital cost, improper operation, and an over reliance on treatment technologies that are unaffordable when maintained in areas with low population densities and dispersed households. Decentralized wastewater treatment systems that employ a combination of onsite or cluster (Figure 4.2)

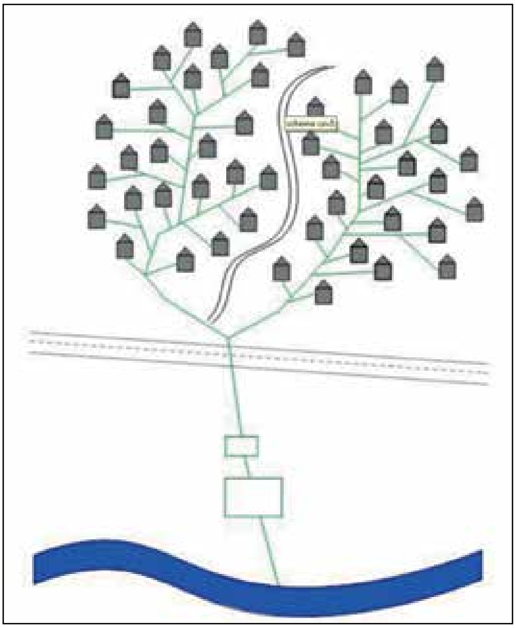

Figure 4.1 Centralized sewer system.
(Source: Matuska et al) p. 377

systems are increasingly recognised as a feasible approach towards resolving the water supply and sanitation issues. Such approaches are recognised as available long term solution for small communities, rural centres, and industrial, commercial and residential areas in developing countries, because they are more flexible, less resource intensive, and more ecologically sustainable (Zhang). A comparison between the centralized and decentralized systems is shown in Table 4.1.

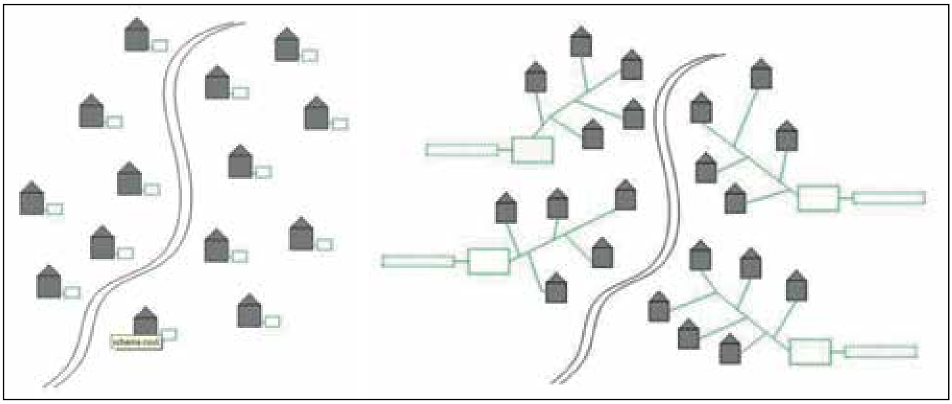

Figure 4.2. On-site system (left) and Group sewer system (right). (Source: Matuska et al ; Stovall) p. 377

Table 4.1. Comparison of the centralized and decentralized system. (Source: Matuska et al) p. 377

Centralized system	Decentralized system
The cost of waste water collection system are several times the actual cost of the waste water treatment plant	No high costs for waste water collection system
The basic network of collection system is usually necessary to build in frame of one large investment project	Waste water collection system of the village can be built gradually, individual houses or group of homes are not mutually dependent
Specific costs of a central wastewater treatment plant and its operational costs are lower	Specific costs for waste water treatment plant are higher
The bigger the waste water treatment plant, the operation can be more reliable with better cleaning effect and at the same time, its technology is easier to manage and control	Small and residential wastewater treatment plants are often not properly operated and they lack control of technology - the project of such a system should include a proposal to eliminate these disadvantages
In the case of a single collection system rainwater negatively affects the purification process. In case of a divided system, rain water is collected separately and a special storm drainage system is build.	Local municipality easier accepts the idea of decentralized rainwater solutions - local infiltration or use of rainwater on the local level
Treated waste water is usually discharged into the watercourse (river, stream)	Often there is a problem with the discharge of treated waste water, particularly in terms of groundwater protection requirements

4.2 Wastewater and needs of treatment

The constituents in untreated wastewater can be divided into three types: physical, chemical and biological. Physical constituents are the particles or solids in the effluent. Effluent is defined as liquid waste that is untreated, partially treated or completely treated. Chemical constituents include nutrients and heavy metals. Biological constituents include coliform organisms and other microorganisms such as bacteria, protozoa, helminths and viruses. These constituents need to be removed for various reasons (see Table 4.2).

Municipal wastewater is mainly comprised of water (99.9%) together with relatively small concentrations of suspended and dissolved organic and inorganic solids. Among the organic substances present in sewage are carbohydrates, lignin, fats, soaps, synthetic detergents, proteins and their decomposition products, as well as various natural and synthetic organic chemicals from the process industries. Municipal wastewater also contains a variety of inorganic substances from domestic and industrial sources, including a number of potentially toxic elements such as arsenic, cadmium, chromium, copper, lead, mercury, zinc, etc. Pathogenic viruses, bacteria, protozoa and helminths may be present in raw municipal wastewater and can survive in the environment for long periods. Pathogenic bacteria will be present in wastewater at much lower levels than the coliform group of bacteria, which are much easier to identify and enumerate (as total coliforms/100ml). *Escherichia coli* are the most widely adopted indicator of faecal pollution (FAO).

For the assessment of wastewater quality in Central Europe the unit loads given by German Standard ATV-DVWK-A 131 E is used (Table 4.3). Person

Table 4.2. Wastewater constituents and reason for concern (Stovall)

Constituents	Reasons for concern
Total suspended solids	Sludge deposits and anaerobic conditions.
Biodegradable organics	Depletion of natural oxygen resources and the development of septic conditions
Dissolved organics (e.g. total dissolved solids)	Inorganic mconstituents added by usage, recycling and reuse applications.
Heavy metals	Metallic constituents added by usage. Many metals are also classified as priority pollutants.
Nutrients	Excessive growth of undesirable aquatic life, eutrophication, nitrate contamination of drinking water.
Pathogens	Communicable diseases.
Priority organic pollutants	Susopected carcinogenecity, mutagenicity, teratogenecity, or high acute toxicity. Many priority pollutants resist conventional treatment methods (known as refractory organics).

loads of pollutants in various counties are given in Table 4.4. Polish data from small wastewater treatment plant is presented in Table 4.5.

Concentration of different pollutants in wastewater (Table 4.6) is the result of unit loads and volumes of water use in households. Table 4.6 provides information on the use of water from public water supply. In most cases the main users of water in the EU were households. A majority of the EU Member States for which data are available reported a decrease in their water use by the domestic sector in years 2003-2013. The highest increases in the 10-year period were recorded in Greece (49.6%) and Lithuania (20.8%), while the largest decreases were observed in Hungary (-18.8%) and, in particular, Belgium (-75.9%). Per inhabitant water use by the domestic sector was particularly high among the Mediterranean Member States, with Greece (82.5 m^3 per inhabitant and year) and Spain (70.0

Table 4.3. Unit loads of pollutants in raw wastewater [g per $person^{-1}$ d^{-1}]

Index	Municipal (Novotny et al. 1989)	Municipal German Standard (ATV-DVWK-A 131 E)	Municipal Polish research (Heidrich and Kozak 2009)	Municipal (Libhaber and Orozco-Jaromillo 2012)
Solids	80	70	66	35
BOD5	60	60	68	48
COD	-	120	125	103
Ntot	15,5	11	12.8	7
Ptot	3	1.8	1.96	1

Table 4.4. Person loads in various countries [g per person-1 d-1] (Source: Henze)

Index	Brasil	Egypt	India	Turkey	uUS	Denmark	Germany
BOD	55-68	27-41	27-41	27-41	82-96	55-68	55-68
SS	55-68	41-68		41-68	82-96	82-96	82-96
TN	o8-14	o8-14		o8-14	14-19	14-19	o11-16
TP	1.4-2.7	1.1-1.6		1.1-1.6	2.2-3.3	2.2-3.3	1.9-2.7

Table 4.5. Unit wastewater flow and unit pollution loads (per capita) in inflow to small WWTP (Source: Mucha)

Unit value for…	Range	Mean and standard deviation
wastewater flow, dm3/PE*d	55 – 185	119 ± 36
BOD5 load, gO2/PE*d	17 – 76	43.4 ± 16
COD load, gO2/PE*d	36 – 159	85.8 ± 37
TSS load, g/PE*d	14.2 – 87	37.4 ± 19
TN load, gN/PE*d	4.2 – 18	9.3 ± 3.8
TP load, gP/PE*d	0.68 - 2.5	1.3 ± 0.5

Table 4.6. Pollutant concentration in raw municipal wastewater [g m^{-3}] (Henze)

Index	High concentration	Medium concentration	Low concentration
BOD	560	350	230
COD	1200	750	500
SS	600	400	250
TN	100	60	30
TP	25	15	6

Table 4.7. Use of water by the domestic sector (households and services) [m^3 per inhabitant per year] (Eurostat)

	A. Precipitation	B. Evapotranspiration	C. Internal flow (C. = A.–B.)	D. External inflow	E. Freshwater resources (E. = C.+D.)	Outflow
Belgium	28.9	16.6	12.3	7.6	19.9	15.6
Bulgaria	69.9	52.3	17.6	89.1	106.7	108.0
Czech Republic	54.7	39.4	15.2	0.7	16.0	16.0
Denmark	38.5	22.1	16.3	*0.0*	16.3	1.9
Germany	307.0	190.0	117.0	75.0	188.0	182.0
Estonia	29.0	:	12.3	:	12.3	:
Ireland	80.0	32.5	47.5	3.5	51.0	:
Greece	115.0	55.0	60.0	12.0	72.0	:
Spain	346.5	235.4	111.1	0.0	111.1	111.1
France	500.8	320.8	180.0	11.0	186.3	168.0
Croatia	65.7	39.6	26.1	85.6	111.7	111.7
Italy	241.1	155.8	85.3	30.5	115.8	115.9
Cyprus	3.0	2.7	0.3	0.0	0.3	0.1
Latvia	42.7	25.8	16.9	16.8	33.7	32.9
Lithuania	44.0	28.5	15.5	9.0	24.5	25.9
Luxembourg	2.0	1.1	0.9	0.7	1.6	1.6
Hungary	55.7	48.2	7.5	108.9	116.4	115.7
Malta	0.2	0.1	0.1	0.0	0.1	0.1
Netherlands	31.6	21.3	10.3	81.5	91.8	90.9
Austria	98.0	43.0	55.0	29.0	84.0	84.0
Poland	193.1	138.3	54.8	8.3	63.1	63.1
Portugal	82.2	43.6	38.6	35.0	73.6	34.0
Romania	154.0	114.6	39.4	2.9	42.3	17.9
Slovenia	31.7	13.1	18.6	13.5	32.1	32.3
Slovakia	37.4	24.3	13.1	67.3	80.3	81.7
Finland	222.0	115.0	107.0	3.2	110.0	110.0
Sweden	342.2	169.9	172.6	13.6	186.2	186.2
United Kingdom	287.6	127.3	161.4	6.5	172.9	171.0
Iceland	200.0	30.0	170.0	0.0	170.0	170.0
Norway	470.7	112.0	380.7	12.3	393.0	393.0
Switzerland	61.2	21.4	39.8	12.6	52.4	53.1
FYR of Macedonia	19.5	:	:	1.0	:	6.3
Serbia	56.1	43.3	12.8	162.6	175.4	175.4
Turkey	503.1	275.7	227.4	6.9	234.3	178.0

(*) The minimum period taken into account for the calculation of long term annual averages is 20 years.
Source: Eurostat (online data code: env_wat_res)

m^3 per inhabitant and year) recording the highest values, followed by Sweden, Malta and Portugal.

4.3 Wastewater treatment systems

Any wastewater system deals with collecting, treating and disposing of wastewater (Figure 4.3). Conventional wastewater treatment goes through three stages. In the first stage, which is primary treatment, solids settle out of the wastewater. The settled solids are called sludge and have to be removed and utilized. The next stage is called secondary treatment, where dissolved or suspended materials are

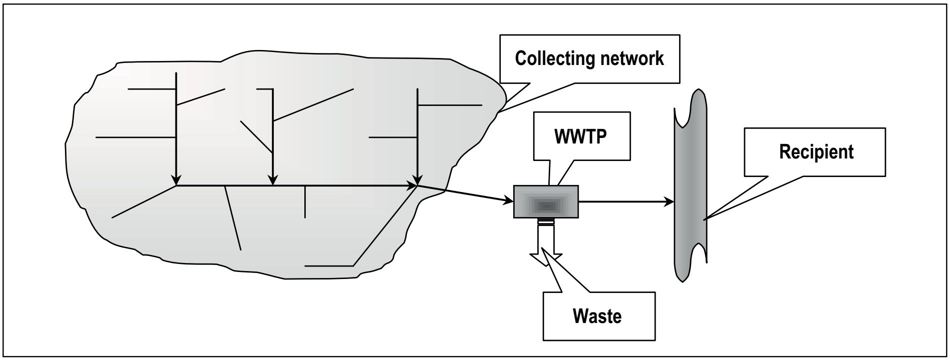

Figure 4.3. Components of the centralized sewage system Source: Matuska et al)

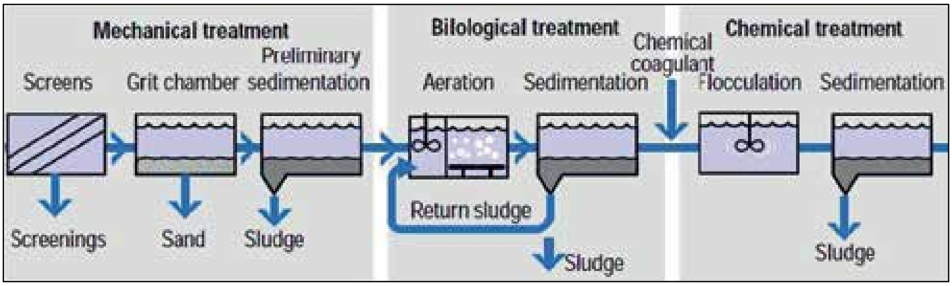

Figure 4.4. Large-scale wastewater treatment process (Kimointernational)

converted to a microbial biomass so that they can be separated from the water. The third step called tertiary treatment is where particles and nutrients such as phosphorus and nitrogen are removed (Stovall).

In general three stages of treatment can be identified (Figure 4.4), they are usually introduced in large-scale centralised treatment systems. However, these basic steps can be adapted in small-scale systems to achieve different nutrient reductions. Small-scale and on-site treatment processes vary, some fully treat wastewater to a high standard before discharging into the natural environment, whilst others carry out some basic primary or secondary processes and depend on receiving environments to further treat effluents (Kimo international).

4.4 Hard (conventional) vs. low (natural/ecological) wastewater treatment

All wastewater treatment systems utilize natural processes. For example, gravity is used to remove particulates and bacterial decomposition reduces organics. In conventional treatment systems, these natural processes are supported by a com-

Table 4.8. Wastewater treatment stages (Kimointernational, p 382)

Primary				
	Screening	**Sedimentation**	**Secondary**	**Tertiary**
Method	Coarse to fine screens, filters, settling tanks, skimmers	Settling tanks, separation machin- ery, filters and skimmers	Surface aerated basins; Filter beds; biological aeration; membrane bioreactors, secondary sedimentation	Lagooning; constructed wetlands, N and P removal; disinfection e.g. chlorination
Purpose	Removal of separable materials (fats, oils and greases, solids etc) that could block or damage a system	Sludge settling, removal of remaining solids, fats, oils and greases and, separation of sludge from liquid content	Degradation of the biological content of sewage by the attached and suspended growth of bacteria	Final stage of treatment to raise water quality to acceptable standard for discharge, by removing nutrients and remaining pollutants and harmful content
Process	Settling, skimming, scraping and filtering	Settling, skimming and scraping and filtering	Aeration (stimulating biological breakdown of organic matter by providing an oxygen source for bacteria) Filtration (providing a media for bacteria to grow on that wastewater can be passed through) Settling to remove suspended solids	Chemical precipitation (trickling wastewater through chemicals to bind contaminants e.g. P) Chemical dosing (adding chemicals to wastewater to bind nutrients for later removal as solids)Natural processes to remove contaminants like denitrification by plants and animals Dosing wastewater with chemicals to kill harmful organisms

plex array of energy-intensive mechanical equipment. Natural treatment systems, by contrast, utilize biological and physical/chemical processes to accomplish a wide range of treatment objectives, with minimal dependence on energy inputs and mechanical assistance.

These systems can also go beyond simply providing treatment services; many provide an aesthetic benefit, and some include opportunities for wildlife viewing, environmental education, and outdoor recreation (Oregon Department of Environmental Quality).

Natural treatment systems:

- utilize natural elements, features and processes (soil, vegetation, micro-organisms);
- integrate treatment and environmental functions;
- are robust and flexible;
- are multiple-contaminant removal;
- minimise the use of chemicals and energy (Figures 4.5 and 4.6, Table 4.9).

Natural treatment systems are engineered systems that have a minimal dependence on mechanical elements to support the wastewater treatment process. Instead

Figure 4.5. Natural (left) and conventional (right) wastewater treatment system

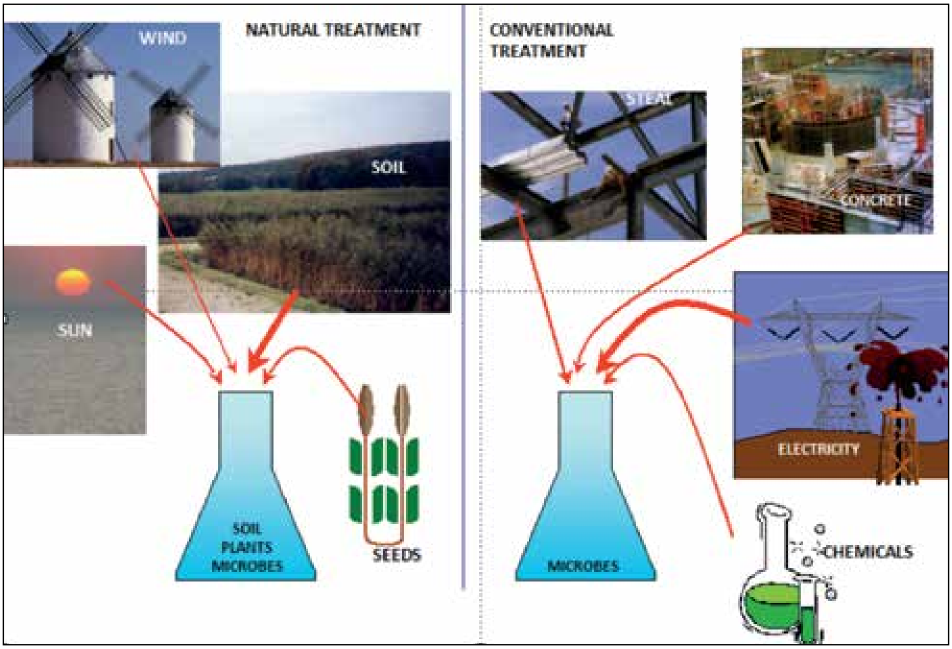

Figure 4.6. Comparison of energy sources in natural and conventional westewater treatment

Table 4.9. Wastewater treatment energy use base on conventional system (activated sludge) and natural system (subsurface flow constructed wetland)

Parameters	Units	Conventional activated sludge	Subsurface flow constructed wetland
Total energy consumption	kWh/1,000 gal	4	< 0.4
Fraction of energy used for aeration	%	56	0
Fraction of energy used for pumping	%	20	100
Fraction of energy used for other processes	%	24	0

they use plants, soil, bacteria, and other natural processes to break down and treat pollutants in wastewater. Natural treatment systems use rather than dispose of water, minimize the use of chemicals, and require limited energy to operate.

These systems clean contaminated water in a sustainable, low cost, low impact manner, and can be designed to have a long life (Oregon Department of Environmental Quality). They need more land to ensure effective treatment. Their footprint, however, is smaller than for conventional technologies.

Designing and installing natural treatment systems can cost less than conventional systems (Oregon Department of Environmental Quality). For instance, the City of Medford programme to use water quality trading to reduce its temperature impacts on the Rogue River costs $6 million, compared to $16 million and additional O&M costs for chillers. The Roseburg Urban Sanitary Authority natural treatment system was installed at a cost of $9 million compared to $100 million for a conventional treatment system that also had much higher operating costs. The City of Salem wetland treatment system treats for ammonia and temperature at an operating cost of $80 per day. In the 10 years that the Clean Water Services has operated its temperature water quality trading program, it has saved rate payers $100 million. Clean Water Services is meeting its DEQ permit at a 95% cost saving compared to conventional wastewater treatment technologies.

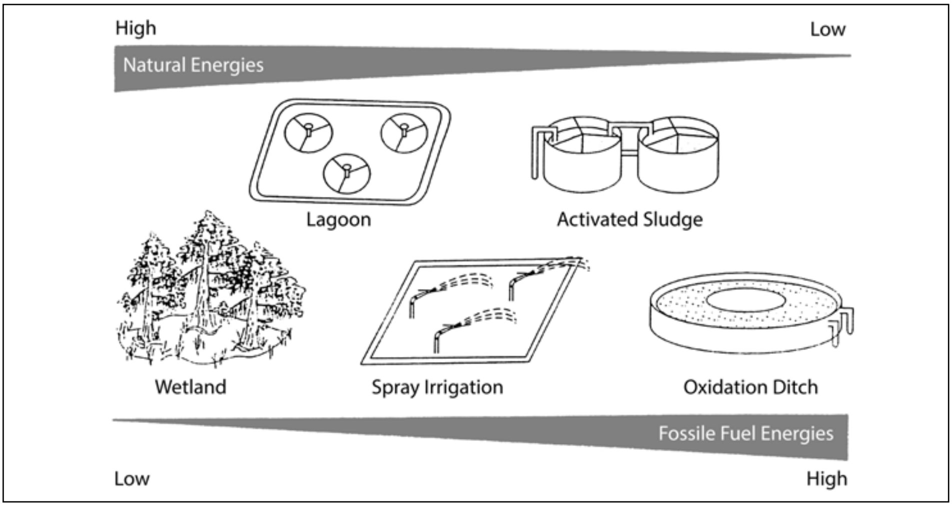

Figure 4.7. Manipulation of natural systems to generate energy

4.5 The concept of ecological engineering

The main concept of ecological engineering is to use small amounts of supplied energy to manipulate natural systems having their own major energy sources, such as solar and bioenergy (Figure 4.7). The most important “key words” of ecological engineering in the scope of wastewater treatment are:

- high treatment efficiency,
- limited use of resources (e.g. energy and chemicals),
- low production of waste (e.g. limited production of wastewater sludge) and
- no damage to the environment.

Recycling is a logical consequence of ecological thinking, especially to recycle within spatially small loops and a limited timeframe. Recycling is facilitated by decentralized or on-site treatment (better source control and shorter transport distances).

Chapter 4 sources:

[1] Zang D.Q., Jinadasa K.B.S.N. Gersberg R.M., Liu Y., Ng W.J., Tan S.K., 2014: Application of constructed wetlands for wastewater treatment in developing countries - A review of recent developments (2000-2013) Journal of Environmental Management 141, 116-131

[2] Study of alternative solutions for waste water treatment in Richnava local municipality. Matuska M., Fatulova E., Bodik I., Zvara R., Global Water Partnership Central and Eastern Europe. Slovakia Water Partnership

[3] Natural Alternatives to Conventional Wastewater Treatment By: Heather Stovall June 2007

[4] http://www.fao.org/docrep/t0551e/t0551e03.htm

[5] Henze M., Comeau Y., Wastewater characterization https://www.researchgate.net/file.PostFileLoader.html?id=5677dd705cd9e3c0bb8b459d&assetKey=AS%3A309055778689024%401450696047576

[6] Mucha Z., Mikosz J., Analysis of unit pollution loads for small wastewater treatment plants http://rymd.lwr.kth.se/forskningsprojekt/Polishproject/rep15/MuchaMikosz.pdf

[7] http://ec.europa.eu/eurostat/statistics-explained/index.php

[8] Mitigating Eutrophication: A Manual for Municipalities. Good Practice Guide Series. Local Authorities International Environmental Organisation KIMO, 2011 http://www.kimointernational.org/KIMOPublications.aspx

[9] Biofilters (Bioswales, Vegetative Buffers, & Constructed Wetlands) For Storm Water Discharge Pollution Removal Guidance for using Bioswales, Vegetative Buffers, and Constructed Wetlands for reducing, minimizing, or eliminating pollutant discharges to surface waters By Dennis Jurries, PE, NWR Storm Water Engineer DEQ Northwest Region Document January 2003

[10] Natural treatment systems – A water quality match for Oregon’s cities and towns. A report prepared jointly by Oregon Department of Environmental Quality and the Oregon Association of Clean Water Agencies July, 2014

Chapter 5
Semi-centralized and centralised treatment technologies

5.1 Black water treatment system with effluent transport

This system is characterized by the use of a household-level technology to remove and digest settleable solids from the black water, and a simplified or solids-free sewer system to transport the effluent to a (semi-) centralized treatment facility.

Inputs to the system can include faeces, urine, flush water, anal cleansing water, dry cleansing materials and grey water. This system is comparable to black water treatment system with infiltration except that the management of the effluent generated during collection and storage/treatment of the black water is different: the effluent from septic tanks, anaerobic baffled reactors or anaerobic

Application Level:	**Management Level:**	**Inputs:** Blackwater, Brownwater, Greywater
★★ Household	★★ Household	**Outputs:** Effluent, Sludge
★★ Neighbourhood	★★ Shared	
City	★★ Public	

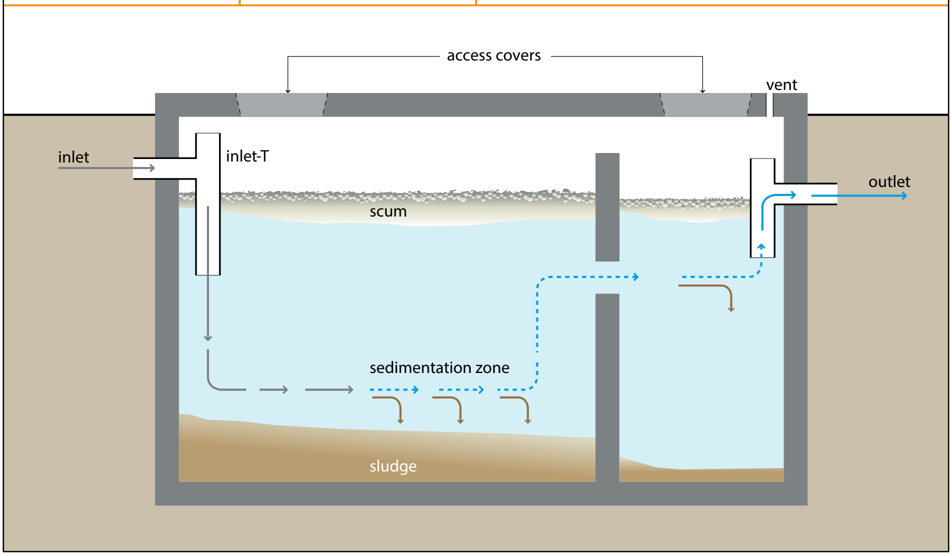

Figure 5.8. Septic Tank (Source: Tilley et al).

filters is transported to a (semi-) centralized treatment facility via a simplified or a solids-free sewer. The effluent can also alternatively be discharged into the storm water drainage network for water disposal/groundwater recharge, although this is not the recommended approach. This should only be considered if the quality of the effluent is high and transportation to a treatment plant is not feasible. Effluent transported to a treatment facility is treated using a combination of the technologies. The sludge from the collection and storage/treatment technology must be removed and transported for further treatment in a dedicated sludge treatment facility.

Appropriateness: simplified sewers can be installed in almost all types of settlements and are especially appropriate for dense urban areas where space for onsite technologies is limited. They should be considered as an option where there is a sufficient population density (about 150 people per hectare) and a reliable water supply (at least 60 L/person/day). Where the ground is rocky or the groundwater table high, excavation may be difficult. Under these circumstances, the cost of installing sewers is significantly higher than in favourable conditions. Regardless, simplified sewerage is between 20 and 50% less expensive than conventional sewerage.

Solids-free sewers is best suited to medium-density (peri-)urban areas and less appropriate in low-density or rural settings. It is most appropriate where there is no space for a leach field, or where effluents cannot otherwise be disposed of onsite (e.g., due to low infiltration capacity or high groundwater). It is also suitable where there is undulating terrain or rocky soil. A solids-free sewer can be connected to existing septic tanks where infiltration is no longer appropriate (e.g., due to increased housing density and/or water use). As opposed to a simplified sewer a solids-free sewer can also be used where domestic water consumption is limited. This technology is a flexible option that can be easily extended as the population grows. Because of shallow excavations and the use of fewer materials, it can be built at considerably lower cost than a conventional sewer.

Considerations: this system is especially appropriate for urban settlements where the soil is not suitable for the infiltration of effluent. Since the sewer network is shallow and (ideally) watertight, it is also applicable for areas with high ground water tables. This system can be used as a way of upgrading existing, under-performing collection and storage/treatment technologies (e.g., septic tanks) by providing improved treatment. The success of this system depends on high user commitment concerning the operation and maintenance of the sewer network.

This water-based system is suitable for anal cleansing water inputs, and, since the solids are settled and digested onsite, easily degradable dry cleansing materials can be used. However, rigid or non-degradable materials (e.g. leaves, rags) could clog the system and cause problems with emptying and, therefore, should not be used. In cases when dry cleansing materials are separately collected from the flush toilets, they should be disposed of in an appropriate way. With the offsite transport of the effluent to a (semi-) centralized treatment facility, the capital investment for this system is considerable.

Installation of an onsite Collection and Storage/Treatment technology may be costly, but the design and installation of a simplified or solids-free sewer will be considerably less expensive than a conventional gravity sewer network. The offsite treatment plant itself is also an important cost factor, particularly, if there is no pre-existing facility to which the sewer can be connected.

Design Considerations: in contrast to conventional sewers that are designed to ensure a minimum self-cleansing velocity, the design of simplified sewers is based on a minimum tractive tension of 1 N/m^2 (1 Pa) at peak flow. The minimum peak flow should be 1.5 L/s and a minimum sewer diameter of 100 mm is required. A gradient of 0.5% is usually sufficient. For example, a 100 mm sewer laid at a gradient of 1 m in 200 m will serve around 2,800 users with a wastewater flow of 60 L/person/day. PVC pipes are recommended to use. The depth at which they should be laid depends mainly on the amount of traffic. Below sidewalks, covers of 40 to 65 cm are typical. The simplified design can also be applied to sewer mains; they can also be laid at a shallow depth, provided that they are placed away from traffic. Expensive manholes are normally not needed. At each junction or change in direction, simple inspection chambers (or cleanouts) are sufficient. Inspection boxes are also used at each house connection.

Where kitchen grey water contains an appreciable amount of oil and grease, the installation of grease traps is recommended to prevent clogging. Grey water should be discharged into the sewer to ensure adequate hydraulic loading, but storm water connections should be discouraged. However, in practice it is difficult to exclude all storm water flows, especially where there is no alternative for storm drainage. The design of the sewers (and treatment plant) should, therefore, take into account the extra flow that may result from storm water inflow.

If the interceptors are correctly designed and operated, solid-free sewer does not require self-cleansing velocities or minimum slopes. Even inflective gradients are possible, as long as the downstream end of the sewer is lower than the upstream end. In sections where there is pressure flow, the water level in any interceptor tank must be higher than the hydraulic head within the sewer, otherwise the liquid will flow back into the tank. At high points in sections with pressure flow, the pipes must be ventilated. Solid-free sewers do not have to be

Application Level:	Management Level:	Inputs/Outputs:
★★ Household	Household	Sludge, Blackwater
★★ Neighbourhood	★ Shared	Effluent, Urine, Stored Urine
★ City	★★ Public	

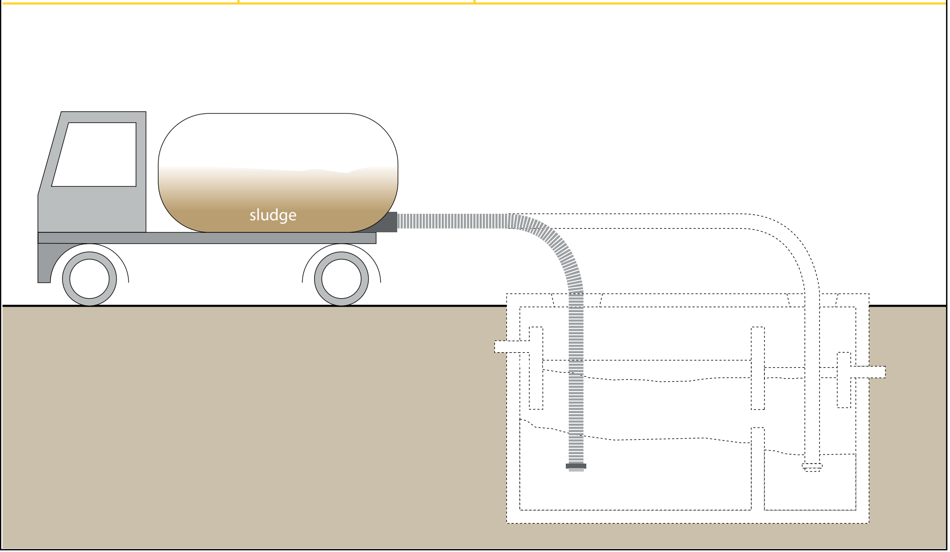

Figure 5.9. Motorized Emptying and Transport (Source: Tilley et al).

installed on a uniform gradient with a straight alignment between inspection points. The alignment may curve to avoid obstacles, allowing for greater construction tolerance.

A minimum diameter of 75 mm is required to facilitate cleaning. Expensive manholes are not needed because access for mechanical cleaning equipment is not necessary. Cleanouts or flushing points are sufficient and are installed at upstream ends, high points, intersections, or major changes in direction or pipe size. Compared to manholes, cleanouts can be more tightly sealed to prevent storm water from entering. Storm water must be excluded as it could exceed pipe capacity and lead to blockages due to grit depositions. Ideally, there should not be any storm- and groundwater in the sewers, but, in practice, some imperfectly sealed pipe joints must be expected. Estimates of groundwater infiltration and storm water inflow must, therefore, be made when designing the system. The use of PVC pipes can minimize the risk of leakages.

Operation & Maintenance: trained and responsible users are essential to ensure that the flow in simplified sewer is undisturbed and to avoid clogging by

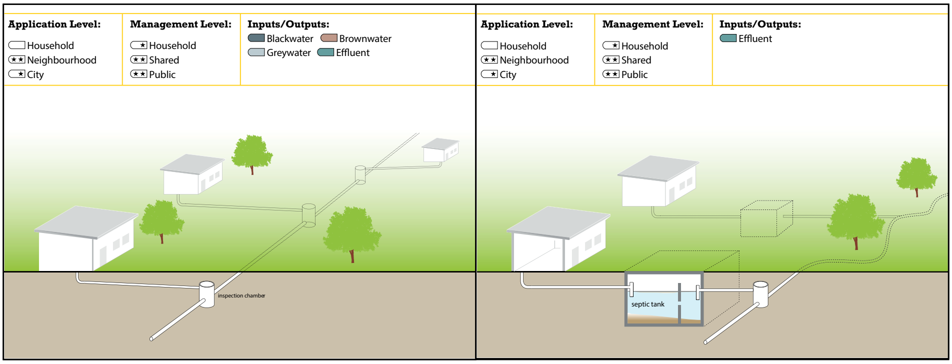

Figure 5.10. Simplified Sewer (left) and Solids-Free Sewer (right)

trash and other solids. Occasional flushing of the pipes is recommended to insure against blockages. Blockages can usually be removed by opening the cleanouts and forcing a rigid wire through the pipe. Inspection chambers must be periodically emptied to prevent grit overflowing into the system.

The operation of the system depends on clearly defined responsibilities between the sewerage authority and the community. Ideally, households will be responsible for the maintenance of pre-treatment units and the simplified sewerage, known as *condominial sewerage*, part of the sewer. However, in practice this may not be feasible because users may not detect problems before they become severe and costly to repair. Alternatively, a private contractor or users committee can be hired to do the maintenance.

Trained and responsible users are essential to avoid clogging by trash and other solids in solids-free sewer. Regular desludging of the septic tanks is critical to ensure optimal performance of the sewer. Periodic flushing of the pipes is recommended to insure against blockages. Special precautions should be taken to prevent illegal connections, since it is likely that interceptors would not be installed and solids would enter the system. The sewerage authority, a private contractor or users committee should be responsible for the management of the system, particularly, to ensure that the inter interceptors are regularly desludged and to prevent illegal connections.

Pros & Cons A simplified sewer

\+ Can be laid at a shallower depth and flatter gradient than conventional sewers
\+ Lower capital costs than conventional sewers; low operating costs
\+ Can be extended as a community grows

+ Grey water can be managed concurrently
+ Does not require onsite primary treatment units
- Requires repairs and removals of blockages more frequently than a con ventional gravity sewer
- Requires expert design and construction
- Leakages pose a risk of wastewater exfiltration and groundwater infiltra tion and are difficult to identify

Pros & Cons A solids-free sewer
+ Does not require a minimum gradient or flow velocity
+ Can be used where water supply is limited
+ Lower capital costs than conventional gravity sewers; low operating costs
+ Can be extended as a community grows
+ Grey water can be managed concurrently
- Space for interceptors is required
- Interceptors require regular desludging to prevent clogging
- Requires training and acceptance to be used correctly
- Requires repairs and removals of blockages more frequently than a con ventional gravity sewer
- Requires expert design and construction
- Leakages pose a risk of wastewater exfiltration and groundwater infiltra tion and are difficult to identify

5.2 Sewerage system with urine diversion

This is a water-based system that requires a urine-diverting flush toilet (UDFT) and a sewer. The UDFT is a special user interface that allows for the separate collection of urine without water, although it uses water to flush faeces. Inputs to the system can include faeces, urine, flush water, anal cleansing water, dry cleansing materials and grey water. Brown water and urine are separated at the UDFT.

Brown water bypasses a collection and storage/treatment technology and is conveyed directly to a (semi-) centralized treatment facility using a sewer network. Grey water is also transported in the sewer and is not separately treated. Urine diverted at the UDFT is collected in a storage tank. Stored urine can be handled easily and with little risk because it is nearly sterile. With its high nutrient content it can be used as a good liquid fertilizer. Brown water is treated at a (semi-) centralized treatment facility. The sludge generated must be further treated in a dedicated sludge treatment facility prior to use and/or disposal. Options for the use and/or disposal of the treated effluent include irrigation, fish ponds, floating plant ponds or discharge to a water body.

Appropriateness: a UDFT is adequate when there is enough water for flushing, a treatment technology for the brown water and a use for the collected urine. To improve diversion efficiency, urinals for men are recommended. UDFTs are suitable for public and private applications, although significant training and awareness is required in public settings to ensure proper use and minimize clogging.

Since this technology requires separate pipes for urine and brown water collection, the plumbing is more complicated than for cistern flush toilets. Particularly, the proper design and installation of the urine pipes is crucial, and requires expertise.

Considerations: this system is only appropriate when there is a need for the separated urine and/or when there is a desire to limit water consumption by using a low-flush UDFT (although the system still requires a constant source of water).

There may also be benefits to the treatment plant if it is normally overloaded; the reduced nutrient load (by removing the urine) could optimize treatment. However, if the plant is currently under-loaded (i.e., it has been overdesigned), then this system could further aggravate the problem. Depending on the type of sewers used, this system can be adapted for both dense urban and peri-urban areas. It is not well-suited to rural areas with low housing densities. Since the sewer network is (ideally) watertight, it is also applicable for areas with high groundwater tables. Dry cleansing materials can be handled by the system or they can be collected and separately disposed of (e.g., surface disposal). UD-

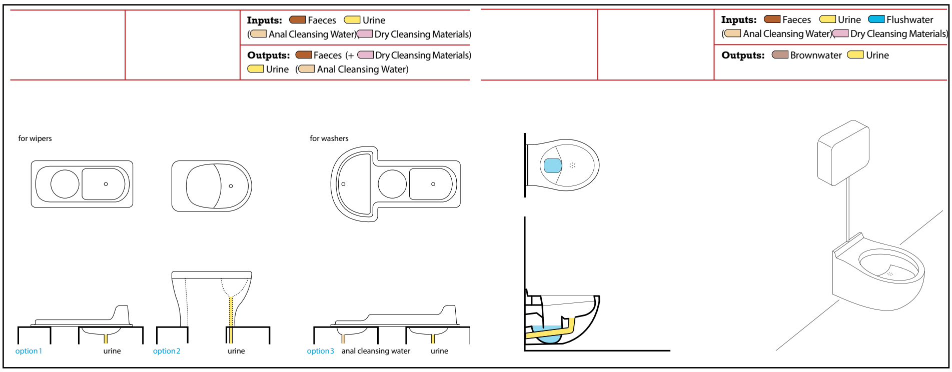

Figure 5.11. Urine-Diverting Dry Toilet UDDT (left) and Urine-Diverting Flush Toilet UDFT (right) (Source: Tilley et al).

FTs are not common and the capital cost for this system can be very high. This is partly due to the fact that there is limited competition in the User Interface market and also because high quality workmanship is required for the dual plumbing system.

Conventional gravity sewers require extensive excavation and installation which is expensive, whereas simplified sewers are generally less expensive if the site conditions permit a condominial design. Users may be required to pay user fees for the system and its maintenance. Depending on the sewer type and management structure (simplified vs. conventional, city-run vs. community-operated, urine transport and application) there will be varying degrees of operation or maintenance responsibilities for the homeowner. This system is most appropriate when there is a high willingness and ability to pay for the capital investment and maintenance costs and where there is a pre-existing treatment facility that has the capacity to accept additional flow.

Design Considerations: the system requires dual plumbing, i.e., separate piping for urine and brown water (faeces, dry cleansing material and flushing water). The toilet should be installed carefully with an understanding of how and where clogs may occur so that they can be prevented and easily removed. For the discharge of urine, plastic pipes should be used to prevent corrosion. To limit scaling, all connections (pipes) to storage tanks should be kept as short as possible; whenever they exist, pipes should be installed with at least a 1% slope, and sharp angles (90°) should be avoided. A pipe diameter of 50 mm is sufficient for steep slopes and where maintenance is easy. Larger diameter pipes (> 75 mm) should be used elsewhere, especially for minimum slopes, and where access is difficult.

Operation & Maintenance: as with any toilet, proper cleaning is important to keep the bowl(s) clean and prevent stains from forming. Because urine is collected separately, calcium- and magnesium-based minerals and salts can precipitate and build up in the fittings and pipes. Washing the bowl with a mild acid (e.g. vinegar) and/or hot water can prevent the build-up of mineral deposits and scaling. Stronger (> 24% acetic) acid or a caustic soda solution (2 parts water to 1 part soda) can be used for removing blockages. However, in some cases manual removal may be required.

Pros & Cons

\+ Requires less water than a traditional cistern flush toilet
\+ No real problems with odours if used correctly
\+ Looks like, and can be used almost like, a cistern flush toilet
\- Limited availability; cannot be built or repaired locally
\- High capital costs; operating costs depend on parts and maintenance

- Labour-intensive maintenance
- Requires training and acceptance to be used correctly
- Is prone to misuse and clogging
- Requires a constant source of water
- Men usually require a separate urinal for optimum collection of urine

5.3 Black water transport to (semi-) centralized treatment systems

This is a water-based sewer system in which black water is transported to a centralized or semi-centralized treatment facility. The important characteristic of this system is that there is no collection and storage/treatment. Inputs to the system include faeces, urine, flush water, anal cleansing water, dry cleansing materials and grey water. The Blackwater that is generated together with grey water is directly conveyed to a (semi-) centralized treatment facility through a sewer network. As there is no collection and storage/treatment, all of the black water is transported to a (semi-) centralized treatment facility. The inclusion of grey water in the conveyance technology helps to prevent solids from accumulating in the sewers.

Considerations: this system is especially appropriate for dense, urban and peri-urban settlements where there is little or no space for onsite storage technologies or emptying. The system is not well-suited to rural areas with low housing densities. Since the sewer network is (ideally) watertight, it is also applicable for areas with high groundwater tables. There must be a constant supply of water to ensure that the sewers do not become blocked. The capital investment for this system can be very high. Conventional gravity sewers require extensive excavation and installation that is expensive, whereas simplified sewers are generally less expensive if the site conditions permit a condominial design. Users may be required to pay user fees for the system and its maintenance. Depending on the sewer type and management structure (simplified vs. conventional, city-run vs. community-operated) there will be varying degrees of operation or maintenance responsibilities for the homeowner. This system is most appropriate when there is a high willingness and ability to pay for the capital investment and maintenance costs and where there is a pre-existing treatment facility that has the capacity to accept additional flow.

5.4 (Semi-) centralized pre-treatment technologies

Pre-treatment is the preliminary removal of wastewater or sludge constituents, such as oil, grease, and various solids (e.g., sand, fibres and trash). Built before a conveyance or treatment technology, pre-treatment units can retard the accumulation of solids and minimize subsequent blockages. They can also help reduce abrasion of mechanical parts and extend the life of the sanitation infrastructure.

Oil, grease, sand and suspended solids can impair transport and/or treatment efficiency through clogging and wear. Therefore, prevention and early removal of these substances is crucial for the durability of a treatment system.

Pre-treatment technologies use physical removal mechanisms, such as screening, flotation, settling and filtration. Behavioural and technical source control measures at the household or building level can reduce pollution loads and keep pre-treatment requirements low. For example, solid waste and cooking oil should be collected separately and not disposed of in sanitation systems. Equipping sinks, showers and the like with appropriate screens, filters and water seals can prevent solids from entering the system. Sewer inspection chambers should always be closed with manhole covers to prevent extraneous material from entering the sewer.

The goal of *the grease* trap is to trap oil and grease so that it can be easily collected and removed. Grease traps are chambers made out of brickwork, concrete or plastic, with an odour-tight cover. Baffles or tees at the inlet and outlet prevent turbulence at the water surface and separate floating components from the effluent. A grease trap can either be located directly under the sink, or, for larger amounts of oil and grease, a bigger grease interceptor can be installed outdoors.

An under-the-sink grease trap is relatively low cost, but must be cleaned frequently (once a week to once a month), whereas a larger grease interceptor has

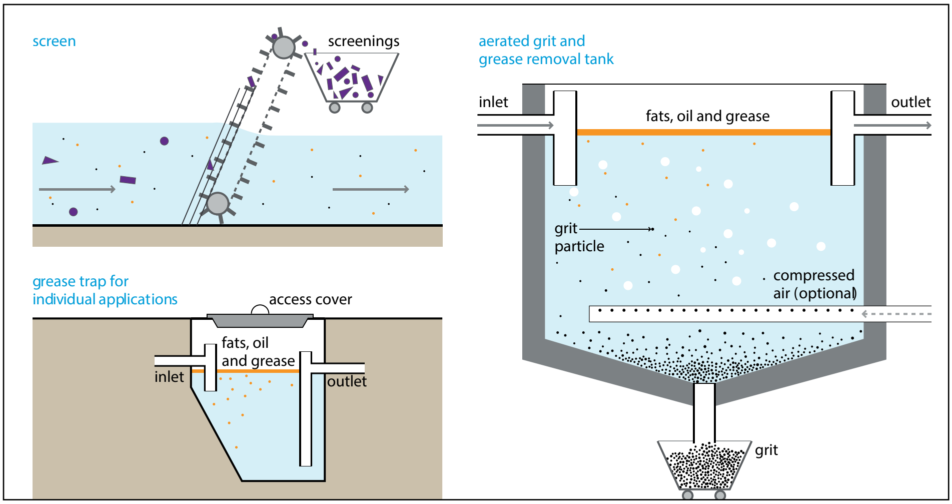

Figure 5.12. Pre-Treatment Technologies (Source: Tilley et al).

a higher capital cost, but is designed to be pumped out every 6 to 12 months. If designed to be large enough, grease traps can also remove grit and other settleable solids through sedimentation, similar to septic tanks.

Screening aims to prevent coarse solids, such as plastics, rags and other trash, from entering a sewage system or treatment plant. Solids get trapped by inclined screens or bar racks. The spacing between the bars usually is 15 to 40 mm, depending on cleaning patterns. Screens can be cleaned by hand or mechanically raked. The latter allows for a more frequent solids removal and, correspondingly, a smaller design.

Where subsequent treatment technologies could be hindered or damaged by the presence of sand, *grit chambers* (or sand traps) allow for the removal of heavy inorganic fractions by settling. There are three general types of grit chambers: horizontal-flow, aerated, or vortex chambers. All of these designs allow heavy grit particles to settle out, while lighter, principally organic particles remain in suspension.

A *settler* is designed to remove suspended solids by sedimentation. It may also be referred to as a sedimentation or settling basin/tank, or clarifier. The low flow velocity in a settler allows settleable particles to sink to the bottom, while

Application Level:	**Management Level:**	**Inputs:** Blackwater, Brownwater, Greywater
Household	Household	**Outputs:** Effluent, Sludge
★★ Neighbourhood	★ Shared	
★★ City	★★ Public	

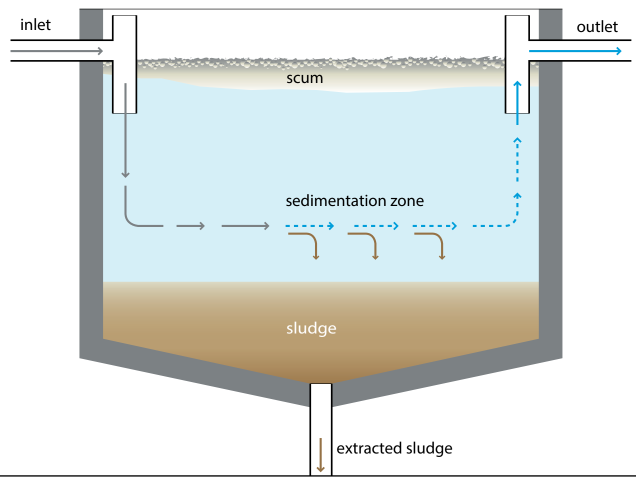

Figure 5.13. Settler (Source: Tilley et al).

constituents lighter than water float to the surface. Settlers can achieve a significant initial reduction in suspended solids (50-70% removal) and organic material (20-40% BOD removal) and ensure that these constituents do not impair subsequent treatment processes.

Imhoff tank is designed for solid-liquid separation and digestion of the settled sludge. It consists of a V-shaped settling compartment above a tapering sludge digestion chamber with gas vents. The Imhoff tank is a robust and effective settler that causes a suspended solids reduction of 50 to 70%, COD reduction of 25 to 50%, and leads to potentially good sludge stabilization – depending on the design and conditions. The settling compartment has a circular or rectangular shape with V-shaped walls and a slot at the bottom, allowing solids to settle into the digestion compartment, while preventing foul gas from rising up and disturbing the settling process. Gas produced in the digestion chamber rises into the gas vents at the edge of the reactor. It transports sludge particles to the water surface, creating a scum layer. The sludge accumulates in the sludge digestion compartment, and is compacted and partially stabilized through anaerobic digestion.

Application Level:	**Management Level:**	**Inputs:** Blackwater, Brownwater, Greywater
Household ★ Neighbourhood ★★ City	Household Shared ★★ Public	**Outputs:** Effluent, Sludge

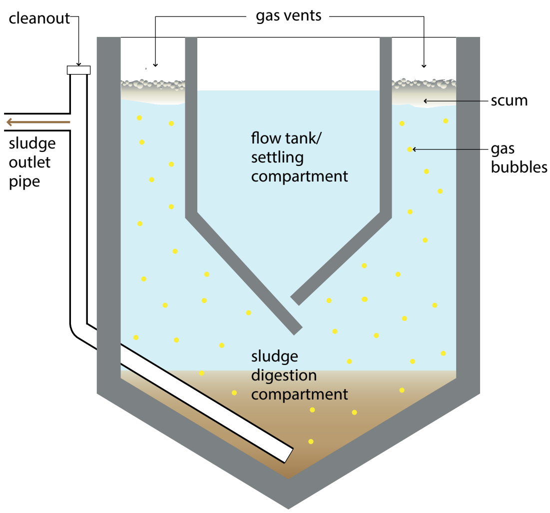

Figure 5.14. Imhoff Tank (Source: Tilley et al)

An *anaerobic baffled reactor (ABR)* is an improved septic tank with a series of baffles under which the wastewater is forced to flow. The increased contact time with the active biomass (sludge) results in improved treatment. The up-flow chambers provide enhanced removal and digestion of organic matter. BOD may be reduced by up to 90%, which is far superior to its removal in a conventional septic tank.

Appropriateness: grease traps should be applied where considerable amounts of oil and grease are discharged. They can be installed at single households, restaurants or industrial sites. Grease removal is especially important where there is an immediate risk of clogging (e.g., a constructed wetland for the treatment of grey water).

Screening is essential where solid waste may enter a sewer system, as well as at the entrance of treatment plants. Trash traps, e.g., mesh boxes, can also be applied at strategic locations like market drains. A grit chamber helps prevent sand deposits and abrasion in wastewater treatment plants, particularly, where roads are not paved and/or storm water may enter the sewer system. As laundries release high amounts of fabric fibres and particles with their wastewater, they should be equipped with lint trap devices. Imhoff tanks are recommended for domestic or mixed wastewater flows between 50 and 20,000 population equivalents. They are able to treat high organic loads and are resistant against organic shock loads. Space requirements are low. Imhoff tanks can be used in warm and cold climates. As the tank is very high, it can be built underground if the groundwater table is low and the location is not flood prone. An anaerobic baffled reactor (ABR) is easily adaptable and can be applied at the household level, in small neighbourhoods or even in bigger catchment areas.

It is most appropriate where a relatively constant amount of black water and grey water is generated. A (semi-) centralized ABR is appropriate when there is a pre-existing conveyance technology, such as a simplified sewer. This technology is suitable for areas where land may be limited since the tank is most commonly installed underground and requires a small area. However, a vacuum truck should be able to access the location because the sludge must be regularly removed (particularly from the settler).

Operation & Maintenance: all pre-treatment facilities must be regularly monitored and cleaned to ensure proper functioning. If the maintenance frequency is too low, strong odours can result from the degradation of the accumulated material. Insufficiently maintained pre-treatment units can eventually lead to the failure of downstream elements of a sanitation system. The pre-treatment products should be disposed of as solid waste in an environmentally sound way. In the

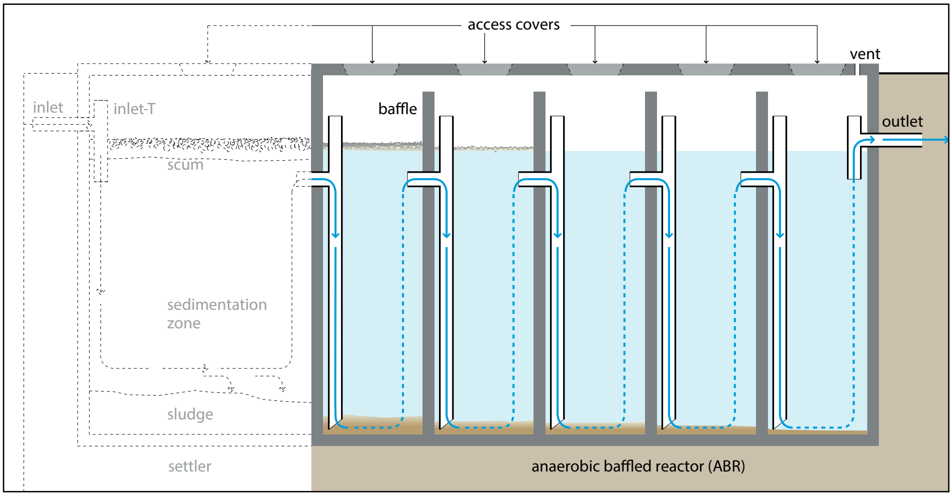

Figure 5.15. Anaerobic Baffled Reactor (ABR) (Source: Tilley et al).

case of grease, it may be used for energy production (e.g., biodiesel or co-digestion), or recycled for re-use.

5.5 Treatment technologies – Activated sludge

An activated sludge process refers to a multi-chamber reactor unit that makes use of highly concentrated microorganisms to degrade organics and remove nutrients from wastewater to produce a high-quality effluent. To maintain aerobic conditions and to keep the activated sludge suspended, a continuous and well-timed supply of oxygen is required. Different configurations of the activated sludge process can be employed to ensure that the wastewater is mixed and aerated in an aeration tank. Aeration and mixing can be provided by pumping air or oxygen into the tank or by using surface aerators. The microorganisms oxidize the organic carbon in the wastewater to produce new cells, carbon dioxide and water.

Although aerobic bacteria are the most common organisms, facultative bacteria along with higher organisms can be present. The exact composition depends on the reactor design, environment, and wastewater characteristics. The flocs (agglomerations of sludge particles), which form in the aerated tank, can be removed in the secondary clarifier by gravity settling. Some of this sludge is recycled from the clarifier back to the reactor. The effluent can be discharged or treated in a tertiary treatment facility if necessary for further use.

Design Considerations: Activated sludge processes are one part of a complex treatment system. They are usually used after primary treatment and are sometimes followed by a final polishing step. The biological processes that occur are effective at removing soluble, colloidal and particulate materials. The reactor can be designed for biological nitrification and denitrification, as well as for biological phosphorus removal. The design must be based on an accurate estimation of the wastewater composition and volume. Treatment efficiency can be severely compromised if the plant is under- or over-dimensioned. Depending on the temperature, the solids retention time (SRT) in the reactor ranges from 3 to 5 days for BOD removal, to 3 to 18 days for nitrification.

The excess sludge requires treatment to reduce its water and organic content and to obtain a stabilized product suitable for end-use or final disposal. It is important to consider this step in the planning phase of the treatment plant. To achieve specific effluent goals for BOD, nitrogen and phosphorus, different adaptations and modifications have been made to the basic activated sludge design. Well known modifications include sequencing batch reactors (SBR), oxidation ditches, extended aeration, moving beds and membrane bioreactors.

Appropriateness: An activated sludge process is only appropriate for a centralized treatment facility with a well-trained staff, constant electricity and a highly developed management system that ensures that the facility is correctly operated and maintained. Because of economies of scale and less fluctuating in-

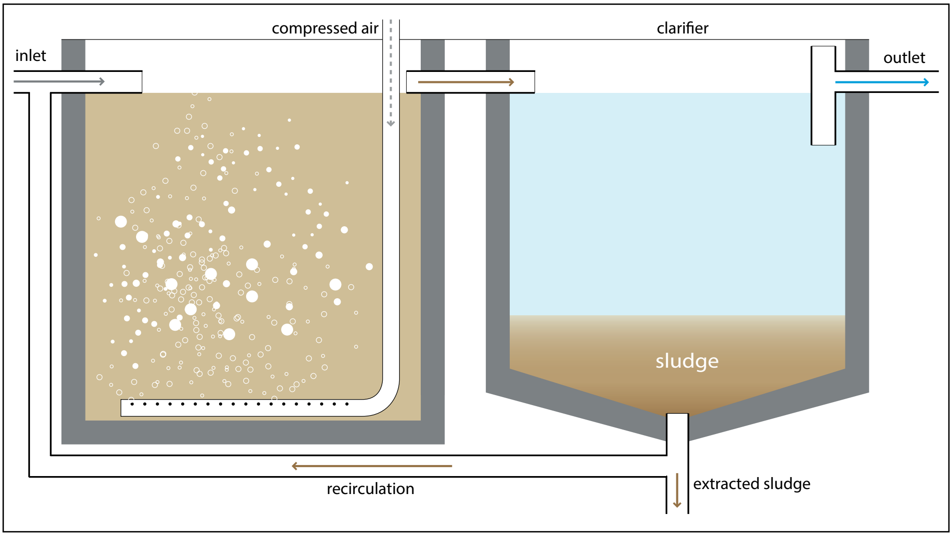

Figure 5.16. Activated Sludge (Source: Tilley et al).

fluent characteristics, this technology is more effective for the treatment of large volumes of flows. An activated sludge process is appropriate in almost every climate. However, treatment capacity is reduced in colder environments.

Health Aspects/Acceptance: Because of space requirements and odours, centralized treatment facilities are generally located in the periphery of densely populated areas. Although the effluent produced is of high quality, it still poses a health risk and should not be directly handled. In the excess sludge pathogens are substantially reduced, but not eliminated.

Operation & Maintenance: Highly trained staff is required for maintenance and trouble-shooting. The mechanical equipment (mixers, aerators and pumps) must be constantly maintained. As well, the influent and effluent must be constantly monitored and the control parameters adjusted, if necessary, to avoid abnormalities that could kill the active biomass and the development of detrimental organisms which could impair the process (e.g., filamentous bacteria).

Pros & Cons

+ Resistant to organic and hydraulic shock loads
+ Can be operated at a range of organic and hydraulic loading rates
+ High reduction of BOD and pathogens (up to 99%)
+ High nutrient removal possible
+ Can be modified to meet specific discharge limits
- High energy consumption, a constant source of electricity is required
- High capital and operating costs
- Requires operation and maintenance by skilled personnel
- Prone to complicated chemical and microbiological problems
- Not all parts and materials may be locally available
- Requires expert design and construction
- Sludge and possibly effluent require further treatment and/or appropriate discharge

5.6 Trickling filter

A trickling filter is a fixed-bed, biological reactor that operates under (mostly) aerobic conditions. Pre-settled wastewater is continuously ‘trickled’ or sprayed over the filter. As the water migrates through the pores of the filter, organics are degraded by the biofilm covering the filter material. The trickling filter is filled with a high specific surface area material, such as rocks, gravel, shredded PVC bottles, or special pre-formed plastic filter media. A high specific surface provides a large area for biofilm formation. Organisms that grow in the thin biofilm over the surface of the media oxidize the organic load in the wastewater to carbon dioxide and water, while generating new biomass. The incoming pre-treated wastewater is 'trickled' over the filter, e.g., with the use of a rotating sprinkler. In this way, the filter media goes through cycles of being dosed and exposed to air. However, oxygen is depleted within the biomass and the inner layers may be anoxic or anaerobic.

Design Considerations: the filter is usually 1 to 2.5 m deep, but filters packed with lighter plastic filling can be up to 12 m deep. The ideal filter material is low cost and durable, has a high surface to volume ratio, is light, and allows air to circulate.

Whenever it is available, crushed rock or gravel is the cheapest option. The particles should be uniform and 95% of them should have a diameter between 7 and 10 cm. A material with a specific surface area between 45 and 60 m2/m3 for rocks and 90 to 150 m2/m3 for plastic packing is normally used. Larger pores (as in plastic packing) are less prone to clogging and provide for good air circulation. Primary treatment is also essential to prevent clogging and to ensure efficient treatment. Adequate air flow is important to ensure sufficient treatment performance and prevent odours. The underdrains should provide a passageway for air at the maximum filling rate. A perforated slab supports the bottom of the filter, allowing the effluent and excess sludge to be collected. The trickling filter is usually designed with a recirculation pattern for the effluent to improve wetting and flushing of the filter material.

With time, the biomass will grow thick and the attached layer will be deprived of oxygen; it will enter an endogenous state, will lose its ability to stay attached and will slough off. High-rate loading conditions will also cause sloughing. The collected effluent should be clarified in a settling tank to remove any biomass that may have dislodged from the filter. The hydraulic and nutrient loading rate (i.e., how much wastewater can be applied to the filter) is determined based on the characteristics of the wastewater, the type of filter media, the ambient temperature, and the discharge requirements.

Appropriateness: This technology can only be used following primary clarification since high solids loading will cause the filter to clog. A low-energy (gravity) trickling system can be designed, but in general, a continuous supply of power and wastewater is required. Compared to other technologies, trickling filters are compact, although they are still best suited for peri-urban or large, rural settlements.

Trickling filters can be built in almost all environments, but special adaptations for cold climates are required.

Health Aspects/Acceptance: Odour and fly problems require that the filter be built away from homes and businesses. Appropriate measures must be taken for

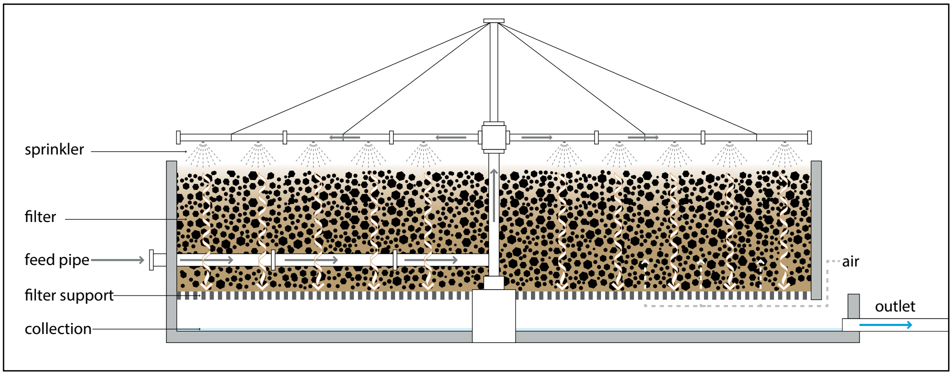

Figure 5.17 Trickling filter (Source: Tilley et al).

pre- and primary treatment, effluent discharge and solids treatment, all of which can still pose health risks.

Operation & Maintenance: A skilled operator is required to monitor the filter and repair the pump in case of problems. The sludge that accumulates on the filter must be periodically washed away to prevent clogging and keep the biofilm thin and aerobic. High hydraulic loading rates (flushing doses) can be used to flush the filter. Optimum dosing rates and flushing frequency should be determined from the field operation. The packing must be kept moist. This may be problematic at night when the water flow is reduced or when there are power failures. Snails grazing on the biofilm and filter flies are well known problems associated with trickling filters and must be handled by backwashing and periodic flooding.

Pros & Cons

+ Can be operated at a range of organic and hydraulic loading rates
+ Efficient nitrification (ammonium oxidation)
+ Small land area required compared to constructed wetlands
- High capital costs
- Requires expert design and construction, particularly, the dosing system
- Requires operation and maintenance by skilled personnel
- Requires a constant source of electricity and constant wastewater flow
- Flies and odours are often problematic
- Risk of clogging, depending on pre- and primary treatment
- Not all parts and materials may be locally available

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Chapter 6
The use of ponds for wastewater treatment

6.1 Waste stabilization ponds (WSP)

Waste Stabilization Ponds (WSPs) are large, manmade water bodies. The ponds can be used individually, or linked in a series for improved treatment. There are three types of ponds, (1) anaerobic, (2) facultative and (3) aerobic (maturation), each with different treatment and design characteristics. For the most effective treatment, WSPs should be linked in a series of three or more with effluent flowing from the anaerobic pond to the facultative pond and, finally, to the aerobic pond. The anaerobic pond is the primary treatment stage and reduces the organic load in the wastewater. The entire depth of this fairly deep pond is anaerobic.

Solids and BOD removal occurs by sedimentation and through subsequent anaerobic digestion inside the sludge. Anaerobic bacteria convert organic carbon into methane and, through this process, remove up to 60% of the BOD. In a series of WSPs, the effluent from the anaerobic pond is transferred to the facultative pond, where further BOD is removed. The top layer of the pond receives oxygen from natural diffusion, wind mixing and algae-driven photosynthesis. The lower layer is deprived of oxygen and becomes anoxic or anaerobic. Settleable solids accumulate and are digested on the bottom of the pond. The aerobic and anaerobic organisms work together to achieve BOD reductions of up to 75%.

Anaerobic and facultative ponds are designed for BOD removal, while aerobic ponds are designed for pathogen removal. An aerobic pond is commonly referred to as a maturation, polishing, or finishing pond because it is usually the last step in a series of ponds and provides the final level of treatment. It is the shallowest of the ponds, ensuring that sunlight penetrates the full depth for photosynthesis to occur. Photosynthetic algae release oxygen into the water and at the same time consume carbon dioxide produced by the respiration of bacteria. Because photosynthesis is driven by sunlight, the dissolved oxygen levels are highest during the day and drop off at night. Dissolved oxygen is also provided by natural wind mixing.

Design Considerations: anaerobic ponds are built to a depth of 2 to 5 m and have a relatively short detention time of 1 to 7 days. Facultative ponds should be constructed to a depth of 1 to 2.5 m and have a detention time between 5 to 30

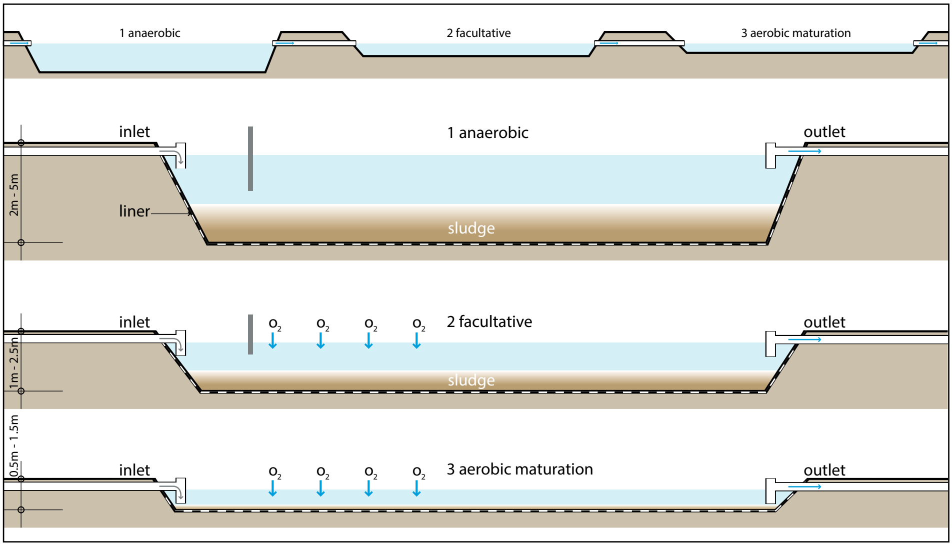

Figure 6.1 Waste stabilization ponds (WSP) (Source: Tilley et al).

days. Aerobic ponds are usually between 0.5 to 1.5 m deep. If used in combination with algae and/or fish harvesting, this type of pond is effective at removing the majority of nitrogen and phosphorus from the effluent. Ideally, several aerobic ponds can be built in series to provide a high level of pathogen removal. Pre-treatment is essential to prevent scum formation and to hinder excess solids and garbage from entering the ponds. To prevent leaching into the groundwater, the ponds should have a liner. The liner can be made from clay, asphalt, compacted earth, or any other impervious material. To protect the pond from runoff and erosion, a protective berm should be constructed around the pond using the excavated material.

A fence should be installed to ensure that people and animals stay out of the area and that garbage does not enter the ponds.

Appropriateness: WSPs are among the most common and efficient methods of wastewater treatment around the world. They are especially appropriate for rural and peri-urban communities that have large, unused land, at a distance from homes and public spaces. They are not appropriate for very dense or urban areas.

Health Aspects/Acceptance: Although effluent from aerobic ponds is generally low in pathogens, the ponds should in no way be used for recreation or as a direct source of water for consumption or domestic use.

Operation & Maintenance: Scum that builds up on the pond surface should be regularly removed. Aquatic plants (macrophytes) that are present in the pond should also be removed as they may provide a breeding habitat for mosquitoes and prevent light from penetrating the water column. The anaerobic pond must be desludged approximately once every 2 to 5 years, when the accumulated solids reach one third of the pond volume. For facultative ponds sludge removal is even rarer and maturation ponds hardly ever need desludging. Sludge can be removed by using a raft-mounted sludge pump, a mechanical scraper at the bottom of the pond or by draining and dewatering the pond and removing the sludge with a front-end loader.

Pros & Cons

+ Resistant to organic and hydraulic shock loads
+ High reduction of solids, BOD and pathogens
+ High nutrient removal if combined with aquaculture
+ Low operating costs
+ No electrical energy is required
+ No real problems with insects or odours if designed and maintained correctly
- Requires a large land area
- High capital costs depending on the price of land
- Requires expert design and construction
- Sludge requires proper removal and treatment

6.2 Fish ponds

Fish can be grown in ponds that receive effluent or sludge where they can feed on algae and other organisms that grow in the nutrient-rich water. The fish, thereby, remove the nutrients from the wastewater and are eventually harvested for consumption.

Three kinds of aquaculture designs for raising fish exist: 1) fertilization of fish ponds with effluent; 2) fertilization of fish ponds with excreta/sludge; and 3) fish grown directly in aerobic ponds. Fish introduced into aerobic ponds can effectively reduce algae and help control the mosquito population. It is also possible to combine fish and floating plants in one single pond. The fish themselves do not dramatically improve the water quality, but because of their economic value they can offset the costs of operating a treatment facility. Under ideal operating conditions, up to 10,000 kg/ha of fish can be harvested. If the fish are not acceptable for human consumption, they can be a valuable source of protein for other high-value carnivores (like shrimp) or converted into fishmeal for pigs and chickens.

Design Considerations: The design should be based on the quantity of nutrients to be removed, the nutrients required by the fish and the water requirements needed to ensure healthy living conditions (e.g., low ammonium levels, required water temperature, etc.).

When introducing nutrients in the form of effluent or sludge, it is important to limit the additions so that aerobic conditions are maintained. BOD should not exceed 1 $g/m^2/d$ and oxygen should be at least 4 mg/L. Only fish tolerant of low dissolved oxygen levels should be chosen. They should not be carnivores and they should be tolerant to diseases and adverse environmental conditions. Different varieties of carp, milkfish and tilapia have been successfully used, but the specific choice will depend on local preference and suitability.

Appropriateness: A fish pond is only appropriate where there is a sufficient amount of land (or pre-existing pond), a source of fresh water and a suitable climate. The water used to dilute the waste should not be too warm, and the ammonium levels should be kept low or negligible because of its toxicity to fish. This technology is appropriate for warm or tropical cli-mates with no freezing temperatures, and preferably with high rainfall and minimal evaporation.

Health Aspects/Acceptance: Where there is no other source of readily available protein, this technology may be embraced. The quality and condition of the fish will also influence local acceptance. There may be concern about contamination of the fish, especially when they are harvested, cleaned and prepared. If they are cooked well, they should be safe, but it is advisable to move the fish to a clear-water pond for several weeks before they are harvested for consumption. WHO guidelines on wastewater and excreta use in aquaculture should be consulted for detailed information and specific guidance.

Operation & Maintenance: The fish need to be harvested when they reach an appropriate age/size. Sometimes after harvesting, the pond should be drained so that it can be desludged and (b) it can be left to dry in the sun for 1 to 2 weeks to destroy any pathogens living on the bottom or sides of the pond. Workers should wear appropriate protective clothing.

Pros & Cons

\+ Can provide a cheap, locally available protein source
\+ Potential for local job creation and income generation
\+ Relatively low capital costs; operating costs should be offset by production revenue
\+ Can be built and maintained with locally available materials
\- Requires abundance of fresh water
\- Requires a large land (pond) area
\- May require expert design and installation
\- Fish may pose a health risk if improperly prepared or cooked
\- Social acceptance may be low in some areas

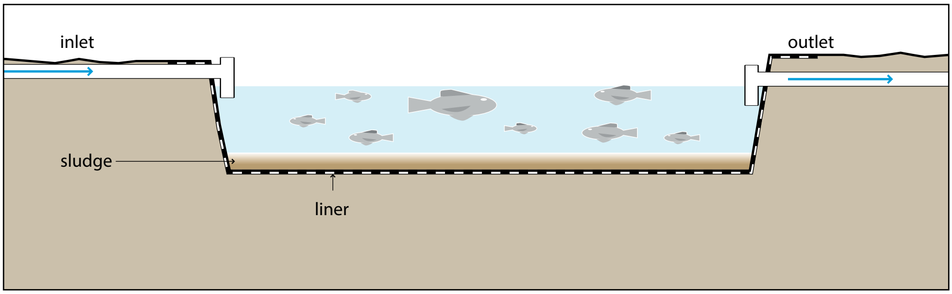

Figure 6.2 Fish pond (Source: Tilley et al).

6.3 Floating plant pond

A floating plant pond is a modified maturation pond with floating (macrophyte) plants. Plants such as water hyacinths or duckweed float on the surface while the roots hang down into the water to uptake nutrients and filter the water that flows by. Water hyacinths are perennial, freshwater, aquatic macrophytes that grow especially fast in wastewater. The plants can grow large: between 0.5 to 1.2 m from top to bottom. The long roots provide a fixed medium for bacteria which in turn degrade the organics in the water passing by. Duckweed is a fast growing, high protein plant that can be used fresh or dried as a food for fish or poultry. It is tolerant of a variety of conditions and can significantly remove quantities of nutrients from wastewater.

Design Considerations: locally appropriate plants can be selected depending on their availability and the characteristics of the wastewater. To provide extra oxygen to a floating plant technology, the water can be mechanically aerated but at the cost of increased power and machinery. Aerated ponds can withstand higher loads and can be built with smaller footprints. Non-aerated ponds should not be too deep otherwise there will be insufficient contact between the bacteria-harbouring roots and the wastewater.

Appropriateness: A floating plant pond is only appropriate when there is a sufficient amount of land (or pre-existing pond). It is appropriate for warm or tropical climates with no freezing temperatures, and preferably with high rainfall and minimal evaporation. The technology can achieve high removal rates of both BOD and suspended solids, although pathogen removal is not substantial. Harvested hyacinths can be used as a source of fibre for rope, textiles, baskets, etc.

Depending on the income generated, the technology can be cost neutral. Duckweed can be used as the sole food source for some herbivorous fish.

Health Aspects/Acceptance: Water hyacinth has attractive, lavender flowers. A well designed and maintained system can add value and interest to otherwise

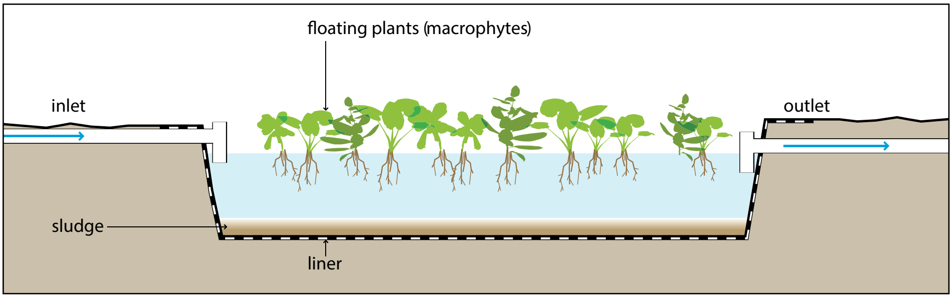

Figure 6.3 Floating plant pond (Source: Tilley et al).

barren land. Adequate signage and fencing should be used to prevent people and animals from coming in contact with the water. Workers should wear appropriate protective clothing. WHO guidelines on wastewater and excreta use in aquaculture should be consulted for detailed information and specific guidance.

Operation & Maintenance: Floating plants require constant harvesting. The harvested biomass can be used for small artisanal businesses, or it can be composted. Mosquito problems can develop when the plants are not regularly harvested. Depending on the amount of solids that enter the pond, it must be periodically desludged. Trained staff is required to constantly operate and maintain it.

Pros & Cons

+ Water hyacinth grows rapidly and is attractive
+ Potential for local job creation and income generation
+ Relatively low capital costs; operating costs can be offset by revenue
+ High reduction of BOD and solids; low reduction of pathogens
+ Can be built and maintained with locally available materials
- Requires a large land (pond) area
- Some plants can become invasive species if released into natural environments

Chapter 7
Ecological wastewater treatment – constructed wetlands

7.1 Advantages of constructed wetland treatment systems

Wetlands, either constructed or natural, offer a cheaper and low-cost alternative technology for wastewater treatment. Wetlands have a capacity to absorb pollutants from water and raise its quality. Natural processes can reduce contaminants and benefit water quality, habitats and biodiversity. Constructed wetlands replicate these natural processes to treat wastewaters. Under controlled conditions, these systems offer potential for secondary and tertiary treatments. Some systems are used for total treatment and others as a final polishing stage.

Constructed wetlands are cheaper alternative for wastewater treatment using local resources. Aesthetically, it is a more landscaped looking wetland site compared to the conventional wastewater treatment plants. This system promotes sustainable use of local resources, which is a more environment friendly biological wastewater treatment system. Constructed wetlands can be created at lower costs than other treatment options, with low-technology methods where no new or complex technological tools are needed. The system relies on renewable energy sources such as solar and kinetic energy, and wetland plants and micro-organisms, which are the active agents in the treatment processes.

The system can tolerate both great and small volumes of water and varying contaminant levels. These include municipal and domestic wastewater, urban storm runoff, agricultural wastewater, industrial effluents and polluted surface waters in rivers and lakes. The system could be promoted to various potential users for water quality improvement and pollutant removal. These potential users include the tourism industry, governmental departments, private entrepreneurs, private residences, aquaculture industries and agro-industries. Utilisation of local products and labour, helps to reduce the operation and maintenance costs of the applied industries. Less energy and raw materials are needed, with periodic on-site labour, rather than continuous full time attention. This system indirectly will contribute greatly in the reduction of use of natural resources in conventional treatment plants, and wastewater discharges to natural waterways are also reduced (Wetlands International, 2003).

The primary purpose of constructed wetland treatment systems is to treat various kinds of wastewater (municipal, industrial, agricultural and storm water). However the system usually serves other purposes as well. A wetland can serve as a wildlife sanctuary and provide a habitat for wetland animals (Wetlands International, 2003). Since natural wetlands were the primary resting grounds for migrating birds, they have fewer and fewer places to stop, rest and eat. Constructed wetlands can take this role and also provide habitat for fish, mammals, reptiles and amphibians (Stovall, 2007). The wetland system can also be aesthetically pleasing and serve as an attractive destination for tourists and local urban dwellers. It can also serve as a public attraction sanctuary for visitors to explore its environmental and educational possibilities. It appeals to different groups varying from engineers to those involved in wastewater facilities as well as environmentalists and people concerned with recreation.

This constructed wetland treatment system also provides a research and training ground for young scientists in this new research and education arena. The constructed wetland system also could be used to clean polluted rivers and other water bodies. This derived technology can eventually be used to rehabilitate grossly polluted rivers in the country. The constructed wetland treatment system is widely applied for various functions. These functions include primary settled and secondary treated sewage treatment, tertiary effluent polishing and disinfecting, urban and rural runoff management, toxicant management, landfill and mining leachate treatment, sludge management, industrial effluent treatment, enhancement of in-stream nutrient assimilation, nutrient removal via biomass production and export, and groundwater recharge (Wetlands International, 2003).

7.2. Types of constructed wetlands

Constructed wetlands treatment systems generally fall into three categories (Figure 7.1): free water subsurface (SF, FWS), subsurface flow (SB, SSF), and hybrid CWs. SSF CWs may be further classified according to flow direction into vertical subsurface flow (VSB, VSSF) and horizontal subsurface flow (HSF, HSSF) systems.

Surface-Flow (SF) or Free-Water Surface (FWS) systems. The FWS wetland has an open water surface with a bed of clay soil for vegetation to take root (Figure 7.2). This vegetation shelters the water surface from the sun, limiting algal growth and reducing water turbulence from wind. Wastewater is spread over a large area at a shallow depth, to achieve effective removal of nutrients by oxidising N and P, adsorption in soils and removal by microbial processes and plant consumption (Kimo, 2011). These types utilise influent waters that flow across a

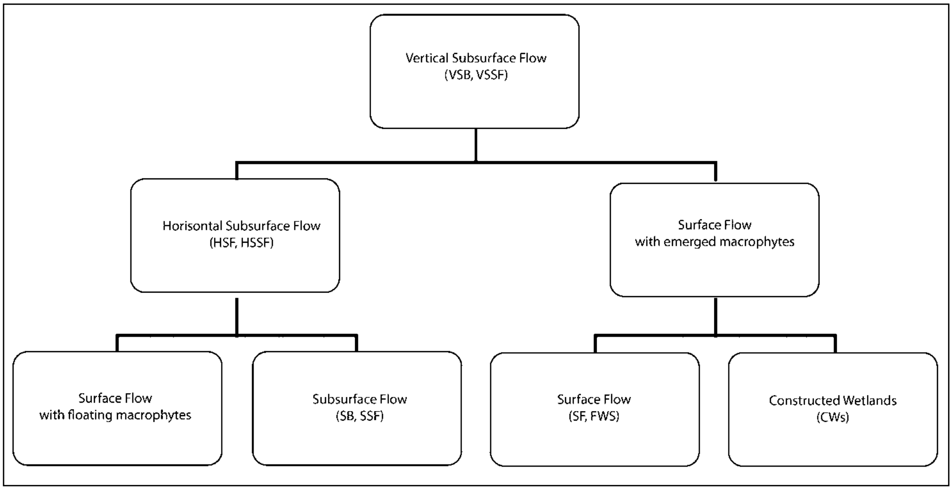

Figure 7.1. Types of constructed wetlands (Source: Kimo, 2011).

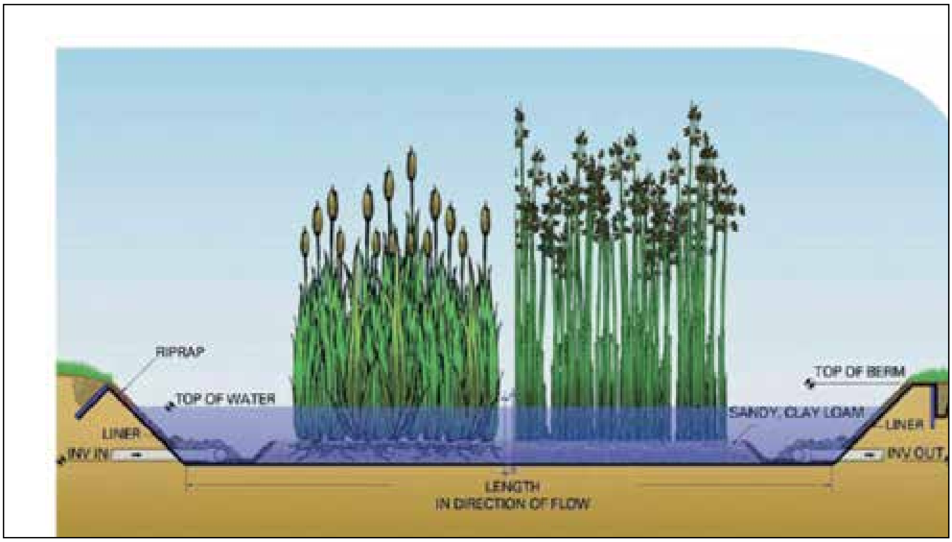

Figure 7.2. Surface Flow Wetland (Kimo, 2011)

basin or a channel that supports a variety of vegetation, and water is visible at a relatively shallow depth above the surface of the substrate materials. Substrates are generally native soils and clay or impervious geotechnical materials that prevent seepage (Wetlands International, 2003).

Surface flow wetlands have the water level and flow above the ground surface and vegetation is rooted and emerges above the water surface. The near surface water layer is aerobic while the deeper water and substrate are usually anaerobic

(Jurries, 2003). Possible implementations of FWS CWs covers: a) storm water treatment; b) upgrading the quality of small water courses; c) agricultural runoff treatment; and d) tertiary treatment of municipal or domestic wastewater.

Subsurface flow wetlands. The subsurface flow wetlands use a filtration medium and vegetation to treat wastewater (Figure 7.3). The water level is kept below the surface of the medium to ensure minimal exposure to humans and to limit the risk of increasing insect populations.

Aerobic conditions around roots and water surfaces allow some removal of N, but anoxic conditions are limiting. Tertiary treatment can be achieved with longer retention of wastewater, aeration devices and vertical-flow systems, which raise oxygen levels for effective treatment.

Phosphorus, metals and persistent organic pollutants are bound in sediments, and accumulate over time; their levels are reduced from effluent discharges but remain in the wetland system (Kimo, 2011).

In a vegetated Sub-surface Flow (SSF) system, water flows from one end to the other end through permeable substrates which is made of mixture of soil and gravel or crusher rock. The substrate will support the growth of rooted emergent vegetation. It is also called "Root-Zone Method" or "Rock-Reed-Filter" or "Emergent Vegetation Bed System".

The media depth is about 0.6 m deep and the bottom is lined to prevent seepage. Media size for most gravel substrate ranged from 5 to 230 mm with 13 to

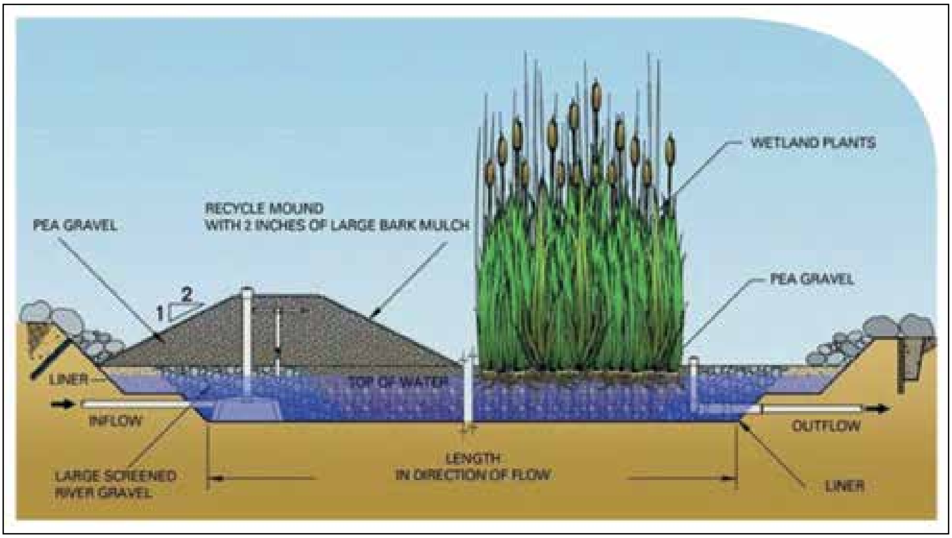

Figure 7.3. Subsurface Flow Wetland (Kimo, 2011)

76 mm being typical. The bottom of the bed is sloped to minimise water that flows overland. Wastewater flows by gravity horizontally through the root zone of the vegetation about 100-150 mm below the gravel surface. Many macro and micro-organisms inhabit the substrates. Free water is not visible. The inlet zone has a buried perforated pipe to distribute maximum flow horizontally through the treatment zone. Treated water is collected at outlets at the base of the media, typically 0.3 to 0.6 m below bed surface (Wetlands International, 2003). Subsurface wetlands provide greater attachment surface area for biota and may treat wastewater faster and thus promote smaller constructed wetlands for the same level of treatment (Jurries, 2003).

7.3. Wetlands plants in wastewater treatment

Selection of wetland plants. Most of water plants types (Figure 5.5) can be used in constructed wetland systems. Emerged plants can be implemented in both surface and subsurface flow wetlands while submerged and floating plants will be found in surface flow systems only.

A range of aquatic plants have shown their ability to assist in the breakdown of wastewater.

The Water Hyacinth (*Eichhornia crassipes*), and Duckweed (*Lemna*) are common floating aquatic plants which have shown their ability to reduce con-

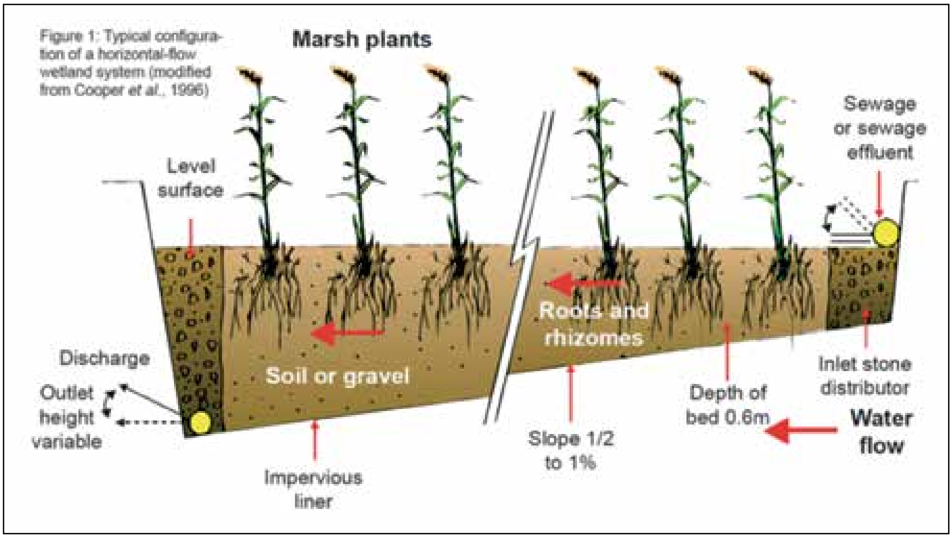

Figure 7.4. Typical configuration of horizontal flow wetland system (Wetands International, 2003).

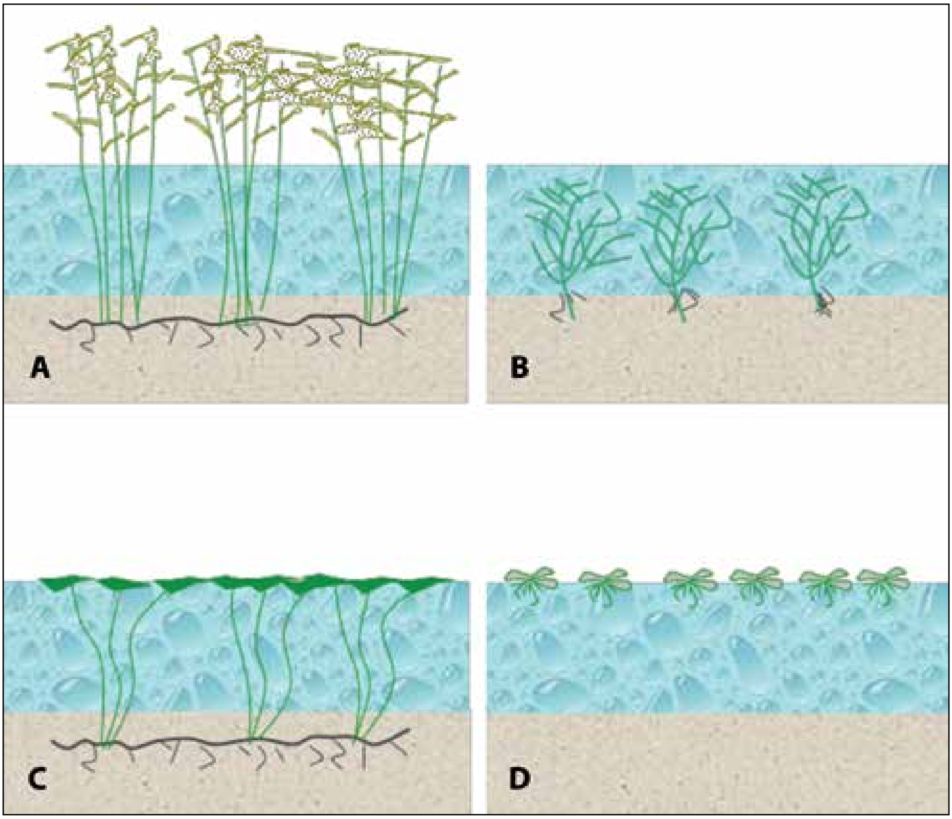

Figure 7.5. Types of plants: a) emegred; b) submerged; c) and d) floating

centrations of BOD, TSS and Total Phosphorus and Total Nitrogen. However prolonged presence of *Eichhornia crassipes* and *Lemna* can lead to deterioration of the water quality unless these plants are manually removed on a regular basis. These floating plants will produce a massive mat that will obstruct light penetration to the lower layer of the water column that will affect the survival of living water organisms.

This system is colonised rapidly with one or only a few initial individuals. The system needs to be closely monitored to prevent attack from these nuisance species. Loss of plant cover will impair the treatment effectiveness. Maintenance cost of a floating plant system is high. Plant biomass should be regularly harvested to ensure significant nutrient removal. Plant growth also needs to be maintained at an optimum rate to maintain treatment efficiency (Wetlands International, 2003).

The Common Reed (*Phragmites* spp.) and Cattail (*Typha* spp.) are good examples of emergent species used in constructed wetland treatment systems. Emergent wetland plants grow best in both SF and SSF systems. These emergent plants play a vital role in the removal and retention of nutrients in a constructed wetland. Although emergent macrophytes are less efficient at lowering Nitrogen and Phosphorus contents by direct uptake due to their lower growth rates (compared to floating and submerged plants), their ability to uptake Nitrogen and Phosphorus from sediment sources through rhizomes is higher than from the water (Wetlands International, 2003).

There is a variety of marsh vegetation that is suitable for planting in a CWs (Table 7.1). These marsh species could be divided into deep and shallow marshes. Reeds *Phragmites* are a tall annual grasses with an extensive perennial rhizome. Reeds have been used in Europe in the root-zone method and are the most widespread emergent aquatic plant. *Phragmites* is a highly invasive plant. *Phragmites* can spread laterally throughout the year by producing new shoots from spreading rhizomes. The plant grows abundantly in moist and water-logged areas, both freshwater and brackish, along rivers, ditches, lake shores and ponds (EPA/625/1-88/022).

Table 7.1. List of emergent wetland plants used in constructed wetland systems in Malaysia (Wetands International, 2003).

Planting zones	Common name	Scientific name
Marsh and deep marsh (0.3-1.0 m)	Common Reed	*Phragmites karka*
	Spike Rush	*Eleocharis dulcis*
	Greater Club Rush	*Scirpus grossus*
	Bog Bulrush	*Scirpus mucronatus*
	Tube Sedge	*Lepironia articulata*
	Fan Grass	*Phylidrium lanuginosum*
	Cattail	*Typha angustifolia*
Shallow marsh (0-0.3 m)	Golden Beak Sedge	*Rhynchospora corymbosa*
	Spike Rush	*Eleocharis variegata*
	Sumatran Scleria	*Scleria sumatrana*
	Globular Fimbristylis	*Fimbristylis globulosa*
	Knot Grass	*Polygonum barbatum*
	Asiatic Pipewort	*Erioucaulon longifolium*

Figure 7.6. Emerged aquatic plants (from the left): reed, cattail and rush

Cattails *Typha spp.* are perennial plants ubiquitous in distribution, hardy, capable of thriving under diverse environmental conditions, and easy to propagate and thus represent an ideal plant species for constructed wetlands. They are also capable of producing a large annual biomass and provide a small potential for N and P removal, when harvesting is practiced. Cattail rhizomes planted at approximately 1 m intervals can produce a dense stand within 3 months (EPA/625/1-88/022).

Rushes *Juncus* are perennial, grasslike herbs that grow in clumps. Bulrushes (*Scirpus spp*.) are ubiquitous plants that grow in a diverse range of inland and coastal waters, brackish and salt marshes and wetlands. Bulrushes are capable of growing well in water that is 5 cm to 3 m deep. Bulrushes are found growing in a pH of 4-9 (EPA/625/1-88/022).

Spike Rush *Eleocharis dulcis* is a perennial plant. It is a tufted plant with leafless slender stems. It has hollow stems with internal transverse partitions. The inflorescence is a single spikelet at the end of the stem, upright with glumes that spirally arranged. It is brownish in colour and 1.5-6.0 cm in length. It is normally found in open wet places, in brackish and freshwater swamps, rice fields, ponds and lakes (Kimo, 2011).

7.4 Role of wetlands plants in wastewater treatment

In general, the most significant functions of wetland plants (emergents) in relation to water purification are the physical effects brought by the presence of the plants (Table 7.2). The plants provide a huge surface area for attachment and growth of microbes. The physical components of the plants stabilise the surface of the beds, slow down the water flow thus assist in sediment settling and trapping process and finally increasing water transparency. Wetland plants play a vital role in the removal and retention of nutrients and help in preventing the eutrophication of wetlands.

Table 7.2. Summary of the major roles of macrophytes in constructed tretment wetlands

Macrophyte property	Role in treatment process	FWS	HSF/VSB
Aerial plant tissue	Light attenuation – reduced growth of phytoplankton	+	+
	Influence of microclimate – insulation during winter	+	+
	Reduced wind velocity – reduced risk of resuspension	+	+
	Aesthetic pleasing appearance of the system	+	+
	Storage of nutrients (but phosphorus is released back from the biomass to the wetland ecosystem after the plant decay)	+	+
	Habitat for wildlife	+	
Plant tissue in water	Filtering effect – filter out large debris	+	
	Reduced current velocity – increased rate of sedimentation, reduced risk of resuspension	+	
	Increased contact time between the water and the plant surface areas	+	
	Provide surface area for attached biofilms	+	
	Excretion of photosynthetic oxygen – increases aerobic degradation	+	
	Uptake of nutrients	+	
	Attached microbes	+	
Roots and rhizomes in the sediment	Stabilizing sediment surface – less erosion	+	
	Stabilizing bed surface	+	+
	Prevent the medium from clogging (in vertical flow systems)	+	+
	Release the oxygen increase degradation and nitrification	+	+
	Uptake of nutrients		+
	Release of antibiotics		+
	Attached microbes		+

A range of wetland plants has shown their ability to assist in the breakdown of wastewater. The Common Reed and Cattail are good examples of marsh species that can effectively uptake nutrients. These plants have a large biomass both above (leaves) and below (underground stem and roots) the surface of the substrate. The sub-surface plant tissues grow horizontally and vertically, and create an extensive matrix, which binds the soil particles and creates a large surface area for the uptake of nutrients and ions. Hollow vessels in the plant tissues enable oxygen to be transported from the leaves to the root zone and to the surrounding. This enables the active microbial aerobic decomposition process and the uptake of pollutants from the water system to take place (Wetlands International, 2003).

The roles of wetland plants in constructed wetland systems can be divided into 6 categories (Wetlands International, 2003):

Box 7.1. Treatment and the role of plants in constructed wetlands

Purification systems by constructed wetlands reproduce the purification process of natural ecosystems (Wetzel, 1993. The great degree of heterogeneity and diversity of plants, soils and types of water flow make a wide variety of methods possible:

- systems that flow below the ground surface (verttical or horisontal flow reed bed filters);
- free water surface flow systems (see natural lagooning);
- more rarely, irrigation of planted systems (with willows for example), of woods with frequent cutting in order to complete treatment by a final filtering;

For all of the constructed wetlands, the following different treatment mechanisms can be found:

Physical mechanisms:

- filtering thorugh porous areas and root systems (see mechanisms in fixed film cultures;
- sedimentation of SS and of colloids in lagoons or marshes (see supended growth cultures mechanisms);

Chemical mechanisms:

- precipitation of insoluble compounds or co-precipitation with insoluble compounds (N, P);
- adsoption of the substrate, according to the characteristics of the support that is set up, or by plants (n, p, metals);
- decomposition by UV radiation phenomena (virus and bacteria), oxidation and reduction (metals);

Biological mechanisms

- Biological mechanisms, due to fixed film or free bacterial development, allow the degradation of organic matter, nitrification in aerobic zones and denitrification (see glossary) in aerobic zones. For free water surface systems, biological purification takes place via aerobic proceses near the water surface and sometimes aerobic processes near the water surface and sometimes aerobic process near the deeper deposits. The development of attached algae or in suspension in the water (phytoplankton) supplies via photosythesis the oxygen that is needed by aerobic purifying bacteria and fixes a part of the nutrients ("lagooning" effect).

Physical – Macrophytes stabilise the surface of plant beds, provide good conditions for physical filtration, and provide a huge surface area for attached microbial growth. Growth of macrophytes reduces current velocity, allowing for sedimentation and increase in contact time between effluent and plant surface area, thus, to an increase in the removal of Nitrogen.

Soil hydraulic conductivity – Soil hydraulic conductivity is improved in an emergent plant bed system. Turnover of root mass creates macropores in a constructed wetland soil system allowing for greater percolation of water, thus increasing effluent/plant interactions.

Org*anic compound release* – Plants have been shown to release a wide variety of organic compounds through their root systems, at rates up to 25% of the total photosynthetically fixed carbon. This carbon release may act as a source of food for denitrifying microbes. Decomposing plant biomass also provides a durable, readily available carbon source for the microbial populations.

Microbial growth – Macrophytes have above and below ground biomass to provide a large surface area for growth of microbial biofilms. These biofilms are responsible for a majority of the microbial processes in a constructed wetland system, including Nitrogen reduction. Plants create and maintain the litter/humus layer that may be likened to a thin biofilm. As plants grow and die, leaves and stems falling to the surface of the substrate create multiple layers of organic debris (the litter/humus component). This accumulation of partially decomposed biomass creates highly porous substrate layers that provide a substantial amount of attachment surface for microbial organisms. The water quality improvement function in constructed and natural wetlands is related to and dependent upon the high conductivity of this litter/humus layer and the large surface area for microbial attachment.

Creation of aerobic soils – Macrophytes mediate transfer of oxygen through the hollow plant tissue and leakage from root systems to the rhizosphere where aerobic degradation of organic matter and nitrification will take place. Wetland plants have adaptations with submersed and lignified layers in the hypodermis and outer cortex to minimise the rate of oxygen leakage. The high Nitrogen removal of *Phragmites* is most likely attributable to the characteristics of its root growth. *Phragmites* allocates 50% of plant biomass to root and rhizome systems. Increased root biomass allows for greater oxygen transport into the substrate, creating a more aerobic environment favouring nitrification reactions. Nitrification requires a minimum of 2 mg O_2/l to proceed at a maximum rate. It is evident that the rate of nitrification is most likely the rate limiting factor for overall Nitrogen removal from a constructed wetland system.

Aesthetic values – The macrophytes have additional site-specific values by providing habitat for wildlife and making wastewater treatment systems aesthetically pleasing.

7.5 Design principles of constructed wetland systems

The principal design criteria for a constructed wetland system includes substrate types, pollutant loading rate and retention time. Some design criteria are discussed in detail as below (Wetlands International, 2003).

Choice of wetland plant species – The selected wetland plants are preferred because they have a rapid and relatively constant growth rate. In a tropical sys-

Figure 7.7.Oxygen transport for the root zone (left) and filtering effect of sedge (right) (Wetands International, 2003).

tem, wetland plants have a higher growth rate. These wetland plants are easily propagated by means of runners and by bits of mats breaking off and drifting to new areas. This will help in increasing the capacity of pollutant absorption by the plants. The plants should also be able to tolerate waterlogged-anoxic and hyper-eutrophic conditions. The plant species should be local species and widely distributed in the country. Use of exotic plants in constructed wetland systems should be avoided as they are highly invasive and difficult to control. The plant should be a perennial with a life cycle of more than one year or two growing seasons to ensure the sustainability of the constructed wetland system. Wetland plants with aesthetic appeal will provide a landscape-pleasing environment.

Substrates - Substrates may remove wastewater constituents by ion exchange/ non-specific adsorption, specific adsorption/precipitation and complexation. The choice of substrate is determined in terms of their hydraulic permeability and their capacity to absorb nutrients and pollutants. The substrate must provide a suitable medium for successful plant growth and allow even infiltration and movement of wastewater. Poor hydraulic conductivity will result in surface flow and channelling of wastewater, severely reducing the effectiveness of the system. A successful operation requires a hydraulic conductance of approximately 10^{-3} to 10^{-4} m/s. The chemical composition of the substrate will also affect the efficiency of the system. Soils with low nutrient content will encourage direct uptake of nutrients from the wastewater by plants. Substrate with high Al or Fe content will be most effective at lowering Phosphate concentrations in the influent. Gravels are washed to reduce clogging (increase void spaces) for better filtration. The reed system on gravel reached better nitrification rates, while denitrification was higher in the soilbased reed system. A mixture of organic clay soils, sand, gravels and crushed stones could be used to provide support for plant growth. These substrates are ideal reactive surfaces for ion complexation and microbial attachment, also provide a sufficiently high hydraulic conductivity to avoid short-circuiting in the system.

Area of reed bed – Most wastewater treatment wetlands have been designed for minimum size and cost to provide the required level of pollutant removal. However, operation and maintenance costs may be high. The creation of a maximum effective treatment area will reduce the short-circuiting problem. Generally, horizontal flow wastewater treatment systems should have a 3-4: 1 length to width ratio and be rectangular in shape if minimal treatment area is available. A long length-width ratio is required to ensure plug flow hydraulics.

The required surface area for a sub-surface flow system is calculated according to an empirical formula for the reduction of BOD5 in sewage effluent:

$A_h = KQ_d$ (In C_0 - In C_n) where A_h = surface area of bed, m^2

K = rate constant, (m/day)

Q_d = average daily flow rate of wastewater (m^3/day)

C_0 = average daily BOD5 of the influent (mg/litre)

C_t = required average daily BOD5 of the effluent (mg/litre)

The value of K = 5.2 was derived for a 0.6 m deep bed and operating at a minimum temperature of 8°C. For less biodegradable wastewater, K values of up to 15 may be appropriate. Using this formula, a minimum area of 2.2 m^2 PE^{-1} is obtained for the treatment of domestic sewage. Population equivalent (PE) or unit per capita loading, (PE), in waste-water treatment is the number expressing the ratio of the sum of the pollution load produced during 24 hours by industrial facilities and services to the individual pollution load in household sewage produced by one person in the same time. In practice, most design systems operate on the basis of 3-5 m^2 PE^{-1}.

Nature, loading and distribution of effluent – The long-term efficiency of an emergent bed system is improved if the effluent is pre-treated prior to discharge to the active bed. Suspended particles are settled during storage in a settlement tank or a pond for 24 hours. The BOD of the primary effluent may be reduced by 40%. The removal of Nitrogen and Phosphorus for secondary wastewater is higher.

The flow of wastewater through the emergent bed system is slow, giving a long retention time, therefore the flow must be regulated so that retention times are sufficiently long for pollutant removal to be efficient. A higher reduction efficiency for mass balances of N and P could be achieved by *Phragmites* if water retention time is more than 5 days. Shorter retention times do not provide adequate time for pollutant degradation to occur. Longer retention times can lead to stagnant and anaerobic conditions. Evapotranspiration can significantly increase the retention time.

Basic Design and Construction (Jurries, 2003):

- Shape should be long and relatively narrow. A length to width ratio of 5:1 is preferred, with a minimum ratio of 2:1 to enhance water quality benefits. The longer length allows more travel time and opportunity for infiltration, biofiltration and sedimentation.
- Soils should be tested to determine suitability. Best when located in clay loams, silty clay loams, sandy clays, silty clays and clays.
- Needs to have a shallow marsh system in association to deal with nutrients.
- For mosquito control either stock the pond with fish or allow it to be drained for short periods of time (do not kill the marsh vegetation). Full vegetation with no clear or open water tends to eliminate or at least restrict mosquito populations.
- Selection of vegetation should be done by a wetland specialist. Three to eight different types of vegetation should be used.
- Relatively low maintenance costs.

Design Considerations (Jurries, 2003):

- Constructed wetlands have larger land requirements for equivalent service compared to conventional systems
- There is a delayed efficiency until plants are well established (1 to 2 seasons).
- Vegetation selection should be chosen not only for pollutant uptake and climate but also for ease and frequency of maintenance.
- Extremes in weather and climate should be considered not the average.
- Design with the landscape not against it.
- Replanting of vegetation which initially fail may be necessary.

7.6 Pollutant removal mechanisms in constructed wetland systems

Scientific processes at play in the natural treatment system include:

- Bacterial decomposition (aerobic and anaerobic) of organic wastes
- Natural aeration through waterfalls
- Settling of particles

- Natural cooling, especially at night
- Nutrient uptake by plants
- Metals reduction through sedimentation
- Adsorption of metals to soils, and
- Filtration through gravel or other media
  (Source: Oregon Association of Clean Water Agencies July, 2014)

Wetlands have been found to be effective in treating BOD, TSS, N and P as well as for reducing metals, organic pollutants and pathogens. The principal pollutant removal mechanisms in constructed wetlands include biological processes such as microbial metabolic activity and plant uptake as well as physico-chemical processes such as sedimentation, adsorption and precipitation at the water-sediment, root-sediment and plant-water interfaces (Figure 5.9, Table 5.4). Microbial degradation plays a dominant role in the removal of soluble/colloidal biodegradable organic matter in wastewater.

Biodegradation occurs when dissolved organic matter is carried into the biofilms that attached on submerged plant stems, root systems and surrounding soil or media by diffusion process. Suspended solids are removed by filtration and gravitational settlement. A pollutant may be removed as a result of more than one process at work (Wetlands International, 2003). There are several reasons that organic matter needs to be removed. The first reason is that a high amount of suspended solids decreases the clarity of the water making it difficult for aquatic organisms to catch prey. Another reason is that it can clog the gills of fish and kill them. Also suspended particles block light needed by photosynthetic organisms (Stovall, 2007).

Nitrogen removal mechanisms - The removal of nitrogen is achieved through nitrification/denitrification, volatilisation of ammonia (NH_3) storage in detritus and sediment, and uptake by wetland plants and storage in plant biomass (Figure 5.8). A majority of nitrogen removal occurs through either plant uptake or denitrification. Nitrogen uptake is significant if plants are harvested and biomass is removed from the system. At the root-soil interface, atmospheric oxygen diffuses into the rhizosphere through the leaves, stems, rhizomes and roots of the wetland plants thus creating an aerobic layer similar to those that exists in the media-water or media-air interface.

Nitrogen transformation takes place in the oxidised and reduced layers of media, the root-media interface and the below ground portion of the emergent plants. Ammonification takes place where organic N is mineralised to NH^{4+} ammonium in both oxidised and reduced layers. The oxidised layer and the submerged portions of plants are important sites for nitrification in which ammoniac nitrogen is converted to nitrite (NO^{2-}) by the *Nitrosomonas* bacteria and eventually to nitrate (NO^{3-}) by the *Nitrobacter* bacteria which is either taken up by the plants or diffuses into the reduced zone where it is converted to N_2 and N_2O in the denitrification process.

Denitrification is the permanent removal of nitrogen from the system, however the process is limited by a number of factors, such as temperature, pH, redox potential, carbon availability and nitrate availability. The annual denitrification rate of a surface-flow wetland could be determined using a nitrogen mass-balance approach, accounting for measured influx and efflux of nitrogen, measured uptake of nitrogen by plants, and sediment, and estimated NH_3 volatilisation. The extent of nitrogen removal depends on the design of the system and the form and amount of nitrogen present in the wastewater. If influent nitrogen content is low, wetland plants will compete directly with nitrifying and denitrifying bacteria for NH^{4+} and NO^{3-}, while in high nitrogen content, particularly ammonia, this will stimulate nitrifying and denitrifying activity (Wetlands International, 2003).

Phosphorus removal mechanisms - Phosphorus is present in wastewaters as orthophosphate, dehydrated orthophosphate (polyphosphate) and organic phosphorus. The conversion of most phosphorus to the orthophosphate forms (H_2PO^{4-}, PO_4^{2-}, PO_4^{3-}) is caused by biological oxidation. Most of the phospho-

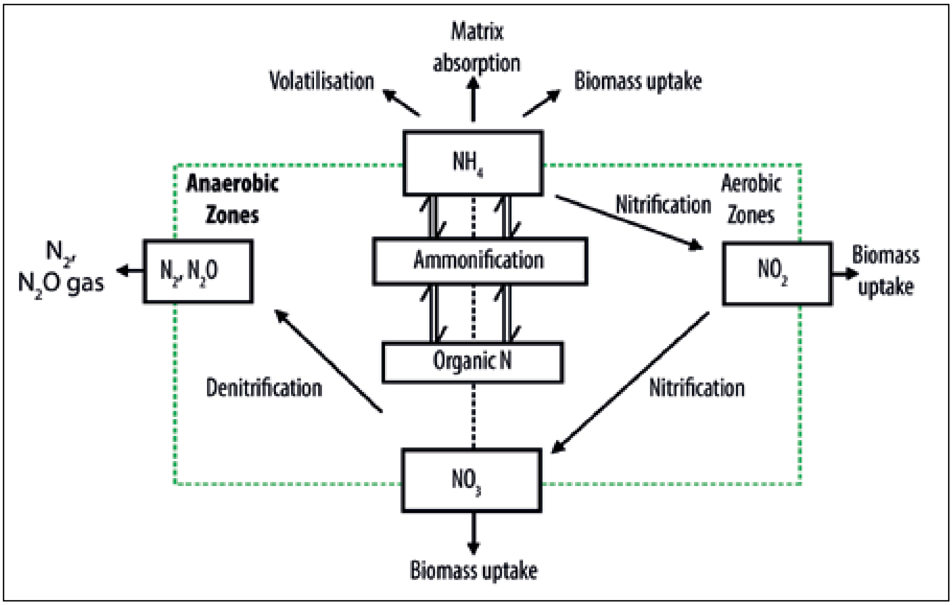

Figure 7.8. Nitrogen transformations in CWs (Wetands International, 2003).

rus component may fix within the soil media. Phosphate removal is achieved by physical-chemical processes, by adsorption, complex formation and precipitation reactions involving calcium (Ca), iron (Fe) and aluminium (Al). The capacity of wetland systems to absorb phosphorus is positively correlated with the sediment concentration of extractable amorphous aluminium and iron (Fe).

Although plant uptake may be substantial, the sorption of phosphorus (orthophosphate P) by anaerobic reducing sediments appears to be the most important process. The removal of phosphorus is more dependent on biomass uptake in constructed wetland systems with subsequent harvesting (Wetlands International, 2003).

Metals are primarily removed by sedimentation after chemical reactions cause them to precipitate out. Some removal is also achieved by plant uptake. Metals should be removed because they can be toxic to organisms (Stovall, 2007).

Faecal coliform organisms such as *E coli* need to be removed from the wastewater. Their presence indicates that other pathogens are likely to be present which could cause diseases such as dysentery, typhoid fever and hepatitis A. The removal mechanism for faecal coliform organisms is not exactly known but is thought to be one or more of the following: sedimentation, adsorption, temperature ingestion or denaturing. Wetlands remove 99% of faecal coliform organisms after about 6 days and 99.9% after 10 days; therefore wetlands can effectively remove pathogens that are hazardous to human health. Each substance has a minimum hydraulic retention time or the time a particle of water takes to travel through the wetland for the substance to be removed to acceptable levels (Stovall, 2007).

Other pollutant removal mechanisms - Evapotranspiration is one of the mechanisms for pollutant removal. Atmospheric water losses from a wetland that occurs from the water and soil is termed as evaporation and from emergent portions of plants is termed as transpiration. The combination of both processes is termed as evapotranspiration. Daily transpiration is positively related to mineral adsorption and daily transpiration could be used as an index of the water purification capability of plants. Precipitation and evapotranspiration influence the water flow through a wetland system. Evapotranspiration slows water flow and increases contact times, whereas rainfall, which has the opposite effect, will cause dilution and increased flow. Precipitation and evaporation are likely to have minimal effects on constructed wetlands in most areas. If the wetland type is primarily shallow open water, precipitation/evaporation ratios fairly approximate water balances. However, in large, dense stands of tall plants, transpiration losses from photosynthetically active plants become significant (Wetlands International, 2003).

Pollutant removal performance varies for each system based on factors such as wastewater influent flow, pollutant load, characteristics of the sediment and/

or vegetation in place, local climatic conditions, and others (Oregon Association of Clean Water Agencies July, 2014). A variety of factors will influence each treatment systems performance. These discharge chemistries are the result of a number of factors, including but not limited to: influent parameter concentrations and loadings; regional parameter background concentrations in similar natural wetlands; hydraulic loading rate; residence time HRT (Table 5.3); water depth; vegetation density and type; media/sediment composition and chemistry; system age; climate and seasonal factors such as temperature, precipitation, snow cover depth, and snow melt; internal erosion (e.g. wave activity) and wildlife use (especially waterfowl).

All of these factors are addressed in design to optimize outcomes, but some can also be managed during the treatment system life, while some remain fixed. These factors lead to variability in discharge concentrations from a wetland treatment system seasonally and annually, and the range of discharge concentrations summarized below for selected treatment wetland types (Source: Oregon Association of Clean Water Agencies July, 2014).

For free water surface wetlands, the final effluent characteristics are likely to be:

- BOD values in the range of 4.8 - 14.1 milligrams per litre (mg/l)
- Total Suspended Solids in the range of 2.8-29.7 mg/l
- Temperature reduction
- Phosphorus reduction to 0.01-4 mg/l
- Total Kjeldahl Nitrogen in the range of 1.35-11 mg/l
- Ammonia reduction to 0.1-56.9 mg/l
- Nitrate in the range of 0.05-48 mg/l

For vegetated submerged bed wetlands, the final effluent characteristics are likely to be:

- BOD values in the range of 2.2 - 55.4 mg/l
- Total Suspended Solids in the range of 4-35 mg/l
- Phosphorus reduction to 3.2-3.9 mg/l

7.7 Wetland monitoring and maintenance

Monitoring and maintenance of the wetland areas is a key issue in maintaining wetland functioning. Wetland monitoring is required to obtain sufficient data to determine the wetland performance in fulfilling the objectives. Wetland maintenance is required to manage macrophytes and desirable species, to remove invading weeds, to remove sediment from the wetlands, and to remove litter from the wetlands. Effective wetland performance depends on adequate pre-treatment,

Table 7.3 Minimum HRTs (Stovall, 2007)

Substance removed	Minimum Hydraulic Retention Time (HRT)
BOD	5-7 days
TSS	5 days
Nitrogen	3-5 days
Phosphorus	21 days

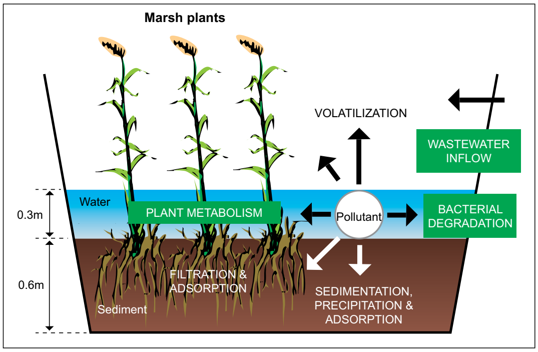

Figure 7.9. Pollutant removal processes in CWs (Wetands International, 2003).

conservative constituent and hydraulic loading rates, collection of monitoring information to assess system performance, and knowledge of successful operation strategies. Sustaining a dense stand of desirable vegetation within the wetland is crucial to ensure treatment efficiency. Aggressive species will out-compete less competitive ones and cause gradual changes in wetland vegetation. Certain undesirable plant species or weeds may be introduced to the wetland from the catchment. Natural succession of wetland plants will take place. However, some aquatic weeds may require maintenance by manually being removed. Weed invasion can dramatically reduce the ability of wetlands to meet its design objectives.

Water levels are important in wetlands with effects on hydrology and hydraulics and impact on wetland biota. Water level should be monitored using water level control structures to ensure successful plant growth. Monitoring of mosquito populations should be undertaken to avoid diseases, which can result in a local health problem (Wetlands International, 2003). Operation of vertical and horizontal flow wetlands is presented in Table 7.5 and 7.6.

Table 7.5. Operation of vertical flow filters (European Commission. International, 2001).

Tasks	Frequency	Observations
Weeding	the 1st year	• Manual weeding of self-propagating plants (Kadlec et al,2000). Once predominance is established, this operation is no longer necessary.
Cutting	1 / year (autumn)	• Cutting down and disposal of reeds. Disposing of them stops them accumulating on the surface of the filters. With a view to reducing this maintenance time, reeds can sometimes be burned if the waterproo- fing does not use a geomembrane, and if the feed pipes are made of cast iron (Liénard et al, 1994).
Regular maintenance and follow-up	1 / quarter 1 / week	• Clean the feeding siphon at the first stage by pressure washing. • Periodic analyses of nitrates in the effluent will indicate the health of the plants*
Regular maintenance	1 to 2/ week 1 / week 2 / week	• Clean the bar screen. • Regularly check the correct operation of the electromagnetic devices and detect breakdowns as quickly as possible. • Changing the valves
Other maintenance operations	Each visit	• Keep a maintenance log noting all the tasks carried out, flow measure- ments (flow meter canal, operating time of the pumps), to obtain good understanding of the flow.This also allows operating assessments to be produced.

Table 7.6. Operation of horisontal flow filters (European Commission, 2001).

Tasks	Frequency	Observations
Maintenance of pre-treatment structures	1 / week	The aim is to ensure their proper operation and that they do not discharge too many SS which could cause clogging.
Adjustment of output level	1 / week	Regular adjusting of the output water level makes it possible to avoid surface runoff. For large plants (> 500 m3d-1), verifying the output level could require daily inspection. The hydraulic aspect with this type of process is a key item. The correct distribution of the effluent in the filter should be checked. Cleaning the feed distribution device should be incorporated into the design.
Vegetation Weeding Cutting	1st year not necessary	During the first year (and even during the second) it is preferable to weed the self-propagating plants manually so as not to hinder reed deve- lopment (Kadlec R.H. et al, 2000).This operation can also be carried out by slightly immersing the surface of the filter (10 cm) to the detriment of purification output (Cooper, 1996). Once predominance of reeds is established, this operation is no longer necessary. The absence of surface runoff makes it possible to avoid cutting. Dead plants do not hinder in any way the hydraulics of the filters and furthermore allow the filter to be thermally insulated.
Other maintenance operations	Each visit	Keep a maintenance log with all the tasks that are carried out and the flow measurements (flow meter canal, pump operating time), so as to obtain good understanding of the flows.This also allows operating assessments to be produced.

Chapter 8
Construction of Wetlands

8.1 Free-water surface constructed wetland (FWS CW)

A free-water surface constructed wetland aims to replicate the naturally occurring processes of a natural wetland, marsh or swamp. As water slowly flows through the wetland, particles settle, pathogens are destroyed, and organisms and plants utilize the nutrients. This type of constructed wetland is commonly used as an advanced treatment after secondary or tertiary treatment processes. Free-water surface constructed wetland allows water to flow above ground exposed to the atmosphere and to direct sunlight. As the water slowly flows through the wetland, simultaneous physical, chemical and biological processes filter solids, degrade organics and remove nutrients from the wastewater.

Raw black water should be pre-treated to prevent the excess accumulation of solids and garbage. Once in the pond, the heavier sediment particles settle out, and this also removes the nutrients attached to them. Plants, and the communities of microorganisms that they support (on the stems and roots), take up nutrients like nitrogen and phosphorus.

Chemical reactions may cause other elements to precipitate out of the wastewater.

Pathogens are removed from the water by natural decay, predation from higher organisms, sedimentation and UV irradiation. Although the soil layer below the water is anaerobic, the plant roots exude (release) oxygen into the area immediately surrounding the root hairs, thus, creating an environment for complex biological and chemical activity.

Design Considerations: The channel or basin is lined with an impermeable barrier (clay or geo-textile) covered with rocks, gravel and soil and planted with native vegetation (e.g., cattails, reeds and/or rushes). The wetland is flooded with wastewater to a depth of 10 to 45 cm above ground level. The wetland is compartmentalized into at least two independent flow paths. The number of compartments in series depends on the treatment target. The efficiency of the free-water surface constructed wetland also depends on how well the water is distributed at the inlet. Wastewater can be fed into the wetland, using weirs or by drilling holes in a distribution pipe, to allow it to enter at evenly spaced intervals.

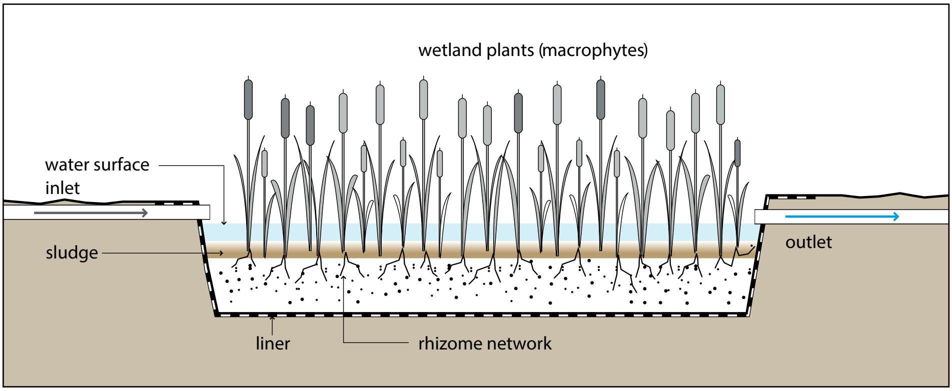

Figure 8.1 Free-water surface constructed wetland (FWS CW) (Source: Tilley et al).

Appropriateness: Free-water surface constructed wetlands can achieve a high removal of suspended solids and moderate removal of pathogens, nutrients and other pollutants, such as heavy metals. This technology is able to tolerate variable water levels and nutrient loads. Plants limit the dissolved oxygen in the water from their shade and their buffering of the wind; therefore, this type of wetland is only appropriate for low-strength wastewater. This also makes it appropriate only when it follows some type of primary treatment to lower the BOD. Because of the potential for human exposure to pathogens, this technology is rarely used as secondary treatment. Typically, it is used for polishing effluent that has been through secondary treatment, or for storm water retention and treatment.

The free-water surface wetland is a good option where land is cheap and available. Depending on the volume of the water and the corresponding area requirement of the wetland, it can be appropriate for small sections of urban areas, as well as for peri-urban and rural communities. This technology is best suited for warm climates, but can be designed to tolerate some freezing and periods of low biological activity.

Health Aspects/Acceptance: The open surface can act as a potential breeding ground for mosquitoes. However, good design and maintenance can prevent this. Free-water surface constructed wetlands are generally aesthetically pleasing, especially when they are integrated into pre-existing natural areas. Care should be taken to prevent people from coming in contact with the effluent because of the potential for disease transmission and the risk of drowning in deep water.

Operation & Maintenance: Regular maintenance should ensure that water is not short-circuiting, or backing up because of fallen branches, garbage, or beaver dams blocking the wetland outlet. Vegetation may have to be periodically cut back or thinned out.

Pros & Cons

+ Aesthetically pleasing and provides animal habitat
+ High reduction of BOD and solids; moderate pathogen removal
+ Can be built and repaired with locally available materials
+ No electrical energy is required
+ No real problems with odours if designed and maintained correctly
+ Low operating costs
- May facilitate mosquito breeding
- Requires a large land area
- Long start-up time to work at full capacity
- Requires expert design and construction

8.2 Horizontal subsurface flow constructed wetland (HSF CW)

A horizontal subsurface flow constructed wetland is a large gravel and sand-filled basin that is planted with wetland vegetation. As wastewater flows horizontally through the basin, the filter material filters out particles and microorganisms degrade the organics. The filter media acts as a filter for removing solids, a fixed surface upon which bacteria can attach, and a base for the vegetation. Although facultative and anaerobic bacteria degrade most organics, the vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize

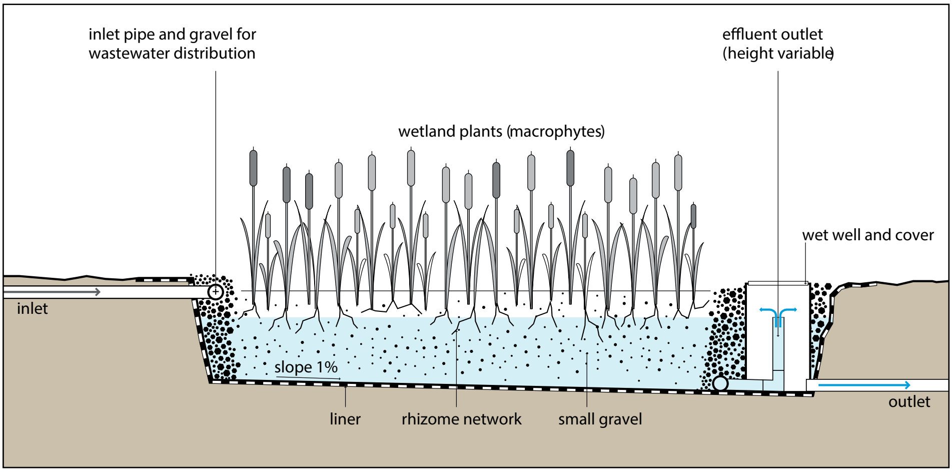

Figure 8.2 Horizontal subsurface flow constructed wetland (Source: Tilley et al).

the area and degrade organics as well. The plant roots play an important role in maintaining the permeability of the filter.

Design Considerations: the design of a horizontal subsurface flow constructed wetland depends on the treatment target and the amount and quality of the influent. It includes decisions about the amount of parallel flow paths and compartmentalisation. The removal efficiency of the wetland is a function of the surface area (length multiplied by width), while the cross-sectional area (width multiplied by depth) determines the maximum possible flow. Generally, a surface area of about 5 to 10 m2 per person equivalent is required. Pre- and primary treatment is essential to prevent clogging and ensure efficient treatment.

The influent can be aerated by an inlet cascade to support oxygen-dependent processes, such as BOD reduction and nitrification. The bed should be lined with an impermeable liner (clay or geotextile) to prevent leaching. It should be wide and shallow so that the flow path of the water in contact with vegetation roots is maximized. A wide inlet zone should be used to evenly distribute the flow. A well-designed inlet that allows for even distribution is important to prevent short-circuiting.

The outlet should be variable so that the water surface can be adjusted to optimize treatment performance. Small, round, evenly sized gravel (3 to 32 mm in diameter) is most commonly used to fill the bed to a depth of 0.5 to 1 m. To limit clogging, the gravel should be clean and free of fines. Sand is also acceptable, but is more prone to clogging than gravel. In recent years, alternative filter materials, such as PET, have been successfully used.

The water level in the wetland is maintained at 5 to 15 cm below the surface to ensure subsurface flow. Any native plant with deep, wide roots that can grow in the wet, nutrient-rich environment is appropriate. *Phragmites australis* (reed) is a common choice because it forms horizontal rhizomes that penetrate the entire filter depth.

Appropriateness: clogging is a common problem and, therefore, the influent should be well settled with primary treatment before flowing into the wetland. This technology is not appropriate for untreated domestic wastewater (i.e. black water). It is a good treatment for communities that have primary treatment (e.g. septic tanks), but are looking to achieve a higher quality effluent. The horizontal subsurface flow constructed wetland is a good option where land is cheap and available. Depending on the volume of the water and the corresponding area requirement of the wetland, it can be appropriate for small sections of urban areas, as well as for peri-urban and rural communities. It can also be designed for single households. This technology is best suited for warm climates, but it can be designed to tolerate some freezing and periods of low biological activity. If the effluent is to be reused, the losses due to high evapotranspiration rates could be a drawback of this technology, depending on the climate.

Health Aspects/Acceptance: significant pathogen removal is accomplished by natural decay, predation by higher organisms, and filtration. As the water flows below the surface, any contact of pathogenic organisms with humans and wildlife is minimized. The risk of mosquito breeding is reduced since there is no standing water compared to the risk associated with FWS constructed wetlands. The wetland is aesthetically pleasing and can be integrated into wild areas or parklands.

Operation & Maintenance: during the first growing season, it is important to remove weeds that can compete with the planted wetland vegetation. With time, the gravel will become clogged with accumulated solids and bacterial film. The filter material at the inlet zone will require replacement every 10 or more years. Maintenance activities should focus on ensuring that primary treatment is effective at reducing the concentration of solids in the wastewater before it enters the wetland. Maintenance should also ensure that trees do not grow in the area as the roots can harm the liner.

Pros & Cons

+ High reduction of BOD, suspended solids and pathogens
+ Does not have the mosquito problems of the Free-Water Surface Constructed Wetland
+ No electrical energy is required
+ Low operating costs
- Requires a large land area
- Little nutrient removal
- Risk of clogging, depending on pre- and primary treatment
- Long start-up time to work at full capacity
- Requires expert design and construction

8.3 Vertical flow constructed wetland

A vertical flow constructed wetland is a planted filter bed **that** is drained at the bottom. Wastewater is poured or dosed onto the surface from above using a mechanical dosing system. The water flows vertically down through the filter matrix to the bottom of the basin where it is collected in a drainage pipe. The important difference between a vertical and horizontal wetland is not simply the direction of the flow path, but rather the aerobic conditions. By intermittently dosing the wetland (4 to 10 times a day), the filter goes through stages of being saturated and unsaturated, and, accordingly, different phases of aerobic and anaerobic conditions.

During a flush phase, the wastewater percolates down through the unsaturated bed. As the bed drains, air is drawn into it and the oxygen has time to diffuse through the porous media. The filter media acts as a filter for removing solids, a fixed surface upon which bacteria can attach and a base for the vegetation. The top layer is planted and the vegetation is allowed to develop deep, wide roots, which permeate the filter media.

The vegetation transfers a small amount of oxygen to the root zone so that aerobic bacteria can colonize the area and degrade organics. However, the primary role of vegetation is to maintain permeability in the filter and provide habitat for microorganisms. Nutrients and organic material are absorbed and degraded by the dense microbial populations. By forcing the organisms into a starvation phase between dosing phases, excessive biomass growth can be decreased and porosity increased.

Design Considerations: The vertical flow constructed wetland can be designed as a shallow excavation or as an above ground construction. Clogging is a common problem. Therefore, the influent should be well settled in a primary treatment stage before flowing into the wetland. The design and size of the wetland is dependent on hydraulic and organic loads. Generally, a surface area of about 1 to 3 m^2 per person equivalent is required. Each filter should have an impermeable liner and an effluent collection system. A ventilation pipe connected to the drainage system can contribute to aerobic conditions in the filter. Structurally, there is a layer of gravel for drainage (a minimum of 20 cm), followed by layers of sand and gravel. Depending on the climate, *Phragmites australis* (reed), *Typha* sp. (cattails) or *Echinochloa pyramidalis* are common plant options. Testing may be required to determine the suitability of locally available plants with the specific wastewater. Due to good oxygen transfer, vertical flow wetlands have the

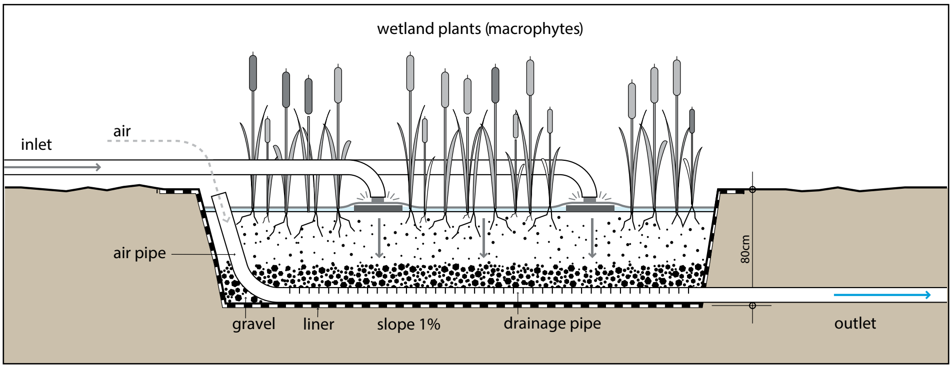

Figure 8.3 Vertical flow constructed wetland (Source: Tilley et al).

ability to nitrify, but denitrification is limited. In order to create a nitrification-denitrification treatment train, this technology can be combined with a Free-Water Surface or Horizontal Flow Wetland.

Appropriateness: The vertical flow constructed wetland is a good treatment for communities that have primary treatment (e.g., septic tanks), but are looking to achieve a higher quality effluent. Because of the mechanical dosing system, this technology is most appropriate where trained maintenance staff, constant power supply, and spare parts are available. Since vertical flow constructed wetlands are able to nitrify, they can be an appropriate technology in the treatment process for wastewater with high ammonium concentrations. Vertical flow constructed wetlands are best suited to warm climates, but can be designed to tolerate some freezing and periods of low biological activity.

Health Aspects/Acceptance: Pathogen removal is accomplished by natural decay, predation by higher organisms, and filtration. The risk of mosquito breeding is low since there is no standing water. The system is generally aesthetic and can be integrated into wild areas or parklands. Care should be taken to ensure that people do not come in contact with the influent because of the risk of infection.

Operation & Maintenance: During the first growing season, it is important to remove weeds that can compete with the planted wetland vegetation. Distribution pipes should be cleaned once a year to remove sludge and biofilm that might block the holes. With time, the gravel will become clogged by accumulated solids and bacterial film. Resting intervals may restore the hydraulic conductivity of the bed. If this does not help, the accumulated material has to be removed and clogged parts of the filter material replaced. Maintenance activities should focus on ensuring that primary treatment is effective at reducing the concentration of solids in the wastewater before it enters the wetland. Maintenance should also ensure that trees do not grow in the area as the roots can harm the liner.

Pros & Cons

\+ High reduction of BOD, suspended solids and pathogens

\+ Ability to nitrify due to good oxygen transfer

\+ Does not have the mosquito problems of the Free-Water Surface Constructed Wetland

\+ Less clogging than in a Horizontal Subsurface Flow Constructed Wetland

\+ Requires less space than a Free-Water Surface or Horizontal Flow Wetland

\+ Low operating costs

\- Requires expert design and construction, particularly, the dosing system

\- Requires more frequent maintenance than a Horizontal Subsurface Flow Constructed Wetland

- A constant source of electrical energy may be required
- Long start-up time to work at full capacity
- Not all parts and materials may be locally available

8.4 Leach field

A leach field, or drainage field, is a network of perforated pipes that are laid in underground gravel- filled trenches to dissipate the effluent from a water-based collection and storage/treatment or (semi-) centralized treatment technology.

Pre-settled effluent is fed into a piping system (distribution box and several parallel channels) that distributes the flow into the subsurface soil for absorption and subsequent treatment. A dosing or pressurized distribution system may be installed to ensure that the whole length of the leach field is utilized and that aerobic conditions are allowed to recover between dosings. Such a dosing system releases the pressurized effluent into the leach field with a timer (usually 3 to 4 times a day).

Design Considerations: each trench is 0.3 to 1.5 m deep and 0.3 to 1 m wide. The bottom of each trench is filled with about 15 cm of clean rock and a perforated distribution pipe is laid on top. More rock is placed to cover the pipe. A layer of geotextile fabric is placed on the rock layer to prevent small particles from plugging the pipe. A final layer of sand and/or topsoil covers the fabric and fills the trench to the ground level. The pipe should be placed at least 15 cm beneath the surface to prevent effluent from surfacing. The trenches should be dug no

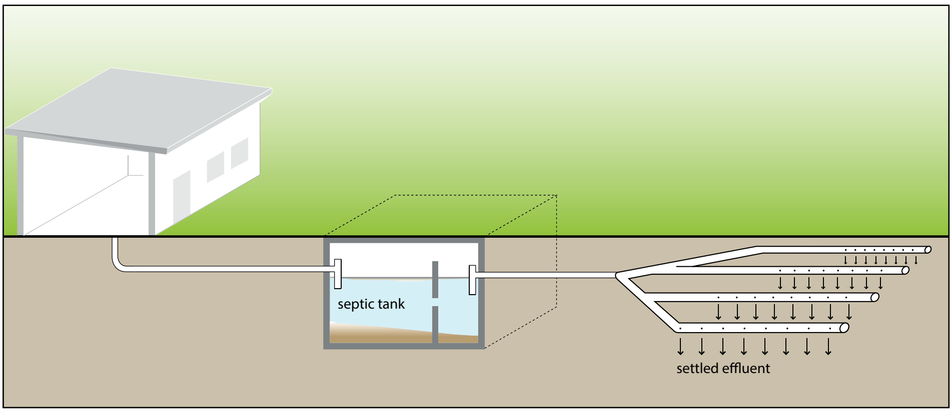

Figure 8.4 Leach field (infiltration system) (Source: Tilley et al).

longer than 20 m in length and at least 1 to 2 m apart. To prevent contamination, a leach field should be located at least 30 m away from any drinking water source.

A leach field should be laid out such that it will not interfere with a future sewer connection. The collection technology which precedes the leach field (e.g., septic tank) should be equipped with a sewer connection so that if, or when, the leach field needs to be replaced, the changeover can be done with minimal disruption.

Appropriateness: Leach fields require a large area and unsaturated soil with good absorptive capacity to effectively dissipate the effluent. Due to potential oversaturation of the soil, leach fields are not appropriate for dense urban areas. They can be used in almost every temperature, although there may be problems with pooling effluent in areas where the ground freezes. Homeowners who have a leach field must be aware of how it works and of their maintenance responsibilities.

Trees and deep-rooted plants should be kept away from the leach field as they can crack and disturb the tile bed.

Health Aspects/Acceptance: Since the technology is underground and requires little attention, users will rarely come in contact with the effluent and, therefore, it has no health risk. The leach field must be kept as far away as possible (at least 30 m) from any potential potable water source to avoid contamination.

Operation & Maintenance: A leach field will become clogged over time, although this may take 20 or more years, if a well-maintained and well-functioning primary treatment technology is in place. Effectively, a leach field should require minimal maintenance; however, if the system stops working efficiently, the pipes should be cleaned and/or removed and replaced. To maintain the leach field, there should be no plants or trees on it. There should also be no heavy traffic above it because this could crush the pipes or compact the soil.

Pros & Cons

\+ Can be used for the combined treatment and disposal of effluent
\+ Has a long lifespan (depending on conditions)
\+ Low maintenance requirements if operating without mechanical equipment
\+ Relatively low capital costs; low operating costs
\- Requires expert design and construction
\- Not all parts and materials may be locally available
\- Requires a large area
\- Primary treatment is required to prevent clogging
\- May negatively affect soil and groundwater properties

8.5. Cases of constructed wetlands in Sweden

In South Sweden, four large (20-28 ha) FWS wetlands are operated to treat wastewater from municipal wastewater treatment plants. Those are, in order from south to north, Magle in Hässleholm, the wetland in Oxelösund, Ekeby in Eskilstuna and Alhagen in Nynäshamn, south of the capital Stockholm. Two of the wetlands, Magle and Ekeby, receive wastewater that has been treated both biologically and chemically, whereas the other two receive effluent from a WWTP with only chemical treatment and settling.

Magle wetland was constructed in 1995 with the prime aim to reduce the P load to the downstream eutrophic lake. It consists of an inflow basin from which the water is distributed to four parallel basins and subsequently collected in an outflow channel, in total a wet area of 20 ha. The average depth is 0.5 m but each basin is subdivided in three sections starting with a deeper part to redistribute the water and favour anaerobic conditions and denitrification. Most of the wetland basins are dominated by the submerged macrophytes *Elodea candensis* and *Myriophyllum spicatum*, mixed with large stands of filamentous green algae.

Oxelösund wetland was created in 1993, it covers 23 ha and consists of two parallel systems (South and North) with two basins each, emptying to a joint final basin which is always flooded. Each system is currently filled up during 2-3 days followed by draining during an equal time period to ensure utilization of the whole wetland area and to favour nitrification followed by denitrification. All basins are dominated by emergent macrophytes, mainly *Typha latifolia*. In deeper sections and in the channels connecting the basins, large stands of submerged plants such as *Elodea canadensis* and *Potamogeton sp.* are found.

Ekeby wetland has been in operation since 1999, and is operated from May to December each year. From an inlet channel, the effluent from the WWTP is

Figure 8.5. Magle wetland (Source: http://www.mior.se/skane/finjasjon/maglevatmark/?lang=en)

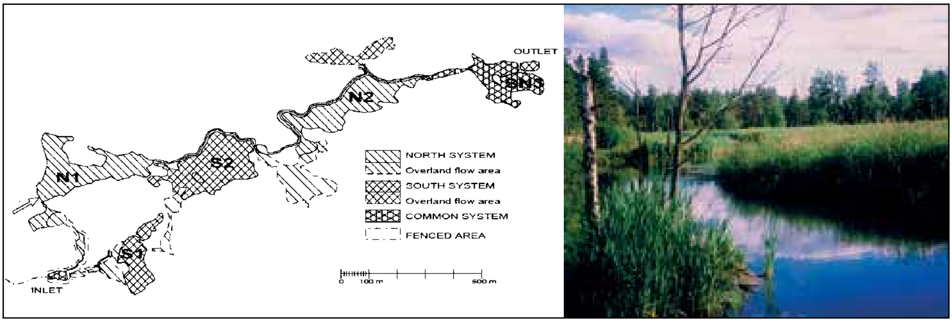

Figure 8.6. Oxelösund wetland (Source: http://www.wrs.se/wp-content/uploads/2014/03/Oxelo-sund_Andersson-et-al_2000.pdf)

Figure 8.7. Ekeby wetland (Source: http://www.vattenavlopp.info/vatmark/wetland.htm)

distributed to five parallel basins and subsequently to a collecting channel from which the water is distributed to another set of three parallel basins. The flooded area covers 28 ha with a mean depth of 1 m. About 20 % of the basins have been covered by emergent macrophytes, e.g. *Glyceria maxima* and *Typha sp.,* with various submerged species and filamentous algae in the remaining areas.

Wetland Alhagen was constructed in 1997 and covers 28 ha including an overland flow area. From an inflow basin, the water is alternately fed to two parallel ponds with fluctuating water levels. After passing through two wetland

Figure 8.8. Alhagen Wetlands (Source: http://www.visitnynashamn.se/en/home/todo/aktorer/alhagenwetlands.5.787ba9a21361e2e3bfa800029458.html)

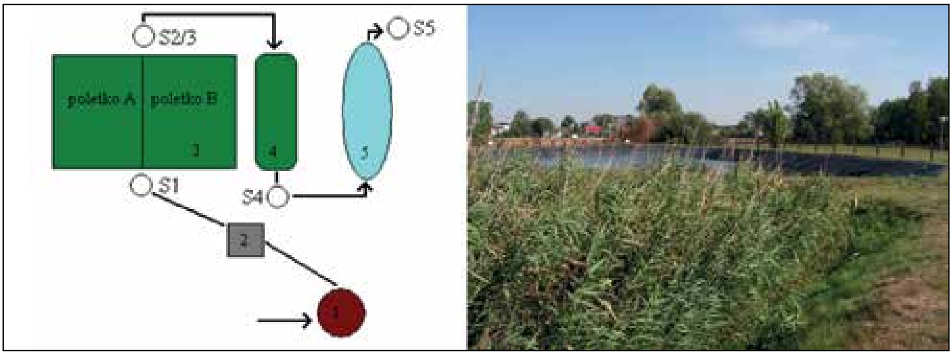

Figure 8.9. Schematic view of HSF CW: 1 – septic tank, 2 – pumps, 3 – horizontal subsurface flow reed bed, 4 – phosphorus removal step, 5 – stabilization pond, S1, S2/S3, S4, S5 – wells. Photos: on the left – bed medium sampling, on the right - view of the reed bed and stabilization pond.

basins in series, the water is intermittently (2 d intervals) distributed to a 2 ha overland flow area from which it is collected in a collection pond and passes through a channel to two shallow fens, where it is mixed with storm water and flows to the Baltic Sea.

During 1999-2001, the wetland received wastewater only in April – December each year. In the first wetlands, the plant community is dominated by emergent species such as *Phragmites australis*, *Typha sp.* and *Carex riparia*. Downstream the overland flow area, large stands of *Elodea canadensis* and *Ceratophyllum demersum* are observed. In the final wetland, various *Carex* species are predominant.

8.6 Subsurface flow constructed wetlands for wastewater treatment in Poland

The HSFCW in Sadowa (a village close to Warsaw) consists of two parallel CW surface areas of 990 m^2 each, planted with common reed (*Phragmites australis*

Table 8.1. Inflow water quality and hydraulic loads of four large FWS treatment wetlands in South Sweden (n.d. = not determined). Data from Andersson & Kallner Bastviken, 2002.

Wetland **Time period**	**Magle** **1995 - 2001**	**Ekeby** **1999 - 2001**	**Oxelösund** **1994 - 2001**	**Alhagen** **1999 - 2001**
Total wet area, ha	20	28	23	28
Hydraulic load, mm d^{-1}	57	155	21	17
Detention time, d	7-8	6-7	8	14
--------------------------------- mg L^{-1} ---------------------------------				
BOD_7	2.4	5.2	22	38
Tot-P	0.15	0.23	0.40	0.37
PO_4^{3-}-P	0.11	0.12	n.d.	n.d.
Tot-N	20	20	23	37
NH_4^+-N 6 5 17 37	6	5	17	37

Table 8.2. Concentrations in outlet water, and removal of tot-P and tot-N in four large FWS treatment wetlands in South Sweden. Data from Andersson & Kallner Bastviken, 2002.

Wetland **Time period**	**Magle** **1995-2001**	**Ekeby** **1999-2001**	**Oxelösund** **1994-2001**	**Alhagen** **1999-2001**
Tot-P in outflow	0.11	0.10	0.04	0.12
Tot-N in outflow	14	15	15	11
----------------------------- mg L^{-1} -----------------------------				
Tot-P load	33	77	30	17
Tot-P removal	10	41	27	12
--------------------------------- kg ha^{-1} yr^{-1} ---------------------------------				
Tot-N load	4200	6300[1]	1700	1600[1]
Tot-N removal	1200	1500[1]	700	1100[1]

[1]Annual load and removal has been calculated for the operation period only.

(Cav.) Steud.) and constructed with medium sand, with additions of calcium (Ca), scraped iron, bentonite, crushed bark and straw (Kickuth technology). Each CW is 0.6 m deep, underlined with gravel and isolated with weld polyethylene liner (2 mm) from the surrounding soil. The plant has been operating since December 1998 and treats domestic wastewater from 150 inhabitants. The wastewater is pre-treated in a three-chamber sedimentation tank and when distributed to the CW, BOD_5 and soluble reactive phosphorus (SRP) have a concentration of 245 ± 112 mg/litre and 8 ± 6.6 mg/litre, respectively. The CW is loaded with wastewater by pumps several times each day (intermittent discharge) with a total volume not exceeding 24 m^3 d^{-1}, resulting in a theoretical hydraulic retention time of 8.6 days. A perforated pipe along the width of the

Table 8.3. Technical data on the constructed wetland treatment system in Sadowa, Poland (Karczmarczyk A., Renman G., 2011)

Parameter	**Value**
Person equivalents, (PE)	150
Daily flow of wastewater	
Max	24 m3 d–1
Average (winter/summer)	16 m3 d–1 / 20 m3 d–1
Pre-treatment:	
3-chamber septic tank	Tank volume: 55 m3
Biological treatment:	
HSF CW (2 parallel beds)	Total surface: 1980 m2 (2 x 990 m2) Bed length: 33 m Bed width: 30 m ed depth: 0.6 m
Hydraulic retention time (HRT)	8.6 d
Hydraulic loading rate (HLR)	0.024 m3 m–2 d–1
Organic load (Dry matter)	6.4 g m–2 d–1
Phosphorus load (SRP)	0.15 g m–2 d–1

bed distributes wastewater. Technical data on the treatment system are shown in Table 8.3.

8.7 Living Machines

Living Machines were created by John Todd, an ecological designer and founder of the non-profit organization Ocean Arks International. Living Machines are a series of tanks with plants and other organisms contained in them. Wastewater is then pumped through these tanks to naturally treat the water. They mimic wetland ecology to treat wastewater, but require less space and do it more efficiently than a wetland because the conditions can be controlled so they are more ideal. For example, the organisms have more oxygen than in a wetland because air is bubbled through the tanks. Some Living Machines also produce beneficial by-products such as methane gas, edible and ornamental plants and fish.

Living Machines are not any less expensive than conventional wastewater treatment. Because the tanks are aerated about the same amount as in conventional wastewater treatment, the same amount of energy is used. In colder areas, Living Machines must be located inside greenhouses which also use energy to heat and cool them. If a renewable source of energy is used, then Living Ma-

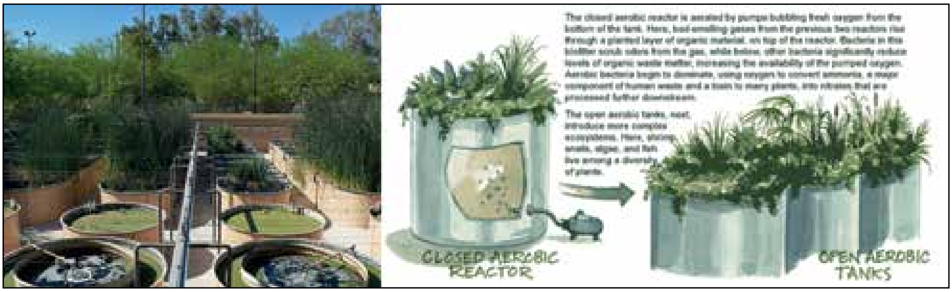

Figure 8.10. Living Machines (Source: http://news.psu.edu/story/140601/2000/09/01/research/living-machine).

Figure 8.11. Ecoparqué, Tijuana, Mexico

chines would be more sustainable and cost effective. However the plants do not significantly contribute to the treatment but just make the wastewater treatment more aesthetic.

8.8 Ecoparqué Park in Mexico

Ecoparqué, a combination of a park and a wastewater treatment plant (Figure 8.11), is located in Tijuana, Mexico, and was created in response to poor sanitary conditions and a need to treat wastewater from the city. The wastewater used to go straight into the Tijuana River, which runs along the US Mexico border. Oscar Romo, the Coastal Training Program Coordinator of the Tijuana River National

Estuarine Research Reserve, came up with an environmentally friendly solution in the creation of Ecoparqué.

Ecoparqué treats the wastewater generated from a neighbourhood of 1,200 home and uses no chemicals. The wastewater flows by gravity to Ecoparqué. A microcriba filters out larger organic matter, which is then composted with tiger worms and used in Ecoparqué. Two biofilters, which are large tanks filled with bacteria colonies, treat the water. A clarifier settles the solids out of the water. The operators test the water and if it does not meet their standards, they re-circulate it through the biofilters. The water, which still has nutrients in it, is then used to irrigate the plants that make up Ecoparqué. An important feature of Ecoparqué is that smaller decentralized wastewater treatment systems can be used to successfully serve small communities within a city and that the water can be reused to irrigate parks. People there are willing to use a park even though it is irrigated with treated wastewater. Also, in some circumstances, the nutrients can be left in the water if it is going to be used to irrigate plants which could make use the nutrients.

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UZWATER

This compendium is produced for a master level course in the UZWATER project. It consists of some newly written material as well as previously published texts extracted from freely available books, reports and textbooks on the Internet, dominated by publications from the Baltic University Programme. The sources used for each chapter is listed at the end of the chapter. The compendia of the Uzwater project are produced exclusively for Master students free of charge at the participating Universities and is not to be sold or be freely available on the Internet.

The UZWATER project is an EU TEMPUS project. It includes 8 universities in Uzbekistan and deals with university education for sustainable water managment in Uzbekistan. Uppsala University and Baltic University Programme is one of the six EU partners in the project. Lead partner is Kaunas University of Technology.

The main objective of the project is to introduce a Master level study program in environmental science and sustainable development with focus on water management at the eight partner universities in Uzbekistan. The curriculum of the Master Programme includes Environmental Science, Sustainable Development and Water Management.

The Sustainable Development unit will include the basic methods used in Sustainability Science, in particular introduce systems thinking and systems analysis, resource flows and resource management and a series of practical tools for good resource management, such as recycling, and energy efficiency.

The specific objectives of the project are:
- to establish study centers at the partner universities in Uzbekistan
- to improve the capacity to train master students with expertise to address the severe environmental and water management problems of the country;
- to support the introduction and use in Uzbekistan of modern education methods, study materials, and e-learning tools;
- to encourage international cooperation at the partner universities;
- to strengthen capacities to provide guidance to authorities and the Uzbekistan society at large;
- to ensure the visibility and promotion of the Master Programme through web pages, printed material and cooperation with society;
- to ensure continuity of the Master Programme and long-term support of the project outcomes at partner universities beyond Tempus funding.

http://uzwater.ktu.lt